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Estimating a Freight Mode Choice Model: A Case Study of Commodity Flow Survey 2012

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ESTIMATING A FREIGHT MODE CHOICE MODEL: A CASE STUDY OF COMMODITY FLOW SURVEY 2012

by

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ABSTRACT

This research effort develops a national freight mode choice model employing data from the 2012 Commodity Flow Survey (CFS). While several research efforts have developed mode choice model with multiple modes in the passenger travel context, the literature is sparse in the freight context. The primary reasons being unavailability and/or the high cost associated with the acquisition of mode choice and level of service (LOS) measures – such as travel time and travel cost. The first contribution of the research effort is to develop travel time and cost measures for various modes reported in the CFS. The study considers five modes: hire truck, private truck, air, parcel service and other modes (rail, ship, pipeline, and other miscellaneous single and multiple modes). The LOS estimation is undertaken for a sample of CFS 2012 data that is partitioned into estimation sample and holdout sample. Subsequently, a mixed multinomial logit model is developed using the estimation sample. The exogenous variables considered in the model include LOS measures, freight characteristics, and transportation network and Origin-Destination variables. The model also accounts for unobserved factors that influence the mode choice process. The estimated mode choice model is validated using the holdout sample. Finally, a policy sensitivity analysis is conducted to illustrate the applicability of the proposed model.

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CHAPTER ONE: INTRODUCTION

Efficient and cost-effective freight movement is a prerequisite to a region's economic viability, growth, prosperity, and livability. In the United States, 118.7 million households, 7.4 million businesses and 90 thousand government units, daily depend on the efficient movement of about 54 million tons of freight valued at around $48 million (BTS, 2012). Freight is transported by several modes, including truck, rail, water, air, and pipeline. The percentage share of freight transported in 2013 by weight and value by mode are as follows: truck (70 and 64), rail (9 and 3), water (4 and 1.5), air (0.1 and 6.5) and pipeline (7.7 and 6.0)[1] (FFF, 2015). The contribution of greenhouse gas (GHG) emissions by freight mode in million metric tons of CO_2 equivalent in 2014 are as follows: truck (407.4), rail (41.8), water (6.3), air (16.2) and pipeline (46.5). From these statistics, it is evident that truck dominates the mode share for freight transportation while also accounting for a significant share (79%) of GHG emissions. Furthermore, GHG emissions from trucks have increased by 76% between 1990 and 2014 (EPA, 2016) which is substantially higher than any other mode.

Clearly, the mode chosen for freight transportation has significant implications for the transportation system and the environment at large. The spatial and temporal distribution of benefits and externalities are tied to the mode of transportation. For instance, truck transportation on the existing roadway infrastructure is associated with negative externalities such as air pollution, traffic congestion, traffic crashes (ensuing property damage, injuries and fatalities) and

[1] The remainder of the freight is transported by multiple modes, mail and unknown modes.

transportation infrastructure deterioration. In fact, Austin (2015) indicated that the external cost of truck is as high as eight times the external cost of rail mode. A comprehensive understanding of the decision process for shipping freight by various modes would benefit transportation infrastructure planning decisions in terms of transportation infrastructure management (road, rail, air, sea port and pipeline infrastructure). Further, a quantitative model to study mode choice will allow the understanding of how the choice is altered in response to technological and economic changes. For example, the deployment of connected and automated vehicles is likely to alter the overall shipping patterns for trucks by significantly reducing travel time. These travel time savings accrued from not having to stop across long duration trips would potentially increase the inclination for employing truck freight mode (compared to the current scenario). To accurately predict the potential impact of such technological changes, the development of a behavioral freight mode choice model is beneficial.

The main goal of the current thesis is to develop a national freight mode choice model employing data from the 2012 Commodity Flow Survey (CFS). The first contribution of the research effort is to develop travel time and cost measures for various modes reported in the CFS. The Level of Service (LOS) estimation is undertaken for a sample of CFS 2012 data that is partitioned into an estimation sample and a holdout sample. The modes considered were: hire truck, private truck, air, parcel service and other modes which include rail, ship, pipeline and other miscellaneous single and multiple modes. Subsequently, a mixed multinomial logit (MMNL) model framework is developed using the estimation sample. The exogenous variables considered in the model include LOS measures, freight characteristics, and transportation network and Origin-Destination (O-D) variables. The mode choice model estimated is validated using the holdout sample. Finally, a policy sensitivity analysis is conducted to illustrate the applicability of the proposed model.

1.1 Thesis Structure

The remainder of the thesis is organized as follows. Chapter 2 provides a review of existing literature and positions the current study on freight mode choice analysis. The data compilation and explanation of variables are described in Chapter 3. Chapter 4 discusses LOS measure computation steps. Chapter 5 provides details of the econometric model framework. Chapter 6 presents the empirical analysis results and validation statistics. A policy exercise and its results are described in Chapter 7. Chapter 8 concludes the thesis with necessary recommendation based on the empirical finding of the study.

CHAPTER TWO: LITERATURE REVIEW

Transportation literature on mode choice models can be classified along two main streams: (i) passenger travel behaviour and (ii) freight travel behaviour. There is an extensive body of literature available on passenger travel behavior. However, studies on freight mode choice are relatively sparse. The limited number of studies that have been conducted focus on different aspects of freight transport including shipping cost and travel time by mode, shipment mode choice, and trip planning (trip generation and distribution). A summary of the relevant earlier studies on freight shipping cost computation, mode choice and freight trip planning are discussed in this chapter.

2.1 Earlier Research

Several studies have estimated freight shipping costs. Table 2.1 represents the studies related to this context. These studies mainly considered three types of costs: (i) operational costs (based on fuel price, labor cost, capital cost); (ii) external costs (based on accidents, pollution, and congestion); and (iii) shipment costs (based on product weight, product value). Based on the context, studies consider one or more of these three types (for example see Forkenbrock, 2001; Kim et al., 2002; Micco and Perez, 2002; Onghena et al., 2014; Resor and Blaze, 2014; Dolinayova et al., 2015 for operational cost and external cost computation of rail mode; Janic, 2007 for all three costs of rail and truck modes; Hummels, 2007 for shipment cost). The methodologies considered for cost computation range from translog function[2] (Forkenbrock, 2001; Kim, 2002;

[2] The translog cost function is a flexible functional form that can be used to approximate any twice-differentiable

Onghena et al., 2014), regression analysis (Hummels, 2007), and instrumented variables approaches (Micco and Perez, 2002). From the Table, we can see that in majority of the studies, cost is calculated for either a single mode, or at most for two modes. Variables influencing shipment cost include fuel cost, labor cost, product weight and product value commonly. Onghena et al. (2014) found capital cost influenced shipping cost by Fedex, but fuel cost influenced UPS shipping cost, whereas both of the services' shipping cost were affected by labor cost. Forkenbrock (2001) found that external cost generated by truck is three time more than freight train, which means truck generates more accidents, congestion and pollution. Janic (2007) in his study found that cost decreases as distance and load increases, faster in intermodal service than road. Micco and Perez (2002) implied that if the port efficiency improves from 25th percentile to 75th percentile, then shipping cost is reduced by 12 percent. Also handling cost decreases with port improved port efficiency.

A summary of earlier research on freight mode choice is presented in Table 2.2. The Table provides information on the study area, data source and type, model framework, dependent variable of interest, modes considered, and independent variables considered. The independent variables are categorized into the following variable groups: (i) LOS measures (such as shipping travel time, shipping cost, speed, delay, fuel cost); (ii) freight characteristics (such as commodity group, commodity size, commodity density, commodity value, commodity weight, product state, temperature controlled or not, perishability, trade type, quantity); (iii) transportation network and O-D attributes (such as shipment O-D, distance, ratio of highway and railway miles in origin and

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function without placing any presumptive restrictions on the production technology.

in destination); and (iv) others (service reliability, service frequency, loss and damage, shipper's characteristics). Some important observations may be made from Table 2.2. *First,* majority of the studies considered either two or three alternative modes. This is particularly true for studies based on national data such as the CFS. *Second,* none of the studies have considered alternative availability in modeling freight mode choice. Based on the freight characteristics (shipping weight and value) and the O-D attributes, the choices available to the shipper might be different from the universal choice set. *Third,* while exogenous variables from 3 or more groups have been considered in these research efforts, both shipping cost and shipping travel time are not always considered in the modeling framework. Most common influencing factors found in the literature were shipping time, shipping cost, commodity type, weight, value, service frequency, distance and reliability. *Finally,* the most commonly utilized model framework for mode choice is the multinomial logit (MNL) model (Holguín-Veras , 2002; Shinghal and Fowkes, 2002; Ohashi et al., 2005, Arunotayanun and Polak, 2011, Yang et al., 2014; Arencibia et al., 2015) and its variants, such as, nested logit (Jiang et al., 1999; Rich et al., 2009; Nugroho et al., 2015) and MMNL (Arunotayanum ad Polak, 2011; Brooks et al., 2012; Mitra and Leon, 2014; Arencibia et al., 2015; Nugroho et al., 2015). More recently artificial neural network approaches (Abdelwahab and Sayed, 1999; Sayed and Razavi, 2000), joint copula models (Pourabdollahi et al, 2013), random regret based MNL (Boeri and Masiero, 2014), and latent class models (Arunotayanum and Polak, 2011; Brooks et al, 2012) have also been employed. Earlier researches have also developed Value of Time (VOT) measures that provide guidance on the premium placed on reducing travel time. For instance, Samimi et al. (2011) concluded that a 50 percent increase in fuel price affects the modal shift from truck to rail minimally; an increase ranging between 150 to 200 percent, shifts about 7 percent of truck share to rail mode. In another study, Brooks et al. (2012) estimated value of transit time savings by mode.

2.2 Current Study in Context

It is evident from the literature review that freight mode choice modeling exercises, in general, have been based on considering two or three alternatives. In this study, our objective is to develop a mode choice model for five alternatives (hire truck, private truck, air, parcel/courier mode and other which includes rail, water and some other modes) with detailed LOS information generated for each of these modes. Furthermore, in our study, we consider alternative availability. For example, it is unlikely that a bulk load (>500 tons) is shipped by air. In this case, allowing air mode as an available alternative affects accuracy of the model parameters. In our study, we employ observed data distributions to identify the alternative availability for the shipment. While the CFS data provides significant information, many variables of interest are unavailable in the dataset, such as shipping cost and time. Hence, the decision process is also likely to be affected by a host of unobserved variables. To accommodate for this unobserved heterogeneity, we estimate a mixed MNL model. The estimated model results are processed to obtain Value of Time (VOT) measures that are informative for policy makers. The results are also employed to generate policy scenario analysis based on changes to operation costs and travel times.

2.3 Summary

The chapter presented a summary of the existing literature of freight mode choice analysis and the limitations of previous studies. This study has accounted all the modes of freight transportation along with availability and shipping cost and time for all modes.

Table 2.1 Previous Literature on Cost of Shipping

Study	Study Area	Methodology	Mode[1]	Cost Types Considered	Influencing Factors
Forkenbrock (1999)	USA	Translog function	Rail, Truck	Operational and external Cost	Labor cost, Materials and Supplies cost, Fuel cost and other cost
Micco and Perez (2002)	USA	1. Instrumental variables technique 2. Ordinary least square	Ship	Operational and Shipment cost	Port efficiency, distance, weight, value, volume,, infrastructure, containerization
Resor and Blaze (2004)	USA	---	Rail intermodal	Operational	Drayage, on dock rail, terminal location, capacity
Hummels (2007)	USA	Regression analysis	Air, Ship	Shipment Cost	Weight/value ratio, fuel cost, distance, trend
Janic (2007),	Europe	Developed equation	Road and intermodal (rail-truck)	Operational, external, shipment	Distance, time, handling
Kim et al. (2010)	Korea	Translog function	Truck	Operational	Capital, labor, operation, fuel, length of haul
Onghena et al. (2014)	USA	Translog cost function	Parcel (FEDEX, UPS)	Operational	Labor price, fuel price, material price, capital price, trend
Dolinayova et al. (2015)	Slovakia	Conversion calculation	Rail	Operational and external	Fuel price, rental or leasing, wagon weight

[1]Mode: When the study specifies particular modes.

Table 2.2 Previous Literature on Freight Mode Choice

Study	Study Area	Data Source and Type[1]	Methodology	Decision Variable	Mode[2]	Independent variables			
						Level of Service Characteristics	Freight Characteristics	Network and O-D Attributes	Other
Nam (1997)	Korea	KOTI 1990a, KNR (RP)	Binary logit	Mode choice	Rail, truck	Cost, time	Weight		Frequency, accessibility
Abdelwahab (1998)	USA	CTS 1977 (RP)	Switching simultaneous equations (binary probit and linear regression)	Mode choice and shipment size	Rail & Truck	Cost, time	Commodity Group	Region	---
Abdelwahab and Sayed (1999)	USA	CTS 1977 (RP)	Artificial Neural Network	Mode choice	Rail & Truck	Cost, time	Size, product state, temperature, perishability,	Region, distance	Loss and damage, reliability
Jiang et al (1999)	France	INRETS 1988 (RP)	Nested logit	Mode choice	Road, rail, combined (private & public)	----	Type of product, value, weight, trade type	Distance, origin, destination,	Packaging, warehouse accessibility, frequency,
Cullinane and Toy (2000)	---	SP	Stated Preference, statistical analysis	Route/ Mode choice	---	Cost, time, speed	Goods characteristics	Distance,	Service, flexibility. Infrastructure availability, capability, inventory, loss/damage, sales per year, previous experience, frequency,
Sayed and Razavi (2000)	USA	CTS 1977 (RP)	1. Artificial Neural Network 2. Neurofuzzy	Mode Choice	Motor Carrier and Rail	Cost, time,	Size, tonnage, value, density, product state, temperature control, protection, perishability	Origin-destination, distance,	Reliability, loss and damage

Study	Study Area	Data Source and Type[1]	Methodology	Decision Variable	Mode[2]	Independent variables			
						Level of Service Characteristics	Freight Characteristics	Network and O-D Attributes	Other
Holguin-Veras (2002)	Guatemala City	Survey in Guatemala City (RP)	1. Heteroscedastic extreme value model 2. Multinomial logit	Shipment size & Mode choice	Truck	Cost	Commodity group	Trip Length	Economic activities
Kim (2002)	UK and Continental Europe	Channel Tunnel Survey 1996 (SP)	Inherent random heterogeneity logit model	Mode choice	Rail and truck	Cost, time	---	---	Reliability
Shinghal and Fowkes (2002)	India (Delhi-Bombay Corridor)	Survey on Delhi-Bombaby corridor 1998 (SP)	Multinomial Logit	Mode choice	Intermodal, rail, parcel	Cost, time	---	---	Frequency
Norojono and Young (2003)	Indonesia (Java)	Survey from 1998 - 1999 (SP)	1. Ordered Probit 2. Heteroscedastic extreme value model	Mode choice	Rail and road	Cost, time	Commodity type, size, value, trade type	Distance	Quality, flexibility, cargo unit
Ohashi et al. (2005)	Northeast Asia	Survey 2000 (RP)	Multinomial Logit	Route choice	Air	Cost, time	---	Distance	Landing fee
Rich et al. (2009)	Sweden	FEMEX/COMVIC 1995-96, VFU (RP)	Nested logit	Mode choice	Truck, rail, ship	Cost, time	Commodity group,	---	---
Arunotayanun and Polak (2011)	Indonesia (Java)	Survey 1998-99 (SP)	1. Multinomial logit 2. Mixed multinomial logit 3. Latent class	Mode choice	Small truck, train	Cost, time	Value, frequency, commodity group	Destination	Quality, flexibility
Feo et al. (2011)	Spain (Zaragoza, Barcelona, Valencia, Madrid, Murcia)	Survey 2006 (SP)	Disaggregated behavior model	Mode Choice	Truck & Ship	Cost, time	---	---	Frequency, reliability

Study	Study Area	Data Source and Type[1]	Methodology	Decision Variable	Mode[2]	Independent variables			
						Level of Service Characteristics	Freight Characteristics	Network and O-D Attributes	Other
Holguin-Veras et al. (2011)	USA and UK	Experiment data in USA 2007, Experiment data in UK (SP)	Game Theory	Mode choice and Shipment size	Truck, Van, combined road-rail	Cost	Shipment size, No. of shipment	---	---
Samimi et al (2011)	USA	Online survey 2009 (RP)	1. Binary logit 2. Binary probit model	Mode choice	Truck & Rail	Cost, time	Weight, value	Distance	---
Brooks et al. (2012)	Australia (Perth-Melbourne, Melbourne-Brisbane, Brisbane-Townsville corridors)	Survey (SP)	1. Mixed logit 2. Latent Class	Mode Choice	Truck, Rail, Ship	Cost, time	---	Distance, direction,	Reliability, carbon pricing, frequency,
Moschovou and Giannopoulos (2012)	Greece	Survey (RP)	1. Linear regression 2. Binary Logit	Mode Choice	Truck and Rail	Cost, time, access to mode	Shipment Type, Shipment Value, Weight,	Distance	Loading Units, Quality of Service, Probability of load Loss and Damage, availability of loading/unloading equipment, service frequency
Shen and Wang (2012)	USA	FAF 2 (RP)	1. Binary logit 2. Linear Regression	Mode choice (cereal grains)	Truck, Rail	Fuel cost, time	Weight, value	Distance	---
Pourabdollahi et al. (2013)	USA	Online survey 2009-2011 (RP)	Copula based joint MNL-MNL	Mode & Shipment Size	Truck, Rail, Air, Courier	Cost	Commodity type, characteristics, value, trade type	Distance	---

Study	Study Area	Data Source and Type[1]	Methodology	Decision Variable	Mode[2]	Independent variables			
						Level of Service Characteristics	Freight Characteristics	Network and O-D Attributes	Other
Wang et al (2013)	USA (Maryland)	FAF 3, NTAD 2006 (RP)	1. Binary Probit 2. Logit Model	Mode Choice	Truck, Rail	Fuel cost, time	Commodity type, weight, value, trade type	Origin, Ratio of Highway milage and Railway milage in origin and destination zone, highway and Railway Distance	---
Boeri and Masiero (2014)	Switzerland (Ticino)	Survey 2008 (SP)	1. Random regret MNL and MXL 2. Random utility maximization MNL and MXL	Freight mode and road alternative s	Truck carried on train, combination of road and rail, best road alternative	Cost, time	---	---	Punctuality
Mitra and Leon (2014)	USA (North Dakota)	Interview of airport managers (RP)	Mixed Logit	Mode Choice	Air-cargo	Cost, time, delay	Commodity density, quantity, perishability,	---	Equipment availability, loss and damage
Reis (2014)	Portugal	Data provided by freight forwarder (RP)	Agent based micro simulation	Mode choice (short distance)	---	Cost, time	Weight, type of commodity,	Origin, destination	---
Yang et al. (2014)	USA (export-import)	USA Trade online database 2012(RP)	Multinomial Logit	Mode Choice	Air & Ship	---	Commodity type, weight, value	---	---

Study	Study Area	Data Source and Type[1]	Methodology	Decision Variable	Mode[2]	Independent variables			
						Level of Service Characteristics	Freight Characteristics	Network and O-D Attributes	Other
Arencibia et al (2015)	Spain	Survey 2011-2012 (SP)	1. Multinomial logit 2. Mixed logit	Mode choice	Truck, intermodal-maritime, intermodal-rail, intermodal-air	Cost, time	---	---	Service frequency , Punctuality
Nugroho et al. (2016)	Indonesia (Java,)	Survey 2014 (SP)	1. Multinomial Logit 2. Nested Logit 3. Mixed Multinomial Logit 4. Mixed nested Logit	Mode Choice	Truck, Rail, Ship	Cost, time	---	---	Green House Gas Emission, Ship Frequency, reliability

[1]Data Type: RP = revealed Preference, SP = Stated Preference
[2]Mode: When the study specifies particular modes.

CHAPTER THREE: DATA ANALYSIS

The previous chapter discussed earlier research on freight mode choice modeling and scope of the thesis. This chapter describes the data source employed for the study and descriptive statistics of the dataset. A discussion on data compilation procedures as well as exogenous variable generation steps is provided in this chapter.

3.1 Data Source

The 2012 CFS data is the main data source for this study. This data, published in June 2015, is provided by the Bureau of Transportation Statistics (BTS). CFS is a joint data collection effort by BTS, US Census Bureau, and U.S. Department of Commerce. It provides a representation of national commodity flows and is the only publicly available source of commodity flow data for the highway mode. The CFS data was augmented with several GIS layers of mega regions, road network, and population density. The Public Use Microdata (PUM) file of CFS, 2012 contains a total of 4,547,661 shipment records from approximately 60,000 responding industries. To manage the burden of LOS variable generation, a random sample of 11,970 records was drawn from the original database. Adequate efforts were undertaken to ensure that the weighted mode shares in the sample match with the weighted mode shares in the full dataset. Off the sample, 8,970 were randomly chosen for estimation sample and 3,000 were set aside for validation.

3.2 Dependent Variable Generation and Alternative Availability

CFS 2012 provides a total of twenty-one mode categories where many of these alternatives have insignificant sample share. Hence, the reported modes were categorized into five groups: (i) hire truck (including truck and hire truck), (ii) private truck, (iii) air, (iv) parcel or courier service, and (v) other mode which includes the rail mode and the rest of the modes. The distribution of the mode share in the sample is shown in Figure 3.1. From the figure it is clear that highest percentage of freight is shipped by parcel mode. Though other mode is only 0.2 percent, but major portion of the other mode is rail (0.13%).

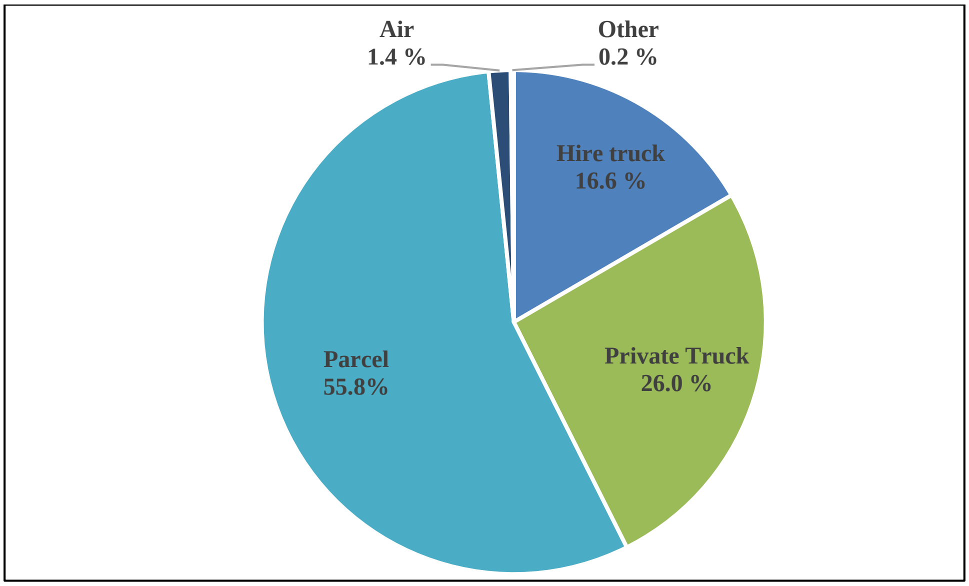

Figure 3.1 Distribution of Freight Mode Share

As described earlier, in our study, we focus on accommodating for alternative availability in our modeling exercise. A heuristic approach was employed to generate the availability option based on shipment weight and routed distance. Specifically, we examined the freight characteristics of the chosen modes and developed guidelines. The availability of the five modes are set according to the conditions below:

- Hire truck alternative is always available.
- Private truck is available when routed distance is less than 413 miles (99 percentile of private truck observed in the data).
- Air is set available when the shipment weight is less than 914 lbs (99 percentile).
- Parcel/Courier service is set available when shipment weight is less than 131 lbs (99 percentile).
- Other mode is always available.

3.3 Exogenous Variable Summary

The CFS data provides information on a host of attributes. The information on freight characteristics includes shipment value, shipment weight, North American Industry Classification System (NAICS) - industry classification of the shipper, quarter in which the shipment was made in 2012, Standard Classification of Transported Goods (SCTG) - commodity type, whether or not the shipment required temperature control, hazardous material code, whether or not the shipment was an export. The O-D variables include shipment origin (State, Metropolitan and CFS Area), shipment destination (State, Metropolitan and CFS Area), great circle distance between the shipment origin and US destination, and routed distance between the shipment origin and US destination. Based on the origin and destination information additional transportation network attributes are generated. The states and CFS areas are categorized into ten mega regions using geographical information system (GIS). The GIS shape file of mega regions has been obtained from http://www.america2050.org/maps/. The states which do not fall into any mega region have been categorized as non-mega region. The details on states comprising each mega region are presented in Table 3.1.

There are 45 types of North American Industry Classification System (NAICS) codes along with industry description. The commodity types are also provided as Standard Classification of Transported Goods (SCTG) classification code. This commodities are then regrouped into nine major categories described in Table 3.2. The categories are raw food, prepared products, stone and non-metallic minerals, petroleum and coal, chemical products, wood, paper and textile, metals and machinery, electronics, furniture and others. SCTG commodity groups have been used as one of the explanatory variables in our study. Shipment value, weight and great circle distance are also regrouped in some categories.

A host of transportation network and O-D attributes were also created. Using the GIS shape files provided by National Transportation Atlas Database 2015 (NTAD 2015), highway and railway densities in CFS areas have been generated. Additionally, population density in each CFS area was estimated based on the census data of population in 2010. The population of each county has been projected for 2012 by multiplying the 2010 population with a factor of 1.015. This factor was calculated by dividing total population of 2012 on April, 1 (313,378,472) by total population of 2010 on April, 1 (308,745,538) as published by United States Census Bureau. Then the total population of each CFS area was calculated by adding the total population of the counties in the CFS area. Population density was obtained by dividing total population by total area of the CFS area.

3.4 Descriptive Analysis

Table 3.3 summarizes the characteristics of explanatory variables from estimation dataset. It can be observed from the Table that almost all the shipments are domestic (98.9%). Also the shipment of temperature controlled product and hazardous materials are comparatively very low (4.7% and 3.1% respectively). Most of the shipments are originating and terminating in non-mega regions (32.4% and 34.9% respectively). Great Lake and Northeast regions are also originating and terminating higher percentage of shipments. Interestingly in the Texas Triangle region shipment terminating (12.5%) is almost double the shipment originating (6.9%). Electronics and wood, papers and textiles are mostly shipped products comprising almost 27 percent each. Stone and non-metallic minerals are the least transported commodity (0.9%). Also the shipments, value less than $300 has been shipped most, which comprises 75.1 percent. Shipment value greater than $5,000 are least shipped (4.2%). Origin and destination mean highway density is 0.20 mi/mi^2 and 0.21 mi/mi^2 which are nearly the same. Also origin and destination mean railway density is 0.11 mi/mi^2. Mean population density in origin is 540.90 per mi^2 and in destination the mean population density is 498.00 per mi^2.

3.5 Summary

In this chapter the source and preparation of the data employed for the study have been discussed. Further, descriptive sample statistics for the five freight modes and exogenous variables were provided. The next chapter describes the details on the generation of level of service variables for each mode.

Table 3.1 States Comprising Mega Regions

Mega Region	States
Arizona	Arizona, Partially Utah, Partially New Mexico
California	California, Partially Nevada
Cascadia	Washington, Oregon
Florida	Florida
Front Range	South of Colorado, Wyoming area, Part of New Mexico
Great Lake	Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio, west Pennsylvania, Kentucky, East part of Missouri, Iowa, West Virginia
Gulf Coast	Part of Mississippi, Partially Louisiana and Alabama
Northeast	East Pennsylvania, New York, Maine, New Hampshire, Massachusetts, Connecticut, Rhode Island, New Jersey, Delaware, Maryland, Delaware, Maryland, Virginia
Piedmont Atlantic	North Carolina, South Carolina, Georgia, Alabama, Tennessee, South part of Kentucky
Texas Triangle	Texas, South West Part of Louisiana, Little part of south Oklahoma
Non-Mega region	Idaho, Montana, North Dakota, South Dakota, Nebraska, Hawaii, Alaska, Mississippi, Vermont

Table 3.2 Newly Grouped SCTG Commodity Type

SCTG	Description	SCTG Group	SCTG_New
01	Animals and Fish (live)	Raw Food	01
02	Cereal Grains (includes seed)		
03	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)		
04	Animal Feed, Eggs, Honey, and Other Products of Animal Origin		
05	Meat, Poultry, Fish, Seafood, and Their Preparations		
06	Milled Grain Products and Preparations, and Bakery Products	Prepared Products	02
07	Other Prepared Foodstuffs, and Fats and Oils		
08	Alcoholic Beverages and Denatured Alcohol		
09	Tobacco Products		
10	Monumental or Building Stone	Materials	03
11	Natural Sands		
12	Gravel and Crushed Stone (excludes Dolomite and Slate)		
13	Other Non-Metallic Minerals not elsewhere classified		
14	Metallic Ores and Concentrates		
15	Coal	Petroleum & Coal	04
16	Crude Petroleum		
17	Gasoline, Aviation Turbine Fuel, and Ethanol (includes Kerosene, and Fuel Alcohols)		

SCTG	Description	SCTG Group	SCTG_New
18	Fuel Oils (includes Diesel, Bunker C, and Biodiesel)		
19	Other Coal and Petroleum Products, not elsewhere classified		
20	Basic Chemicals	Chemical	05
21	Pharmaceutical Products		
22	Fertilizers		
23	Other Chemical Products and Preparations		
24	Plastics and Rubber		
25	Logs and Other Wood in the Rough	Wood & papers	06
26	Wood Products		
27	Pulp, Newsprint, Paper, and Paperboard		
28	Paper or Paperboard Articles		
29	Printed Products		
30	Textiles, Leather, and Articles of Textiles or Leather		
31	Non-Metallic Mineral Products	Metal	07
32	Base Metal in Primary or Semi-Finished Forms and in Finished Basic Shapes		
33	Articles of Base Metal		
34	Machinery		
35	Electronic and Other Electrical Equipment and Components, and Office Equipment	Electronics	08
36	Motorized and Other Vehicles (includes parts)		
37	Transportation Equipment, not elsewhere classified		

SCTG	Description	SCTG Group	SCTG_New
38	Precision Instruments and Apparatus		
39	Furniture, Mattresses and Mattress Supports, Lamps, Lighting Fittings, and Illuminated Signs	Furniture & Others	09
40	Miscellaneous Manufactured Products		
41	Waste and Scrap (excludes of agriculture or food, see 041xx)		
43	Mixed Freight		
99	Missing Code		
00	Commodity code suppressed		

Table 3.3 Summary Statistics of Variables Influencing Freight Mode Choice

Dependent Variable		
Mode	**Frequency**	**Percentage**
Hire Truck	1,739,693,053	16.6
Private Truck	2,735,128,135	26.0
Air	142,407,621	1.4
Parcel	5,861,090,891	55.8
Other	16,673,990	0.2
Total	10,494,993,691	100.0

Explanatory Variables	
Variables	**Sample Characteristics**
Categorical Variables	**Percentage**
Export	
No	98.9
Yes	1.1
Temperature Controlled	
No	95.3
Yes	4.7
Hazardous Materials	
Flammable Liquids	1.2
Non-flammable Liquid and Other Hazardous Material	1.9
Non Hazardous Materials	96.9
Origin Mega Region	
Arizona	2.9
California	8.5
Cascadia	1.0
Florida	2.3
Front Range	2.7
Great Lake	19.0
Gulf Coast	0.4
Northeast	18.7
Atlantic	5.3
Texas	6.9
Non-Mega region	32.4

Categorical Variables	**Percentage**
Destination Mega Region	
Arizona	1.4
California	4.8
Cascadia	1.2
Florida	3.8
Front Range	2.4
Great Lake	16.5
Gulf Coast	0.6
Northeast	15.9
Atlantic	6.0
Texas	12.5
Non-Mega region	34.9
SCTG Commodity Type	
Raw Food	1.7
Prepared Products	4.5
Stone and Non-Metallic Minerals	0.9
Petroleum and Coal	2.7
Chemical Products	12.8
Wood, papers and Textiles	27.1
Metals and Machinery	8.7
Electronics	27.4
Furniture and Others	14.1
Shipment Value	
Value < $300	75.1
$300 ≤ Value ≤ $1,000	13.0
$1,000 < Value ≤ $5,000	7.7
Value > $5,000	4.2
Continuous Variables	**Mean**
Origin Highway Density (mi/mi^2)	.20
Destination Highway Density (mi/mi^2)	.21
Origin Railway Density (mi/mi^2)	.11
Destination Railway Density (mi/mi^2)	.11
Origin Population Density (per mi^2)	540.90
Destination Population Density (per mi^2)	498.00

CHAPTER FOUR: LEVEL OF SERVICE VARIABLES GENERATION

CFS dataset does not have any information regarding shipping cost and time by each mode. This chapter describes the procedures of generating shipping cost and time variables from different sources.

4.1 Shipping Cost Variable Generation

Employing information from several sources, the CFS dataset was augmented with shipping cost information. Examples of shipping cost generation procedures are provided in Table 4.1. The detailed procedures employed by mode are described below:

4.1.1 Shipping Cost for Hire Truck and Private Truck mode

For the two truck mode alternatives, the same approach for cost computation was employed. After a thorough review of various trucking company websites, we could not obtain an easy to automatize measure for shipping cost of truck. These web based shipping cost estimators required details about the product shipped including product dimension, packaging type, freight class, origin and destination zip code which are not available in our data. Hence, we adopted the National Transportation Statistics's (NTS) average freight revenue information to generate shipping cost (NTS, 2016). For truck mode, revenue per ton-mile was available for 2007 (latest year). To extrapolate the value for 2012 (our study year), we employed a correction factor obtained comparing shipping costs in 2008 and 2012 (ATRI, 2014). We calculated a factor (1.51/1.48 = 1.02), assuming that the operating cost does not vary substantially between 2007 and 2008.

Afterwards, revenue per ton-mile for 2007 obtained from RITA website was multiplied by the calculated factor and thereby obtained the shipping cost of truck as 16.88 cents per ton-mile. Further, to account for nationwide differences in shipping cost, we segmented the country in five zones: Northeast, Southeast, Southwest, Midwest, and West Coast. The states comprising each region is listed in Table 4.2. Based on reported values of the average marginal cost per mile for trucks for each region, the average of these costs for five regions was calculated and the ratio with the average was estimated for each region which is presented in Table 4.3.

If the origin and destination of freight shipment were in the same region, the cost per ton-mile was multiplied by that region's ratio. But when the shipment origin and destination fell in two different regions, then the average of the ratio for that two regions was computed and then multiplied. In our data set, weights is given in pounds, so we converted it to tons by multiplying with 0.0005. For instance, if 10,000 lb is shipped from region 1 to region 3 and the routed distance is 1200 miles then the shipping cost would be,

0.1688 $/ton-mile*Shipping weight (ton)*Routed distance (mile)*Regional Ratio

= 0.1688 $/ton-mile*(10000*0.0005)*1200*[(0.983+0.964)/2] = $ 985.96

4.1.2 Shipping Cost for Air mode

The shipping cost per pound for air was estimated based on cost documentation obtained from Southwest Cargo Company, a USA based air Cargo Company. This company divided the country into seven zones with specific costs for Alaska and Hawaii. The zones are listed in Table 4.4. This company has a base rate which is applied when shipment weight is upto 100 lbs. Over 100 pounds, charges are: base charge plus the applicable per pound rate for shipments over 100 pounds. For instance, if the origin is zone 1 and destination is zone 2 and the weight of commodity is 150 lbs then the cost would be, $55 + (150-100)lb * 1.08 $/lb = $109.

4.1.3 Shipping Cost for Parcel/Courier

The cost computation for parcel mode involved two major dimensions: cost based on shipping weight and distance and cost based on speed of shipping service. For the first dimension, we manually provided information for different shipping weights and distances employing the Fedex shipping cost tool. FedEx pricing mechanism is based on the 7 zone system depending on the distance from origin. After generating logarithm of shipping cost values for multiple shipping sizes in each zone, a linear regression based parameterization for cost as a function of weight was generated. The analysis was conducted separately for each shipping speed which is presented in Table 4.5.

To address the second dimension – shipping speed – there was no available information from CFS. Hence, we reviewed the FedEx 2015 annual report and obtained share of various shipping speeds as follows: express overnight (18%), express deferred (9%), and ground service (73%). Based on these shares, we randomly assigned a shipping speed to each record in the estimation sample. After the assignment, the corresponding cost was computed using the equation described earlier. We recognize that the cost computed is a random realization and to account for this we generate 2 random samples of cost and evaluate the differences in the model framework.

For instance, if the weight of shipment is 150 lbs and shipping distance is 1000 miles then the shipping cost for 1 day delivery time from Table 4.4 would be:

Ln of Shipping Cost = 4.700 + (0.015*150) = $6.95

Shipping Cost = exp (6.95) = $1043.15

If the same weight would travelled for 1,000 miles and delivery time would be 5days, then shipping cost would be as follows:

Ln of Shipping Cost = 2.555 + (0.014x *150) = $4.655

Shipping cost = exp (4.655) = $105.11

4.1.4 Shipping Cost by Other Modes

To calculate shipping cost for other mode mainly comprised of rail, the average freight revenue per ton-mile for rail mode provided in the NTS report was used. In this document, the average freight revenue per ton-mile published for rail was 3.95 cents in 2012. The following formula has been used to calculate the shipping cost for each shipment by rail:

0.0395 * Shipment Weight in Ton * Routed Distance

Suppose if any commodity weighs 10,000 lb and shipped for 1,200 miles then,

Shipping Cost = 0.0395 $/ton-mile * (10,000*0.0005) ton * 1200 miles = $237

4.2 Shipping Time Variable Generation

Shipping time is another very important factor for selection of mode. Shipping time is estimated for those modes that are available only.

4.2.1 Shipping Time for Hire Truck and Private Truck:

The shipping time for truck mode is composed of travel time and required breaks for drivers. The travel time component was computed based on the distance measure provided in the data. For this purpose, the distance (in miles) was grouped into five categories: <=50, 51-100, 101-200, 201-500, and >500. The objective was to allow for longer distance bands to have higher average speed limits. Based on the average speed reported in ATRI, 2009 and ATRI, 2014, three speed (in mph) profiles by distance were considered which is described in Table 4.6. These assumptions provided three travel time realizations. After calculating the travel time, the required break time was considered for drivers according to hours of service regulations provided by Federal Motor Carrier Safety Administration (FMCSA). According to the regulations for 2011,

- Truck drivers need to take a 30-minute break during the first eight hours of a shift.
- After first 14 consecutive hours of driving, driver needs to take 10 hours of break.
- After first 14 hours for every 11 consecutive hours of driving drivers are required to take 10 hours of break.

Based on the travel time computed from our approach, the required rest times were computed and added. Thus, three values of travel time were generated. Based on the model fit, the appropriate travel time was chosen.

4.2.2 Shipping Time for Air

An average speed of 549.5 mph by air was opted for travel time after reviewing several sources. Given the distance between origin and destination, the speed was employed to generate travel time. In this case, only the travel time has been considered. The dwell time at airports and time for home delivery has not been accounted for.

4.2.3 Shipping Time for Parcel

As described in the cost computation, the type of parcel service used is not provided in the data. Hence, we resort to a random realization of travel time in accordance with the shares by different shipping speeds. Delivery time has been considered 3 days if the random number is less than or equal to 0.09. The delivery time is considered 1 day when random number falls in the range from 0.10 to 0.27. When the random number is greater than 0.27 then the shipment is considered with the delivery time 5 days. The maximum days has been assumed for each case as the shipper agrees to ship knowing the maximum delivery time. As described earlier, to account for the influence of randomness 2 realizations were considered and tested in the model.

4.2.4 Shipping Time for Other Mode

Similar to the travel cost for other mode, the travel time was computed based on rail travel time. The rail travel time was computed based on the Railroad Performance Measure information. Train Speed is considered as the measures of the line-haul movement between terminals. Then, the average speed is calculated by dividing train-miles by total hours operated, excluding yard and local trains, passenger trains, maintenance of way trains, and terminal time. The average speed till March 2016 has been considered from this website for six railroads (BNSF, CN, CSX, KCS, NS and UP). An overall average speed of 25.8 mph [(28.1+27.9+20.7+27.5+23.6+26.9)/6] was computed by considering the average across all rail companies to generate travel time. This average speed has been used to generate travel time by rail.

4.3 Descriptive Analysis of Shipping Cost and Shipping Time

The average shipping cost and average travel time has been estimated for each mode type for two conditions: when mode is available and when mode is chosen. This information is presented in Table 4.7. It is expected that average shipping cost would be lower when chosen than when available, as it is most likely that shippers would choose a mode with low shipping cost. But in case of shipping by hire truck and other, it is found that average shipping cost is very high for chosen than available presumably due to the fact that, these modes are usually chosen for shipping large loads, while it is available for many other loads. Also, the frequency of other mode chosen was lower. Average travel time for chosen other and air mode is higher than when they are available. The reason may also be in this case that frequency of chosen other and air is very low than when they are available. The mean shipping cost for air mode is highest ($215.43), but mean shipping time is lowest for this mode (1.21 hours) when it is available. On the other hand, shipping cost is lowest for other modes ($8.32) when it is available, but highest when this mode is chosen ($1,624.65).The average shipping cost and time for parcel mode when it is available and when chosen are almost same. Compared to all other modes the mean shipping time is highest for parcel mode both when it is available (100.71 hour) and when chosen (100.32 hours). When private truck is chosen both mean shipping cost ($8.74) and mean shipping time (1.54 hours) are lowest.

4.4 Summary

This chapter discussed in detail the generation of shipping cost and shipping time variables for each mode. Also summary statistics of these variables were presented in this chapter. The next chapter describes the methodology employed in our analysis.

Table 4.1 Shipping Cost and Shipping Time Calculation Details

Mode	Freight Characteristics	Shipping Cost	Shipping Time
Hire Truck Private Truck	Weight = 10,000 lb = (10,000*0.0005) Ton O-D = Northeast to Southwest O-D Distance = 1,200 miles	0.1688 $/ton-mile*Shipping weight (Ton) * Routed distance (mile)*Regional Ratio = 0.1688 $/ton-mile *(10000*0.0005) * 1200 *[(0.983+0.964)/2] = $ 985.96	Distance/Speed = 1200 mile / 50mph = 24 h + Break Time = 24 + 0.5 + 10 = 34.5 h
Air	Weight = 150 lb O-D = Zone 1 to Zone 2 O-D Distance = 1,000 miles	$55 + (150-100) lb * 1.08 $/lb = $ 109.00	Distance/Speed = 1000 mile / 549.5 mph = 1.82 h
Parcel	Weight = 150 lb O-D Distance = 1,000 miles (Considering 5 days shipment)	exp (2.555+0.014*Shipping Weight) = exp (2.555+(0.014*150) = exp (4.655) = $ 105.11	5 Days = (5 * 24) h = 120 h
Other Mode	Weight = 10,000 lb = (10,000*0.0005) Ton O-D Distance = 1,200 miles	0.0395 $/ton-mile * Shipment weight (Ton) * Routed Distance (mile) = 0.0395 $/ton-mile * (10,000*0.0005) ton * 1200 miles = $ 237.00	Distance/Speed = 1200 mile / 25.8 mph = 46.5 h

Table 4.2 Names of Different States within Region

Region	State	Region	State
Northeast	Connecticut	Midwest	Illinois
	Maine		Indiana
	Massachusetts		Iowa
	New Hampshire		Kansas
	New Jersey		Michigan
	New York		Minnesota
	Pennsylvania		Missouri
	Rhode Island		Nebraska
	Vermont		North Dakota
Southeast	Alabama		Ohio
	Arkansas		South Dakota
	Delaware		Wiconsin
	Florida	West Coast	Alaska
	Georgia		Arizona
	Kentucky		California
	Lousiana		Colorado
	Maryland		Hawaii
	Mississippi		Idaho
	North Carolina		Montana
	South Carolina		Nevada
	Tennesse		Oregon
	Virginia		Utah
	West Virginia		Washington
Southwest	New mexico		Wyoming
	Oklahoma		
	Texas		

Table 4.3 Region Wise Operating Cost per Mile for Truck

Region	Cost per mile (dollar)	Ratio
Northeast	1.647	0.983
Southeast	1.756	1.048
Southwest	1.615	0.964
Midwest	1.677	1.001
West Coast	1.687	1.007
Average	**1.676**	**1.000**

Table 4.4 States in Each Zone Described by Southwest Cargo Company

AIR_O/D _Zone	State Name	ORIG/DEST _STATE	AIR_O/D _Zone	State Name	ORIG/DEST _STATE
1	Connecticut	9	4	Arkansas	5
1	Delaware	10	4	Lousiana	22
1	Maine	23	4	New mexico	35
1	Maryland	24	4	Oklahoma	40
1	Massachusetts	25	4	Texas	48
1	New Hampshire	33	5	Colorado	8
1	New York	36	5	Iowa	19
1	Pennsylvania	42	5	Kansas	20
1	Vermont	50	5	Minnesota	27
1	Virginia	51	5	Missouri	29
1	West Virginia	54	5	Nebraska	31
2	Illinois	17	5	North Dakota	38
2	Indiana	18	5	South Dakota	46
2	Kentucky	21	6	Arizona	4
2	Michigan	26	6	California	6
2	Ohio	39	6	Nevada	32
2	Tennessee	47	6	Utah	49
2	Wisconsin	55	7	Idaho	16
3	Alabama	1	7	Montana	30
3	Florida	12	7	Oregon	41
3	Georgia	13	7	Washington	53
3	Mississippi	28	7	Wyoming	56
3	North Carolina	37	8	Alaska	2
3	South Carolina	45	8	Hawaii	15

Table 4.5 Zones and Equations Developed for Parcel Mode for Three Different Shipping Time

Zone	Routed Distance (miles)	Linear Equation (Shipping Time: 5days) (x=SHPMT_WGHT)	Linear Equation (Shipping Time: 3days) (x=SHPMT_WGHT)	Linear Equation (Shipping Time: 1day) (x=SHPMT_WGHT)
2	0-150	2.056+0.016x	3.208+0.014x	3.666+0.015x
3	151-300	2.251+0.015x	3.399+0.015x	3.993+0.016x
4	301-600	2.362+0.015x	3.560+0.015x	4.631+0.015x
5	601-1000	2.555+0.014x	3.624+0.016x	4.700+0.015x
6	1001-1400	2.739+0.013x	3.908+0.016x	4.767+0.015x
7	1401-1800	2.905+0.013x	4.010+0.016x	4.798+0.015x
8	> 1800	3.023+0.013x	4.158+0.016x	4.855+0.015x

Table 4.6 Truck Speed Based on Various Distance Range

Distance (miles)	Speed 1(mph)	Speed 2 (mph)	Speed 3(mph)
<=50	30	25	35
51-100	35	30	40
101-200	40	35	45
201-500	45	40	50
>500	55	50	60

Table 4.7 Summary Statistics of Shipping Cost and Shipping Time of Freight

Mode	Average Shipping Cost ($)		Average Shipping Time (hour)	
	Available	Chosen	Available	Chosen
Hire Truck	35.84	117.61	21.17	15.92
Private Truck	17.43	8.76	2.36	1.54
Air	215.43	85.25	1.21	1.74
Parcel or Courier Service	29.32	29.42	100.71	100.32
Other Mode	8.32	1624.65	25.15	51.09

CHAPTER FIVE: METHODOLOGY

The objective of our study is to develop a mode choice model accounting alternative availability while also accommodating the influence of unobserved heterogeneity on freight mode choice. In this chapter the econometric framework of Multinomial Logit Model and Mixed Multinomial Logit model are presented.

5.1 Econometric Framework

In this analysis, we used the mixed multinomial logit (MMNL) model to analyze mode choice. The modeling framework is briefly presented in this section. In the random utility approach, it is assumed that a decision maker always chooses the alternative with the highest utility. Let n $(n = 1,2, \dots \dots, N)$ be the index for shippers, and i $(i = 1,2, \dots \dots, I)$ be the index for freight mode alternatives. With this notation, the random utility formulation takes the following familiar form:

$$v_{in} = (\beta' + \delta_n')x_{in} + \varepsilon_{in} \qquad (1)$$

In the above equation, v_{in} represents the total utility obtained by the n^{th} shipper in choosing the i^{th} alternative. x_{in} is a vector of exogenous variables (including constants), β' and δ_n' are the column vector of parameters to be estimated, β' represents the mean effect, and δ_n' represents the shipper level disturbance of the coefficient, ε_{in} is an idiosyncratic error term assumed to be standard type-1 extreme value distributed. In the current paper, we assume that δ_n' are independent realizations from normal population distribution; $\delta_n' \sim N(0, \sigma_m^2)$. The probability expression for choosing alternative i is given by:

$$P_{in} = \int \frac{e^{(\beta' + \delta_n')}}{\sum_{i=1}^{I} e^{(\beta' + \delta_n')}} * dF(\delta_n') d(\delta_n') \quad (2)$$

Maximum simulated likelihood (MSL) estimation is employed to estimate β' parameters. For this particular study, we use a quasi-Monte Carlo (QMC) approach (Scrambled Halton draws) with 200 draws for the MSL estimation (see Bhat, 2001 for more details). The reader would note that if σ_n' was restricted to 0 the MMNL will collapse to a simple multinomial logit model (MNL).

5.2 Summary

The current chapter presented the econometric framework employed for freight mode choice analysis. The empirical analysis results are presented in the subsequent chapter.

CHAPTER SIX: EMPIRICAL ANALYSIS

The results of the empirical analysis using the model described in the previous chapter are presented in this chapter. In addition, this chapter also describes the model validation procedures.

6.1 Model Specification and Model Fit

The model estimation process began with the estimation of the traditional MNL model and subsequently a Mixed MNL was estimated. The estimation results for MNL and Mixed MNL are presented in Table 6.1 and Table 6.2. A positive (negative) coefficient for a certain variable-category combination means that an increase in the explanatory variable increases (decreases) the likelihood of that alternative being chosen relative to the base alternative. A blank entry corresponding to the effect of variable indicates no statistically significant effect of the variable on the choice process at 90 percent confidence level.

After extensive specification testing, the final log-likelihood value at convergence for the MNL and MMNL models are found as -1263.11 and -1229.52, respectively. The adjusted rho-square value has been estimated for the MNL and MMNL models using the formula, $\rho^2 = 1 - \frac{L(\beta)-M}{L(C)}$, where $L(\beta)$ is the log-likelihood at convergence, $L(C)$ is the log-likelihood for constant only model (-1553.38) and M is the number of parameters in the model. The adjusted ρ^2 values for the MNL and MMNL mode are 0.1649 and 0.1911 respectively. The significant improvement in the adjusted ρ^2 values clearly demonstrates the superiority of the MMNL model over its traditional counterpart. Hence, in the subsequent sections, we discuss the results of the MMNL model only.

6.2 Analysis Result

In this section the effects of variables by variable category has been discussed.

6.2.1 Constants

The constants do not have a substantive interpretation after introducing other variables. The results highlight the presence of a significant preference heterogeneity parameter for hire truck highlighting that the presence of unobserved factors affect the choice of this alternative.

6.2.2 Level of Service Variables

The LOS variables (shipping cost and shipping time) bear intuitive signs - negatively influencing mode choice and are highly significant. Cost and price are the two most important determinants of transport mode choice, for both freight and passenger modes. As described in the variable generation section (section 3), different realizations of shipping cost and time for hire truck and parcel mode were considered. In our model estimation analysis, we found that altering the cost and time variables based on various realizations had marginal impact on the costs and time coefficients. Hence one of the shipping cost and time realizations for parcel mode and hire truck were employed. Given the computation process for shipping cost and time, we allowed for the presence of unobserved heterogeneity for cost and time coefficients. In our analysis, we found that the coefficient of cost exhibited a statistically significant standard deviation. The coefficient for cost follows a normal distribution with mean and standard deviation as -0.0257 and 0.0177. The distribution implies that for majority of the observations, the impact of cost is negative with a small proportion of cases have the impact of cost being positive (7.35%).

6.2.3 Freight Characteristics

The various freight characteristics considered in the model offer interesting results. Parcel/Courier service is less likely to be chosen for transporting non-flammable liquid and other hazardous materials. This is expected because transporting hazardous material requires professional handling and enhanced safety precautions that are unlikely to be ensured in parcel mode. The utility of private truck alternative increases when the commodity requires temperature control while being shipped, since private truck providers are able to provide the desired vehicle fleet. Abdelwahab and Sayed (1999) and Sayed and Razavi (2000) have considered this variable in their studies for freight mode choice between truck and rail, but have not found it statistically significant. For freight that is exported, the results indicate a preference for air mode and a disinclination to adopt the private truck mode (see Wang et al, 2013 for a similar result).

The SCTG commodity type variables were also found to affect freight mode choice. The results indicate that private truck is preferred for prepared products and petroleum and coals. On the other hand, it is less preferred for transporting stone and non-metallic minerals and electronics. The results from previous studies (Pourabdollahi et al, 2013; Wang et al., 2013) support these results. Further, Parcel/courier service is less likely to be preferred for transporting metals and machinery, as this type of commodities are heavy and preclude the adoption of parcel mode. For transporting electronics goods, air is preferred over other modes. The reason may be electronics products are comparatively light weight, expensive and need special care while transporting (see Pourabdollahi et al., 2013 for the same finding).

In terms of the value of the commodity shipped, the results are quite intuitive. When the value of shipped commodity is under 5000$, private truck is preferred. The inclination is much stronger for shipping value under 1000$. On the other hand, for expensive shipments (value >5000$), the parcel/courier mode is least likely to be considered (see Nam, 1997; Sayed and Razavi, 2000; Arunotayanum and Polak, 2011 for similar findings).

6.2.4 Transportation Network and Origin-Destination Variables

Several variables from transportation network and origin-destination category were considered in the mode choice model. Based on the origin mega region results, we observe that shipments originating in the Great Lake mega region have a negative propensity for private truck mode while shipments originating from Northeast exhibit higher likelihood of choosing private truck mode. Major products shipped from Northeast region are raw food, prepared product, petroleum and coal which are generally transported by truck mode (observed from the data). Shipments originating in the Gulf Coast mega region are unlikely to use parcel/courier mode as the products generated from this region are wood, paper and chemicals that are not conducive for transport by parcel mode. Air mode is the preferred alternative for shipments from the Piedmont Atlantic region. The major product shipped from the Piedmont Atlantic region are electronics and it is logical to observe higher likelihood of air mode (observed from the data). Based on the destination mega region, we observe that shipments destined to California are likely to use private truck. Shipments destined to Front Range mega region are less likely to prefer private truck and parcel/courier service. Finally, air is less preferred for shipments destined to Texas Triangle mega region.

In terms of origin and destination CFS area attributes, only origin attributes - highway density, railway density and population density – affected mode choice. With increase in highway density, air and parcel mode have higher utility. The result is a manifestation of how increased connectivity by road increases the likelihood that air and parcel modes are highly accessible and competitive. An increase in origin railway density reduces the likelihood for parcel/courier service. Finally, with increasing origin population density the likelihood of hire and private truck increase.

6.3 Model Validation

We also performed a validation exercise to evaluate the performance of the model. To examine the fit of the model we used both aggregate and disaggregate measures of fit. The exercise was conducted using the validation sample with 3,000 records. At the disaggregate level, we computed the predictive log-likelihood. The log-likelihood at zero and log likelihood at sample shares are calculated as -1208.69 and -849.693, respectively. The predictive log-likelihood is calculated as –568.91, which is significantly better than the model with only sample shares.

At aggregate level, both root mean square error (RMSE) and mean absolute percentage error (MAPE) were computed by comparing predicted and actual shares of mode choice for the validation sample. The RMSE and MAPE values obtained are 1.69 and 28.55% respectively.

6.4 Summary

This chapter described the empirical analysis results in detail along with model validation. The policy analysis will be discussed in the subsequent chapter

Table 6.1 Estimation Result of Multinomial Logit Model

Explanatory Variables	Hire Truck		Private Truck		Air		Parcel/Courier		Other	
	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Constant	0	-	-0.9065	-2.231	-6.4451	-7.262	2.6431	9.835	-6.6526	-4.729
Level of Service variables										
Shipping Cost (1000 $)	-1.4876	-3.734	-1.4876	-3.734	-1.4876	-3.734	-1.4876	-3.734	-1.4876	-3.734
Shipping Time (100 hrs)	-1.1414	-7.289	-1.1414	-7.289	-1.1414	-7.289	-1.1414	-7.289	-1.1414	-7.289
Freight Characteristics										
Hazardous Material (Base: Not Hazardous)										
Non-flammable Liquid and Other Hazardous Material	-	-	-	-	-	-	-4.1214	-2.548	-	-
Temperature Controlled (Base: No)										
Yes	-	-	2.1483	5.213	-	-	-	-	-	-
Export (Base: NO)										
Yes	-	-	-5.6622	-2.464	2.4524	2.612	-	-	-	-

Explanatory Variables	Hire Truck		Private Truck		Air		Parcel/Courier		Other	
	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
SCTG Commodity Type (Base: Wood, Papers and Textile)										
Prepared Products	-	-	1.8299	4.694	-	-	-	-	-	-
Stone & Non-Metallic Minerals	-	-	-1.0819	-2.114	-	-	-	-	-	-
Petroleum and Coals	-	-	1.5213	3.594	-	-	-	-	-	-
Metals and Machinery	-	-	-	-	-	-	-0.7531	-3.544	-	-
Electronics	-	-	-0.3746	-2.049	2.7274	4.927	-	-	-	-
Shipment Value ($) (Base:Value >5000)										
Value ≤ 1000	-	-	2.2577	6.349	-	-	-	-	-	-
1000 < Value ≤ 5000	-	-	1.3481	3.254	-	-	-	-	-	-
Value > 5000	-	-	-	-	-	-	-2.2678	-3.724	-	-
Transportation Network and Demographic Variables:										
Origin Mega Region (Base: Non Mega Region)										
Front Range	-	-	-	-	-	-	-	-	3.5989	2.563
Great Lake	-	-	-0.5148	-2.415	-	-	-	-	-	-

Explanatory Variables	Hire Truck		Private Truck		Air		Parcel/Courier		Other	
	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Gulf Coast	-	-	-	-	-	-	-2.2505	-2.291	-	-
Northeast	-	-	0.7701	3.729	-	-	-	-	-	-
Piedmont Atlantic	-	-	-	-	3.2992	6.737	-	-	-	-
Destination Mega Region (Base: Non Mega Region)										
California	-	-	-0.6729	-2.065	-	-	-	-	-	-
Front Range	-	-	-1.2304	-2.308	-	-	-1.6141	-4.539	-	-
Piedmont Atlantic	-	-	-	-	-	-			3.4044	2.523
Texas Triangle	-	-	-0.7072	-2.506	-4.4268	-2.270	-0.6201	-3.134	-	-
Origin Highway Density (100 mi/mi^2)	-	-	0.4692	2.908	1.9988	4.572	1.1258	6.911	-	-
Origin Railway Density (100 mi/mi^2)	-	-	-0.8254	-3.630	-1.5951	-2.193	-1.1319	-7.052	-	-
Origin Population Density (pop/mi^2)	0.0013	6.719	0.0013	6.719	-	-	-	-	-	-
Number of cases	8970									
Log Likelihood for Constant only Model	-1553.3798									
Log Likelihood at Convergence	-1263.1106									
Adjusted rho-square	0.1649									

Table 6.2 Estimation Result of Mixed Multinomial Logit Model

Explanatory Variables	Hire Truck		Private Truck		Air		Parcel/Courier		Other	
	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Constant	0	-	-0.9965	-2.560	-5.9690	-6.061	4.9421	7.437	-12.8321	-5.302
Std. Dev.	1.5082	2.109	-	-	-	-	-	-	-	-
Level of Service Variables										
Shipping Cost ($)	-0.0257	-5.048	-0.0257	-5.048	-0.0257	-5.048	-0.0257	-5.048	-0.0257	-5.048
Std. Dev.	0.0177	4.847	0.0177	4.847	0.0177	4.847	0.0177	4.847	0.0177	4.847
Shipping Time (hrs)	-0.0282	-6.827	-0.0282	-6.827	-0.0282	-6.827	-0.0282	-6.827	-0.0282	-6.827
Freight Characteristics										
Hazardous Material (Base: Not Hazardous)										
Non-flammable Liquid and Other Hazardous Materials	-	-	-	-	-	-	-4.9454	-2.746	-	-
Temperature Controlled										
Yes	-	-	2.2501	4.825	-	-	-	-	-	-
Export										
Yes	-	-	-5.4664	-2.177	2.7321	2.503	-	-	-	-
SCTG Commodity Type										

Explanatory Variables	Hire Truck		Private Truck		Air		Parcel/Courier		Other	
	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
(Base: Wood, Papers and Textile)										
Prepared Products	-	-	1.8491	4.435	-	-	-	-	-	-
Stone & Non-Metallic Minerals	-	-	-1.2002	-1.899	-	-	-	-	-	-
Petroleum and Coals	-	-	1.5462	3.073	-	-	-	-	-	-
Metals and Machinery	-	-	-	-	-	-	-0.8294	-3.505	-	-
Electronics	-	-	-0.4618	-2.409	3.0219	4.827	-	-	-	-
Shipment Value ($) (Base: Value>5000)										
Value ≤ 1000	-	-	2.3648	4.483	-	-	-	-	-	-
1000 < Value ≤ 5000	-	-	1.3745	2.850	-	-	-	-	-	-
Value > 5000	-	-	-	-	-	-	-2.4453	-3.247	-	-
Transportation Network and Origin-Destination Variables										
Origin Mega Region (Base: Non Mega Region)										
Great Lake	-	-	-0.6177	-2.914	-	-	-	-	-	-
Gulf Coast	-	-	-	-	-	-	-2.1196	-1.935	-	-
Northeast	-	-	1.1110	5.298	-	-	-	-	-	-
Piedmont Atlantic	-	-	-	-	4.2088	7.898	-	-	-	-

Explanatory Variables	Hire Truck		Private Truck		Air		Parcel/Courier		Other	
	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
Destination Mega Region (Base: Non Mega Region)										
California	-	-	-0.5582	-1.694	-	-	-	-	-	-
Front Range	-	-	-1.1792	-1.943	-	-	-1.6426	-3.936	-	-
Texas Triangle	-	-	-	-	-4.327	-1.97	-	-	-	-
Origin Highway Density (mi/mi^2)	-	-	-	-	11.4310	3.386	7.1750	3.881	-	-
Origin Railway Density (mi/mi^2)	-	-	-	-	-	-	-4.554	-2.379	-	-
Origin Population Density (pop/mi^2)	0.0013	5.106	0.0013	5.106	-	-	-	-	-	-
Number of cases	8970									
Log-Likelihood at Constant	-1553.38									
Log-Likelihood at Convergence	-1229.52									
Adjusted rho-square	0.1911									

CHAPTER SEVEN: POLICY ANALYSIS

The value of the proposed model is demonstrated through a detailed policy analysis. The chapter documents policy analysis measures related to money value of time – a very useful measure for policy makers. Subsequently, we study potential impact of increasing shipping cost and reducing shipping time on freight mode choice through multiple policy scenarios.

7.1 Money Value of Time

The money value of time measure provides an indication of trade-off between shipping cost and shipping travel time. The measure is computed as the ratio of coefficient of shipping time and coefficient of shipping cost ($/hours). In our case, the shipping cost parameter has unobserved heterogeneity, hence the value of time will also have a distribution. Given the large value of the standard deviation, for some values of the shipping cost, money value of time is negative indicating shippers are willing to pay additional money to increase travel time. Of course, the sample for such VOT observations are very small (about 7%). Within the acceptable range, the range of money value of time for 85% of the records is between 0.46 and 5.43 $/hour. As is evident, the money value of time follows a reasonable spread in our model. This is not surprising given the assumptions involved in generating the shipping cost and time variables.

7.2 Impact of Shipping Cost Increment and Shipping Time Reduction

To study the impact of shipping cost and shipping time on freight mode share, we considered different policy scenarios:

- A carbon tax measure on truck modes that increases cost by 25 percent, 35 percent and 50 percent
- Travel time reduction due to automated truck fleet by eliminating breaks in truck travel,
- A carbon tax measure of 50 percent increase and travel time reduction from second scenario
- A carbon tax for air mode of 25 percent, 35 percent and 50 percent increase.

Table 7.1 presents the changes of share upon changing the shipping cost and shipping time. For the carbon tax scenarios, if the shipping cost by truck is increased 25 percent then the reduction in share of hire truck and private truck are 4.8 percent and 3.5 percent respectively. The share of other mode (predominantly rail) increases to 6.9 percent from 0.2 percent. The further increase in shipping cost of hire and private truck by 35 percent and 50 percent, does not reduce the share of these modes much from that after increasing 25 percent shipping cost. When shipping cost in increased by 35 percent more due to carbon tax measures then the share of hire truck becomes 11.1 percent and private truck becomes 21.4 percent. When this cost is increased by 50 percent the share of hire truck reduces to 10.6 percent from 16.6 percent and share of private truck reduces to 20.7 percent from 25.3 percent. The reduction in share of hire truck is only 0.7 percent when the shipping cost is increased to 35 percent from 25 percent. This reduction is only 0.4 percent in case of private truck. Again, the share of hire truck reduced by only 1.1 percent and private truck by only 1.0 percent when the shipping cost is increased to 50 percent from 25 percent.

The shipping time by hire and private truck was reduced by eliminating the break time in the scenario for automated truck fleet. . Usually hours-of service, safety, heavy duty driver shortage and fuel costs are top issues in trucking industries. Introducing automated vehicle will help in optimizing resting time for driver, improving safety issues, mileage and additional fuel efficiency due to better aerodynamics and reducing congestion and emission. It is encouraging to see that this results in an increase in the share of hire truck and private truck by only 2.2 percent and 1.3 percent respectively. But when the shipping cost was increased by 50 percent and shipping time was decreased together of both hire and private truck, the share of hire truck decreased almost 3.1 percent and for private truck the reduction was almost 2.6 percent. The results clearly indicate that shipping cost has a stronger impact on truck mode than shipping time. Also the shipping cost by air mode was increased by 25 percent, 35 percent and 50 percent. It was observed that the share of air mode does not reduce much. The range of reduction varies from 0.20 percent to 0.31 percent.

7.3 Summary

This chapter provided policy based metrics generated based on the MMNL model estimated. The results included money value of time metrics as well as changes to freight mode choice in response to policy scenarios involving changes to travel time and travel cost.

Table 7.1 Percentage of Mode Share over Different Policy Scenario

Mode	Actual Share	Increment of Truck Shipping Cost			Elimination of Truck Break Time	Reduction of Truck Shipping Time and Increment of Truck Shipping Cost by 50%	Increment of Air Shipping Cost		
		25%	35%	50%			5%	10%	15%
Hire Truck	16.6	11.8	11.1	10.6	18.8	13.5	16.7	16.7	16.7
Private Truck	25.3	21.8	21.4	20.7	26.6	22.7	25.3	25.3	25.3
Air	1.4	1.7	1.7	1.7	1.5	1.7	1.3	1.2	1.1
Parcel	56.5	57.8	57.8	58.0	53.0	54.1	56.5	56.6	56.7
Other	0.2	6.9	8.0	9.0	0.2	8.1	0.2	0.2	0.2
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

CHAPTER EIGHT: CONCLUSIONS

Efficient and cost-effective freight movement is a prerequisite to a region's economic viability, growth, prosperity, and livability. The mode chosen for freight transportation has significant implications for the transportation system and the environment at large. A comprehensive understanding of the decision process for shipping freight by various modes would benefit transportation infrastructure planning decisions in terms of transportation infrastructure management. In this context, the main objective of the proposed research effort is to develop a national freight mode choice model employing the data from the 2012 Commodity Flow Survey (CFS). Based on the mode shares observed in CFS 2012, five modes are considered for the analysis including hire truck, private truck, air, parcel service and other modes (rail, ship, pipeline and other miscellaneous single and multiple modes). The data from CFS does not provide any information on level of service (LOS) measures – such as travel time and travel cost for any mode. Hence, the first contribution of the research effort is to generate these LOS measures for all modes considered in the analysis.

While the CFS data provides significant information, many variables of interest are unavailable in the dataset. Hence, the decision process is also likely to be affected by a host of unobserved variables. To accommodate for this unobserved heterogeneity, we estimate a mixed multinomial model. Further, we consider alternative availability explicitly in our model. A heuristic approach was employed to generate the availability option based on shipment weight and routed distance. The exogenous variables considered in the model include LOS measures, freight characteristics, and transportation network and Origin-Destination variables. Of these variables, travel time and travel cost, commodity value, origin mega region and origin CFS attributes such as highway and railway density presented intuitive and significant impacts on mode choice. The model estimation results also highlighted the presence of unobserved heterogeneity related to travel cost coefficient. The model estimated was also validated using a hold-out sample. The validation exercise clearly highlights the data fit offered by the mixed multinomial logit model. The range of money value of time for 85% of the records was found to be 0.46 to 5.43 $/hour within the acceptable range. The result highlights the substantial variation in VOT values across the dataset and points toward the influence of many unobserved variables unavailable to analysts in the CFS dataset. A host of policy exercises conducted also offer plausible results.

The study is not without limitations. Additional work on improving the approaches for LOS computation are required. Further, availability of more detailed freight origin and destination attributes will allow us to consider more detailed land use and built environment attributes in modeling freight mode choice.

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