Effect of Industry Clusters and Commodity Flow Characteristics on the Selection of Freight Transportation Modes in the United States with Advanced Econometric Approaches.

by

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Abstract

Effect of Industry Clusters and Commodity Flow Characteristics on the Selection of Freight Transportation Modes in the United States with Advanced Econometric Approaches.

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Mode choice is an important strategic decision for shippers to carry commodities efficiently. Freight mode-choice is an important activity to develop a successful freight transportation business in the private sector and to plan for economically consistent freight transportation infrastructures in the public sector. Freight activities result from the complex interactions between different economic agents, but these relationships are commonly relaxed to account for three major agents: shippers, carriers and receivers. Furthermore, the behavior of freight choice is commonly not concentrated in one agent, but rather is divided jointly over multiple individuals and firms in a logistics process, each component of which represents particular policies and specialists from different backgrounds. Shipper freight modal choice depends on freight demand, infrastructure, and the quality of service characteristics of alternative transportation modes. Moreover, freight logistics characteristics, like the attributes of the shipper, the attributes of the commodities to be transported, as well as the spatial attributes of shipments strongly influence freight mode selection. In the
United States, due to the heterogeneity of firms, commodities, and issues of confidentiality and reliability of data, relatively little research has been done on modeling freight mode choice compared with the choice behavior associated with passenger travel. This dissertation explores several dimensions of the problem employing advanced econometrics analytical tools. These dimensions include: publicly available freight data 2012 Commodity Flow Survey (CFS) Public Use Microdata (PUM), behavioral attributes driving the selection of freight services, and novel industry-cluster concept. Analytical tools include: sophisticated discrete choice models; multinomial logit model with random parameters, and discrete-continuous econometric framework. The dissertation is organized as follows: Chapter 1 introduces the problem and related concepts. Chapter 2 studies the attributes driving the selection of freight services and propose an econometric model as well as novel industry-cluster concepts to understand the freight mode choice using aggregated data from Commodity Flow Survey. Chapter 3 proposes a discrete-continuous econometric model and a set of industry-type clusters are postulated to describe freight mode choice and tested with the 2012 Commodity Flow Survey. Chapter 4 proposes a choice set approximation for different shipments to demonstrate only the available freight modes for any shipment. Finally, Chapter 5 the outcomes of this research have shown that many of the shipments characteristics and logistics clusters affecting mode choice vary with the shipper and the industry. This research provides meaningful discussion and guidance to understand the
complex process for freight transport selection at regional level. Likewise, the analytical results demonstrate the benefits and efficiencies of the proposed models, which are transportation modeling contributions.
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To my beloved parents

To my loved wife

To my sweet kids

To my dear brothers and sisters
Chapter 1: Introduction

1.1: Freight Demand Modeling and Transportation

Freight demand is the outcome of the complex interactions between different economic agents, i.e., shippers, carriers, freight forwards, producers, consumers, warehouse operators, receivers and others. More specifically, the nature of freight demand modeling mostly involves three agents: shippers, carriers and receivers. Understanding this complex interaction is substantially important for various stakeholders, i.e., shippers, carriers, researchers, transportation logistics, and policy makers. Thus, it is challenging to account for all of the different variables involved in these decisions. Given the economic importance of freight services, improvements in the operation of freight firms represent significant benefits for the firms. Therefore, there is a significant need to develop new models for freight transportation and a remarkable need to have rigorous understanding of the operations, behavior, and strategies of actors in freight transportation markets.

Freight transportation is an important economic indicator of growth in a nation, and it is essential to its existence. Freight movements have interrelated impacts on the economic, society, and the environment. The United States Department of Transportation USDOT BTS (2017) indicates that in 2017 the national freight transportation system moved about 18.1 billion tons of goods with a value of more than $19.2 trillion. In the same year, trucks carried the highest percentage of the
weight, 10.776 billion tons of goods valued at about $10.903. Railroads moved 1.6 billion tons, valued at $623 billion. The waterway industry moved 936 million tons worth $636 billion. Pipelines moved nearly 3.3 billion tons of goods valued at about $1.5 trillion. Airlines carried a total of 10 million tons of cargo worth about $1.188 trillion and multiple modes. Mail shipped almost 1.347 billion tons at a value of $3.581 trillion. The U.S. had more than 400 freight transportation gateways handling international cargo in 2015. The value of U.S-international merchandise trade increased to approximately $3.2 trillion, and at the top of the list of trading partners were China, Canada, Mexico, Japan, and Germany respectively. Understanding the reasons why shippers choose to transport their shipments in a certain manner is critical to developing national policies to promote the freight transportation sector.

1.2: Freight Econometric Approach

Modeling a freight demand is among the most critical logistics decisions because of the complex undertaking, due to a combination of factors and discussions. Although freight mode choice is explored exclusively in many studies using different methodologies models developed long time ago. Discrete choice is one of them in which currently considered the most suitable methodological approach to analyze consumer preferences. Discrete choice models can be utilized to analyze and predict a decision maker’s choice of one alternative from a restricted set of mutually exclusive and collectively exhaustive alternatives. Such models have many applications since numerous behavioral responses are discrete or qualitative in
nature; that is, they correspond to choices of one or another of a set of alternatives. It should be noted that the discrete choice modeling, as in most econometric modeling, lies in being able to predict the decision-making behavior of a group of individuals interchangeably, though the decision-maker may be an individual, a carrier, a shipper, a receiver, an organization, or other decision-making entity. Moreover, the ultimate interest is to determine the relative impact of different attributes of alternatives and characteristics of decision-makers when they make choice decisions.

1.3: Freight Attributes in the Literature

In general, attributes are used to explain variability in mode choice and determine the mode share. Therefore, the analysis of the economic value of freight transport attributes is currently one of the most relevant research topics among transport economists. Traditionally, the attention of researchers was devoted to the monetary attributes (shipment cost) on preferences for selection the freight services and other attributes can be considered as the marginal utility related to reduction in the travel time that is necessary to move a shipment from an origin to destination point. It may be stated that earlier freight mode choice models are exclusively based on direct comparison of shipment costs Cunningham (1982), and McGinnis (1989). However, they ignore important non-monetary attributes. Afterwards, due to logistic complexity, the non-monetary factors become more important and more attention is paid to the integration of service quality and other factors. The importance of these
non-monetary attributes and others factors has raised the attention of transport economists, which have provided a variety of theoretical models and of empirical estimations of the monetary value of various freight-related factors. Moreover, freight transport firms have a strong interest in considering these attributes. For instance, Fowkes et al., (2004) have surveyed the reasons why the freight transport industry may value reliability among several attributes by considering both the demand and the supply. Therefore, it's important that the freight-service modeling considered non-monetary attributes that constitute a strong support towards priorities related to transport infrastructure planning and investments.

1.4: Aggregate and Disaggregate Model

There are few ways of the modeling approach for freight services analyzed in the previous literature. Winston (1983) mentions that there are two types of analytical methods for freight mode choice in the literature: disaggregated and aggregated models, depending on the basic unit of observation and the nature of the data. Disaggregated mode-choice focuses on individual aspects of the shipment and the decision-maker. Data is collected from individual shippers and companies. (Arunotayanun and Polak, 2011; Boerkamps et al., 2000; Liedtke, 2009; Ravibabu, 2013; Samimi et al., 2011a; Wisetjindawat et al., 2007). Aggregated models imply the sharing of a freight mode at a certain geographic level, i.e., national or regional. This type of model focuses on describing the aggregated behavior of firms (Nam, 1997; Shen and Wang, 2012; Sut and Ping, 2010; Wang et al., 2013). It may be stated
that, the disaggregate approach has several important advantages over the aggregate
approach to model the decision-making behavior of a group of individuals. (i) The
disaggregate approach demonstrates why an individual makes a particular choice
given circumstances and thus better able to reflect changes in choice behavior
because of changes in individual characteristics and attributes of alternatives. (ii) The
disaggregate approach is more transferable to a various point in time and to a various
geographic context, a crucial requirement for prediction. (iii) The disaggregate
approach is more efficient in terms of model reliability of the behavior of interest
and in the determinants of that behavior, enabling the efficient estimation of model
parameters. The main limitations of disaggregate models are the considerable
amount of data required, the difficulty that compiling this data on individual mode
choices entails, and the complexity of defining all the attributes that determine the
choice. On the other hand, the aggregate approach is useful for describing general
trends at certain geographic level for the policy-makers who are interested in
decision-making based on general characteristics observed. The aggregate approach
compounds the above but might still be preferable due to lower costs and better
predictability. It has been acknowledged that the aggregated model plays an
important role to understand the general trend of the freight movement at a specific
geographic area. Therefore, a work that exclusively studies the mode choice at the
strategic macroscopic level in the U.S. using public data is important and required to
understand national freight mode choice.
1.5: Discrete Choice Modeling and Freight Mode Choice

For many years, discrete choice models have been increasingly used to analyze freight mode choice decisions (Derakhshan and Shah, 2013; McGinnis et al., 1981; Mitra, 2013; Nam, 1997; Piendl et al., 2017; Pineda Jaramillo et al., 2016; Rich et al., 2009; Saeed, 2013; Samimi et al., 2011b, 2011a). This approach can incorporate the multiple attributes and influences related to behavioral, logistic, and shipper-related variables. The review demonstrates the applications of discrete choice approach for freight mode-choice models in a broad sense. This approach can incorporate multiple structures. First, the most widely used modeling form is the multinomial logit model (Albert and Schäfer, 2013; Catalani, 2001; Golias and Yannis, 1997; Shen and Wang, 2012). Second, nested logit (NL) model Jiang et al., (1999) and Ravibabu, (2013). Third, Samuelson (1977) argues that freight mode choice is jointly determined between shipper-carrier interactions. The vast majority of these formulations (Abate and De Jong, 2014; Abdelwahab and Sargious, 1992; Abdelwahab and Sayes, 1999; Combes, 2012; Inaba and Wallace, 1989; Johnson and De Jong, 2011; McFadden et al., 1985) are considered as a discrete-continuous choice model. Small branches of this formulation consider as a discrete-discrete choice model (Chiang et al., 1981; De Jong, 2007; Pourabdollahi et al., 2013; Windisch et al., 2010). Fourth, the mixed logit model models.(Arencibia et al., 2015; Bergantino et al., 2013; Greene and Hensher, 2003; Kim, 2002). From these models, it is observed that despite the popularity of (MNL) the independence from irrelevant
alternatives (IIA) assumption considers the most notable limitation of using such a model. Therefore, the more sophisticated discrete choice model required to relax the limitation associated with MNL and NL.

1.6: Freight Data and Economic Clusters

As in any freight-related study, data collection is extremely challenging, mainly because of proprietary issues. Moreover, other critical issues associated freight data, such as purpose, quality, cost, and comparability are relevant. Likewise, limitations on freight data availability impose additional obstacles to transportation planning efforts. One of the most comprehensive and public databases on intercity freight movements is the CFS (Commodity Flow Survey, 2012). The objective of the survey is to obtain and maintain an overall picture of freight movement among states and major metropolitan areas by all modes of transportation in the U.S. The shipments in CFS are classified into two major classifications systems: (i) the Standard Classification of Transported Goods (SCTG), and (ii) the North American Industry Classification System (NAICS) to describe the relationship between shipments, goods, and industries. Therefore, it is important to use the publicly available data to understand the general trend and the behavior of actors in the freight transportation market.

The CFS is instrumental in understanding the position of freight transportation modes with respect to other industries in the U.S. However, the significant degree of commodities included in the NAICS and SCTG systems can make freight analyses
and discussions unmanageable and cumbersome, which diminishes its value for decision-making. Although some previous studies group industries to develop freight mode choice analyses, they do not clearly explain the grouping criteria assumed. Thus, employing a well-structured and economically consistent approach to aggregate multiple heterogeneous industry types into freight clusters that allows understanding of the effect of industry clusters in freight mode selection still is missing from the literature. Therefore, economic clusters can be used to interconnect different industries by synergetic supply chains. The logistics clusters can be useful to understand and analyze freight mode choice without having to account for an enormous number of heterogeneous single industry types. Furthermore, logistics clusters are useful for accessibility to different freight modes, cost-effectiveness, logistics efficiency, which enhances the competitive advantages of the regions.

1.7: Motivation

This section clearly presents the incentives that motivated the development of this dissertation. First, understanding the interactions between actors in freight mode choice (Section 1.1). Second, specifying the proper data to calculate the expected demand which in turn determines the type of model (Section 1.6, Section 1.3, and Section 1.4). Third, defining constraints associated with the data in terms of characteristics or methodology which might impact or influence the interpretation of the findings of the research (Section 1.6). Then, developing freight demand model that takes into account of the logistical influences on the shipper’s mode choice
decision-making process (Section 1.2, and Section 1.4). Finally, concluding with freight transportation forecasts, complement freight performance measure, improves the understanding of the general freight market, and also the treatment of real-world practice and decision-making problems.

So far, the freight mode choice problem have been contextualized and motivated. Likewise, limitations and gaps are highlighted in the aforementioned sections. Based on this review, the next section articulates the objectives of the dissertation.

1.8: Dissertation Objectives

The main objective of this dissertation narrows the modeling gaps in literature by developing a set of discrete choice models to understand how shippers select freight services that properly account for the complex interaction between freight transportation modes, shipment-characteristics, and economic clusters. The specific objectives are:

- Objective 1. Utilize the 2012 Commodity Flow Survey data which covers all regions in the U.S to overcome the data-availability issue in any freight-related study.

- Objective 2. Aggregate the industries into economic clusters by employing a well-structured and economically consistent approach to aggregate multiple heterogeneous industry types into industry clusters.
- Objective 3. Develop a framework for the freight choices set for each shipment (choice set approximation) to contain only the possible and feasible freight alternatives.


- Objective 5. Develop a model for freight mode choice in an aggregate model that considers shipments-characteristics including shipment size, logistics clusters, and set of freight transportation modes.

- Objective 6. Develop a model for freight mode choice in aggregate model that considers shipments-characteristics, logistics clusters, set of freight transportation modes, and choice set approximation.

- Objective 7. Demonstrate the economic benefits of the aggregate model required for strategic planning in the development of certain regions in relation to freight transportation investments and policies.

1.9: Expected Contributions

This dissertation provides the following contributions to the transportation community and the specific field of freight and logistics.

Chapter 2

- Understand the behavior behind the selection of freight transportation modes by shippers who require freight services.
• Uncover the economic clusters by following well-structured approaches that are economically consistent where various industries are interconnected by synergetic supply chains.

• Illustrate the effect of industry clusters in freight mode selection and the important role played by logistics clusters in promoting the regional economies.

• Postulate a set of pragmatic attributes to explain freight-modes selection.

• Provide meaningful discussion and guidance to understand the complexities of the freight mode choice process, based on behavioral modeling.

Chapter 3

• Develop an aggregate discrete-continuous choice model for freight mode choice that combines joint mode-choice and shipment-size using 2012 CFS for the first time.

• Address for the first time a joint mode-choice and shipment-size that incorporates the logistic clusters to understand and analyze the choice of freight mode.

• Demonstrate the benefits of considering industry clusters in the joint decision when shippers select freight-services.

• Propose a set of pragmatic attributes to explain freight-service selection.

Chapter 4
• Propose a systematic framework for freight choice set for each shipment.
• Address for the first time the MNL with a random parameter for a macroscopic model to understand the selection of freight-mode in the U.S. explicitly.
• Specify the attributes related to shipment-characteristics and logistic clusters with economic linkages that determine freight-mode choice at the regional level.
• Provide significate discussion about attributes to explain freight mode choice.

1.10: Models applications
Details information of the applications of the estimated models are presented in Appendix A-1. Table A-1 summarizes the applications of the developed models based on the input, output, and outcomes associated with each model. This dissertation considered regularly several stakeholders, i.e., shippers, carriers, researchers, transportation agencies, public and private sectors as well as policymakers. However, this is a difficult task given the multiplicity of actors with different objectives, operations, policies and economic interactions.
Chapter 2: Comparison of Truck-Only, Unimodal, and Multimodal Shipments for Industry-Clusters in the United States.

2.1: Introduction

This chapter investigates the factors that influence the attractiveness of unimodal and multimodal freight modes with respect to the truck-only option. A set of industry-type clusters are postulated to describe freight mode choice and tested with the 2012 Commodity Flow Survey public use microdata. A multinomial logit model with random parameters is estimated to assess modal preferences and their interconnectivity with industry clusters. Analytical results indicate that both shipment characteristics and industry clusters provide a better understanding of regional macroscopic freight mode choices between alternatives including truck-only, unimodal (rail, water, air, and pipeline), and multimodal (parcel, truck-rail, truck-water, and other). Meaningful discussion and guidance is provided to understand this complex process.

Freight activities result from the complex interactions between different economic agents, i.e., shippers, carriers, freight forwarders, producers, consumers, warehouse operators, receivers, and others. These relationships are commonly relaxed to account for three major agents: shippers, carriers and receivers. Still it is challenging to account for all of the different variables involved in their interactions. Furthermore, the scarce availability of publicly available freight data imposes additional challenges for business and regional planning. Undoubtedly, it is
instrumental exploit as much as possible the public sources of freight data for economic analyses.

Freight mode-choice is an important activity to develop successful freight transportation business for several stakeholders. The understanding can be used to inform decisions taken by multiple stakeholders in the public and private sectors, and to expand the understanding of freight mode by transportation modelers and intermodal freight researchers.

First, public administrations, at local, national, and international levels, are also interested in the monetary values of freight transport service quality attributes among other freight-related factors as they can be part of cost benefit, cost effectiveness, and also an integral part of the analyses that aimed at optimizing transport infrastructure policies and strategies. For public agencies at national and local level, this type of models are necessary for certain critical policy issues, such as highway maintenance and construction, planning intermodal facility, and also metropolitan areas needs the model to solve problems related to warehouse distribution, among others. Moreover, government agencies need to predict future transport requirements for both people and goods in order to provide infrastructures and services that allow such a movement.

Second, the private sectors can also benefit from such model by understanding the importance of different freight modes to certain commodities and industrial activities in which can be the center of their interest for anticipating factories
locations, and commodities mobilization, or transport for a new materials. On the other hand, the private sector and to plan for economically consistent freight transportation infrastructures in the public sector to understand the forecast demand for transport services. It is crucial to understand freight mode choice properly to take well-informed decisions in either sector.

In order to understand how shippers select freight transportation modes, a set of shipment characteristics, and novel industry-cluster are proposed and statistically tested through the discrete choice econometric approach. The source data is obtained from public sources the 2012 Commodity Flow Survey. The general mixed logit model is used to (i) test the statistical significance for postulated attributes, (ii) estimate their marginal effects (ME), and (iii) provides meaningful discussion and guidance.

This chapter is organized as follows: Section 2.1 introduces and motivates the problem. Section 2.2 reviews freight mode choice literature and supports the use of the proposed method. Section 2.3 describes the data and sample used in the study. Section 2.4 explains the econometric approach followed in this research. Section 2.5 presents model estimation results and the corresponding analysis. Section 2.6 shows an example of the application of the model. Finally, the chapter is concluded in Section 2.7.
2.2: Literature Review

This section presents a literature review of previous studies that describe the interaction between shipper and carriers with respect to freight mode choice. Likewise, it presents different classification approaches used to facilitate and enhance freight mode choice knowledge. The review demonstrates a gap associated with the utilization of well-defined industry clusters for macroscopic freight mode-choice modeling and analysis.

Modeling a freight demand is among the most critical logistics decisions because of the complex undertaking, due to a combination of factors and discussions. As shown in (Section 1.3), several freight-related attributes may impact the performance of the freight transport services adopted by firms. Several works conclude that service attributes are more important than the cost in determining mode choice (Gray, 1982; Wilson et al., 1986; Mesa-Arango and Ukkusuri 2014, among others). In the last decade, the economic literature that has analyzed this topic has attempted to encompass in the estimations the largest potential number of relevant attributes. Consequently, the relative influence of the different factors differed greatly and depends particularly on the regional context and on the nature of the firm.

All of the studies derive their econometric models based on individual firm level behavior, although they differ in the level of aggregation used to estimate the models and the assumed the role of the mode choice decision maker. (Section 1.4) provides details about the ways of the modeling approach for freight services analyzed in the
previous literature. To understand the effect of those model in selection of freight service more work reviewed next starting with the disaggregate approach.

Several works have contributed to understanding the behavior of shippers and carriers in the context of disaggregated mode-choice focused data obtained at the national level. For example, a national freight microsimulation model for Norway and Sweden is presented by De Jong and Ben-Akiva (2007). This model operates at the level of the firm to firm (sender-receiver) related to the choice of shipment size and transportation chain. Samimi et al., (2014) develop a large-scale behavioral mode-choice model for the entire United States (U.S.). The study is a nationwide freight activity microsimulation model that works at the firm-to-firm level, called named the Freight Activity Microsimulation Estimator (FAME). The estimated model is largely based on public freight data. However, developing freight mode choice analyses with disaggregated data is challenging because the access to such inputs is limited to the general public. The aggregated model supported by public data is proposed to overcome the limitation.

Aggregated models provide a more general explanation of freight mode choice. These analyses focus on shipments transported between certain geographies rather than individual firms, i.e., within national or regional transportation analysis zones (TAZs). The key advantage of developing aggregated models is to capture general freight trends with data that are publicly available, e.g., via national establishment surveys. Nam (1997) develops a mode choice analysis with a binary logit model
applied on aggregated data to understand the effect of heterogeneous commodity types and other variables. Shen and Wang (2012) use a binary regression model and logit model to study the cereal grains movement in the U.S. by truck and rail. The publicly available Freight Analysis Framework (FAF) dataset and U.S. highway and networks are used in the model estimation. Wang et al., (2013) use the same public data with the National Transportation Atlas Database (NTAD) to understand freight mode choice (truck and rail) at the interstate level. Their empirical results indicate that aggregated data can be improved by adding more factors related to warehouses, land use, and zone properties. Sut and Ping (2010) use discrete choice models to determine international freight transport modes based on available macroscopic commodity trade information. They employ aggregated trade data between the U.S. and China, and the U.S. and the European Union to understand strategic planning level decisions, the data comes from the U.S. Census Bureau. Aggregated models play an important role in understanding general trends of freight movements for specific geographic areas. Therefore, a work that exclusively studies the mode choice at the strategic macroscopic level in the U.S. using public data is important and required to understand national freight mode choice.

The above-mentioned works have contributed to understanding the behavior of shippers and carriers in the context of at disaggregate mode-choice at the national level de Jong and Ben-Akiva (2007), and Samimi et al., (2014) and aggregated mode-choice model (Nam, 1997; Shen and Wang, 2012; Sut and Ping, 2010; Wang et al.,
2013) among others. However, many of these studies did not consider the sophisticated econometric approach to analyze freight mode choices to overcome the assumption violation, e.g., independence from (IIA). To the best of the authors’ knowledge, there is no work that estimates the freight mode choice applied advanced econometrics (a multinomial logit model with random parameters) at an aggregated level in this context exclusively.

In the modern era, industry cluster analysis has emerged as a critical component when considering economic development and is an important element in understanding regional differences in development and economic specialization. The earlier studies have been undertaken on understanding industry clusters, mostly focused on methodologies for defining clusters, the advantages and disadvantages of pursuing cluster-based economic development strategies, and in-depth examination of specific industry clusters (Hill and Brennan, 2000; Porter, 1995; Waits, 2000). A limited number of studies have focused on transportation and logistics clusters in the U.S., their role in advancing the economic development of regions and the diversity of industries that form these clusters. At the outset, Krugman (1991) indicated that new economic geography had provided insights on economic processes behind the formation of the industry clusters. Sheffi (2012) stated that, in contrast to other types of industry clusters, transportation and logistics is a unique cluster given the additional “catalytic” role it plays. According to Sheffi (2013), intensive transportation clusters could be an agglomeration of different logistics-related
companies; those provide transporters, carriers, warehousing, distributors, railway and truck terminals, airports and ports, allied manufacturing, and other support services. As noted by Kumar et al., (2017), industry clusters are economic activities with underlying and well-defined spillover processes dependent on the industry type configurations. Therefore, this indicates the importance of regional approach the identification of clusters and in the development of regional policies for cluster growth and development. While it has been recognized the significant role played by the industry clusters in promoting the regional economies in different aspects, the pragmatic structure for logistics clusters which might be helpful understanding the selection of freight patterns are not clearly defined.

The concept of freight-related industry clusters involves groups of interrelated industries that add value to their products and services by strong interaction in terms of demand, supply, transport mean, and logistics. Roepke et al., (1974) utilized factor analysis to evolve groups of industry sectors based on similar selling and purchasing patterns using input-output (IO) tables. The work by Bergman and Feser (1999) specified network analysis as a potential technique to determine industry clusters. DeBresson and Hu (1999) employed European industry surveys to obtain the delineate innovative clusters, making use of innovation matrices, i.e., directed graphs. On the other hand, they highlighted limitations with graphs to analyze interindustry linkages by the deficiency of appropriate visualization software. Ukkusuri et al., (2016), and Mesa-Arango et al., (2015) used network analysis to
understand the properties of the international trade network, where community detection method are utilized to find global-value-chain clusters from historical trade data sets. Later, Mesa-Arango and Kumar (2017) implemented a similar procedure to find value chain communities in the U.S. Their research reveals value chain clusters in which freight transportation modes, i.e., rail, water, truck, and pipelines, and support activities, i.e., messengers, couriers and warehousing and storage, are highly interconnected with other industry sectors using the most recent input-output economic data in the U.S. to generate a network of economic interdependencies between industry sectors. Since this research describe industry clusters relevant for different freight transportation modes and it’s supporting activities in the U.S., it could be implemented to narrow the gap by demonstrating the effect of industry clusters in analysis and understanding the freight mode choice.

In summary, this chapter proposes an aggregated discrete choice model for freight mode choice that overcomes the data-availability issue associated with disaggregated analyses. Subsequently, it employs a well-structured and economically consistent approach to aggregate multiple heterogeneous industry types into freight clusters that allows one to understand the effect of industry clusters in freight mode selection. Finally, it clarifies the connectivity between freight industries and other industries in the U.S. The next section provides an overview of the public datasets employed to construct the proposed model.
The next section describes the 2012 CFS data and presents summary statistics for selected variables collected from the survey.

2.3: Survey Description and Data Characteristics

As shown in (Section 1.6) the 2012 CFS is the primary data source for this research. The CFS is conducted as a partnership between the U.S. Census Bureau and the Bureau of Transportation Statistics. The dataset is commonly used by policy makers and transportation planners to make informed decisions to improve transportation infrastructures. Moreover, the CFS constitutes the main input for the (FAF).

The CFS data is a shipper-based survey and is conducted every five years. It covers a diverse range of business establishments with paid employees, which are classified using the NAICS. A subset of data composed by more than 4.5 million records from approximately 60,000 responding establishments is available to the public.

The CFS data provides details on individual shipments including origin, destination (national/international), shipment value, shipment weight, distance, handling features, commodity type (NAICS classification), and industry type (SCTG classification).

The most serious limitation of the CFS is the absence of information on the level of service variables, shipper and market attributes Abdelwahab and Sargious (1992). Other limitations include mode-specific characteristics, e.g., transport time, cost, and total demand per year, among others Abate and De Jong (2014). All of which are
important attributes to examine the economic considerations involved in the choice of mode. Additionally, the level of aggregation of the CFS zones is larger than the metropolitan areas. Therefore, intra-urban shipments are not captured in the survey. Likewise, the CFS does not include agricultural produce handled by the primary producers. However, agricultural products are captured if they are handled by a secondary manufacturing firm, e.g., food manufacturing industries. Similarly, firms in charge of the primary crude petroleum extraction were not surveyed. However, crude petroleum appears in the CFS if it was handled by petroleum refining firms.

Another limitation of the CFS for discrete mode choice includes lack of information on the complete choice set available to the shipper when selecting a freight transportation mode. Unfortunately, the authors cannot control this source of error and will conservatively assume that all alternatives are available to the decision maker.

Nine transportation modes were selected for model estimation, including single-mode, i.e., truck, air, water, pipeline, and rail and multimodal alternatives include parcel (including U.S. Postal Service (USPS) and other couriers like FedEx, DHL, UPS, etc.), truck-water, truck-rail, and other combinations. It is important to note that single modes, e.g., water or rail, are viable without trucking. For example, some factories and granaries located on the banks of the Mississippi River and other Great Lakes will be directly connected by water modes. Similarly, industries within the same value-chain that obtain economies from rail transportation tend to locate their
facilities in places with railroad access which facilitates direct loading/unloading, e.g., industries related to mining and other bulk commodities.

![Figure 2-1: Summary Statistics for Main Freight Transportation Modes](image)

Figure 2-1 presents the summary statistics associated with selected modes in the datasets. In most of the cases, shippers select trucks for their shipments, i.e., 71.28% of the cases, which is expected, given the availability, reliability and flexibility that truck shipments offer to the shippers. Parcel is the second predominant mode with 25% of the total cases. The parcel mode represents freight moved via express carriers. In the third position, air freight accounts for 1.52% of the total observations. Then, rail transportation represents 0.85% of the total cases. Other important intermodal freight transportation modes in the dataset include truck-rail and truck-water, which represent 0.42% and 0.06% of the cases, respectively. Finally, pipelines, water, and other-mode (single and combinations) are used in 0.08%, 0.07%, and 0.03% of the cases, respectively.
Table 2-1: Summary Statistics for Selected Variables in the Dataset

<table>
<thead>
<tr>
<th>Variable</th>
<th>Truck</th>
<th>Rail</th>
<th>Water</th>
<th>Air</th>
<th>Pipeline</th>
<th>Parcel</th>
<th>Truck-Rail</th>
<th>Truck-Water</th>
<th>Other-Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>Shipment characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipments distance route a</td>
<td>6.9E+03</td>
<td>3.1E+02</td>
<td>5.3E+02</td>
<td>8.4E+02</td>
<td>7.1E+02</td>
<td>4.6E+02</td>
<td>5.5E+02</td>
<td>8.7E+02</td>
<td>6.6E+01</td>
</tr>
<tr>
<td>Destination – Canada b</td>
<td>2.6E-02</td>
<td>3.4E-02</td>
<td>3.0E-02</td>
<td>2.2E-01</td>
<td>7.6E-02</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>5.8E-02</td>
<td>0.0E+00</td>
</tr>
<tr>
<td>Destination – Mexico b</td>
<td>9.1E-03</td>
<td>7.3E-02</td>
<td>6.2E-02</td>
<td>4.6E-01</td>
<td>6.5E-02</td>
<td>7.1E-02</td>
<td>6.2E-02</td>
<td>4.9E-02</td>
<td>2.1E-01</td>
</tr>
<tr>
<td>Destination – Other-country b</td>
<td>1.1E-01</td>
<td>9.9E-03</td>
<td>3.3E-02</td>
<td>2.4E-02</td>
<td>5.4E-02</td>
<td>1.0E-01</td>
<td>1.1E-01</td>
<td>4.0E-01</td>
<td>2.1E-01</td>
</tr>
<tr>
<td>Unitary value of shipments c</td>
<td>6.9E-02</td>
<td>1.1E+01</td>
<td>5.7E-01</td>
<td>1.6E+00</td>
<td>5.3E-01</td>
<td>3.1E+00</td>
<td>4.0E-02</td>
<td>1.3E+00</td>
<td>1.2E+00</td>
</tr>
<tr>
<td>Hazardous shipment e</td>
<td>1.7E-01</td>
<td>5.7E-02</td>
<td>9.7E-02</td>
<td>1.1E-01</td>
<td>1.3E-01</td>
<td>1.9E-01</td>
<td>1.8E-01</td>
<td>1.7E-02</td>
<td>5.4E-02</td>
</tr>
<tr>
<td>Temperature controlled f</td>
<td>1.5E-01</td>
<td>1.8E-02</td>
<td>5.2E-02</td>
<td>8.7E-02</td>
<td>1.1E-01</td>
<td>8.3E-02</td>
<td>1.3E-01</td>
<td>2.1E-01</td>
<td>9.9E-03</td>
</tr>
<tr>
<td>Industry type (NAICS) cluster</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw materials manufacturing</td>
<td>4.8E-02</td>
<td>9.5E-02</td>
<td>1.2E-01</td>
<td>1.5E-01</td>
<td>2.3E-01</td>
<td>2.1E-01</td>
<td>4.2E-02</td>
<td>2.4E-01</td>
<td>2.1E-01</td>
</tr>
<tr>
<td>Raw materials wholesalers</td>
<td>3.5E-02</td>
<td>1.1E-01</td>
<td>6.1E-02</td>
<td>2.5E-02</td>
<td>3.0E-02</td>
<td>5.5E-01</td>
<td>1.4E-01</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
</tr>
<tr>
<td>Service-related manufacturing</td>
<td>1.2E-01</td>
<td>1.1E-01</td>
<td>6.1E-02</td>
<td>2.5E-02</td>
<td>3.0E-02</td>
<td>5.5E-01</td>
<td>1.4E-01</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
</tr>
<tr>
<td>Service-related wholesalers</td>
<td>2.5E-02</td>
<td>8.8E-02</td>
<td>4.7E-02</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>2.2E-01</td>
<td>7.4E-02</td>
</tr>
<tr>
<td>Metals manufacturing</td>
<td>1.0E-01</td>
<td>1.6E-01</td>
<td>1.3E-01</td>
<td>7.2E-02</td>
<td>8.5E-02</td>
<td>4.3E-02</td>
<td>6.7E-02</td>
<td>2.7E-01</td>
<td>1.6E-01</td>
</tr>
<tr>
<td>Metals wholesalers</td>
<td>1.3E-01</td>
<td>1.7E-01</td>
<td>1.5E-02</td>
<td>7.5E-02</td>
<td>9.5E-02</td>
<td>5.8E-02</td>
<td>8.7E-02</td>
<td>1.6E-01</td>
<td>1.4E-01</td>
</tr>
<tr>
<td>Agriculture manufacturing</td>
<td>6.2E-02</td>
<td>1.1E-01</td>
<td>8.1E-02</td>
<td>1.9E-01</td>
<td>1.1E-01</td>
<td>7.1E-03</td>
<td>2.1E-02</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
</tr>
<tr>
<td>Agriculture wholesalers</td>
<td>9.2E-02</td>
<td>7.6E-02</td>
<td>8.0E-02</td>
<td>6.8E-02</td>
<td>7.9E-02</td>
<td>2.9E-01</td>
<td>1.6E-01</td>
<td>1.9E-01</td>
<td>4.2E-02</td>
</tr>
<tr>
<td>Textile/apparel manufacturing</td>
<td>1.8E-01</td>
<td>7.2E-02</td>
<td>1.1E-01</td>
<td>2.4E-01</td>
<td>2.6E-01</td>
<td>3.8E-02</td>
<td>8.5E-02</td>
<td>1.2E-01</td>
<td>2.5E-02</td>
</tr>
<tr>
<td>Textile/apparel wholesalers</td>
<td>3.4E-02</td>
<td>3.1E-01</td>
<td>1.0E-01</td>
<td>1.9E-02</td>
<td>2.6E-02</td>
<td>3.2E-02</td>
<td>3.3E-02</td>
<td>3.0E-02</td>
<td>6.5E-03</td>
</tr>
<tr>
<td>Wood products manufacturing</td>
<td>2.6E-02</td>
<td>2.5E-01</td>
<td>8.1E-02</td>
<td>2.2E-01</td>
<td>7.6E-02</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>2.5E-02</td>
<td>2.6E-02</td>
</tr>
<tr>
<td>Wood products wholesalers</td>
<td>6.2E-03</td>
<td>2.9E-01</td>
<td>4.2E-02</td>
<td>5.7E-03</td>
<td>2.6E-02</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>2.5E-01</td>
</tr>
</tbody>
</table>

S.D.: Standard deviation.

a: Distance in miles. b: Binary variables. c: ($ per lb.).

NAICS: Based on the North America Industry Classification System.
Preliminary numerical experiments indicate that using the entire dataset for mode-choice estimation with commercial software turns unmanageable. Therefore, a sufficiently large subset of observations is sampled to build and run the discrete choice model at a reasonable time without losing its significant explanatory power. Although random sampling could be used to select a subset of observations, it would likely bias the results towards the trucking mode. Therefore, the sampling process is performed in a way that all the modes are properly represented. The Statistical Package for the Social Science (SPSS) is used to sample a sufficiently large number of observations with equal representation between modes and random sampling within them. Finally, each of the nine modes considered in the study was analyzed with 500 observations for a total of 4,500 cases. Notice that 4,500 observations align with the size of datasets used in previous studies as summarized in Table 2-2.

Table 2-2: Sample of the Size of Datasets in the Related Discrete Choice Model in the Literature

<table>
<thead>
<tr>
<th>Work</th>
<th>Sample size (observations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>McGinnis et al., 1981</td>
<td>263</td>
</tr>
<tr>
<td>Shen and Wang, 2012</td>
<td>600</td>
</tr>
<tr>
<td>Samimi et al., 2014</td>
<td>881</td>
</tr>
<tr>
<td>Pourabdollah et al., 2013</td>
<td>1302</td>
</tr>
<tr>
<td>Arunotayanun and Polak, 2007</td>
<td>1487</td>
</tr>
<tr>
<td>Arencibia et al., 2015</td>
<td>1674</td>
</tr>
<tr>
<td>Nam, 1997</td>
<td>1785</td>
</tr>
<tr>
<td>Samimi et al., 2011b</td>
<td>4544</td>
</tr>
<tr>
<td>Holguín-Veras, 2002</td>
<td>5276</td>
</tr>
<tr>
<td>Sou and Ong, 2015</td>
<td>5545</td>
</tr>
</tbody>
</table>

Table 2-1 presents summary statistics for selected variables of the shipments characteristics covered by the dataset and industry sectors which have strong
economic interdependence and linkages. Although the table provides general insights, specific conclusions should be derived from the model developed in the (Section 2.5). The following subsections provide trends on the shipment characteristics and industry clusters observed in the dataset.

2.3.1: Shipment Characteristics

The following trends are observed in the dataset with respect to shipment characteristics.

a) Shipment route distance: The average route distance between shipment origin and destination using combination of truck-water and truck rail is highest among all modes at roughly 1,300 miles, and it is similar with air cargo at 1300 miles. The average traveling distance by unattached rail shipments is about 840 miles. Then, the average truck distance is 400 miles, about half of the average value for rail.

b) Shipments to Canada: About 2.60% of the sampled shipment succor between the U.S. and Canada, 36% of such records are transported by other-mode, 22% by rail, and 13%. On the other hand, modes such as pipeline and maritime have the lowest representation.

c) Shipments to Mexico: Nearly 0.91% of all cases are shipments heading to Mexico, which is relatively small compared to other destinations. It is observed that rail and truck-rail are the dominant modes for this destination with an average of 46% and 24%, respectively.
d) Shipment to other countries: General statistics indicate that 11% of the observations are shipped to other countries. Geographical obstacles give air cargo the priority with 40% observations, followed by truck-rail 21%, truck-water 16%, and water 10%.

e) Unitary value of shipments: The air mode accounts for the largest unitary shipment value $401.8 per lb., followed by parcel $253.4 per lb. Then, truck related modes, truck, truck-rail, and truck-water, the average unitary value does not exceed $10 per lb. Remarkably, unattached rail, and water their average unitary value is below $0.5 per lb.

f) Hazmat (flammable liquids) shipment: About 17% of the observations are hazardous materials; almost 55% of them are shipped via pipelines, 19% via water, and 11% via rail, the remaining observations distribute evenly throughout other modes.

g) Temperature controlled shipments: 15% of the total freightage is associated with some level of temperature-controlled shipment: 33% of the records are transported by air cargo, 20% transported by truck-rail, while truck-water transported 15% and other-mode 12%.

The following subsection describes the structure of industry clusters incorporated to understand the selection of freight mode.
2.3.2: Industry clusters

The advantages of using the industry clusters are explained in (Section 1.6). The set of industry types available in the 2012 CFS is segmented by industry clusters following the taxonomy developed by Mesa-Arango and Kumar (2017). This is possible because both the dataset and cluster classification employ NAICS codes to describe industries. The NAICS employs six-digit codes to hierarchically classify industries. The first digits describe the broader sector of the industry, and the description is narrowed down to a more specific classification as more digits are included. Although there are some mismatches between the number of digits in the two sources, they are harmonized following NAICS aggregation rules. Furthermore, the industry clusters are split into manufacturers and wholesalers to better represent each of these logistics activities. Therefore, taxonomy industries that since the CFS classic, i.e., while the first two digits indicate the broader economic sector of an industry, the NAICS codes vary from classification NAICS is a two-through-six-digit hierarchical classification code system, offering five levels of detail. Each digit in the code is part of a series of progressively narrower categories, and the more digits in the code signify greater classification detail. The first two digits designate the economic sector, the third digit designates the subsector, the fourth digit designates the industry group, the fifth digit designates the NAICS industry, and the sixth digit designates the national industry. Since the CFS only considers a subset of industries and the clustering method accounts for all industries in the U.S., the size
of the clusters presented in this chapter are smaller than those from the original source.

Table 2-3 summarizes the results, in which twelve industry clusters (labeled a to i) are important for freight industries, i.e., (a) raw materials manufacturing; (b) raw materials wholesalers; (c) service-related manufacturing; (d), service-related wholesalers; (e), metals manufacturing; (f), metals wholesalers; (g), agriculture manufacturing; (h), agriculture wholesalers; (i), textile, apparel and paper manufacturing; (j), textile, apparel and paper wholesalers; (k), wood products manufacturing; (l), wood products wholesalers.

The following summary statistics are discussed based on the compilation presented in Table 2-1 and the clusters available in Table 2-3.

a) Raw materials manufacturing: 19% of the observations are from raw materials community.

b) Raw materials wholesalers: only 3.5% of the total cases include petroleum and petroleum products merchant wholesalers. Although different modes are utilized to convey them, the maritime is still the predominant mode with 55%.

c) Service-related manufacturing: In the cases of printing, computer, electronic, and newspaper, looking at delivery times, in the majority of the cases 32% select air cargo and 27% required parcel services which in turn corresponded to the average expected.
Table 2-3: Summary of the industry type (NAICS) clusters

<table>
<thead>
<tr>
<th>Cluster</th>
<th>NAICS in the Community</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Raw materials manufacturing</td>
<td>[212] Mining (except oil and gas); [324] Petroleum and coal products manufacturing; [327] Nonmetallic mineral product manufacturing</td>
</tr>
<tr>
<td>(b) Raw materials wholesalers</td>
<td>[4247] Petroleum and petroleum products merchant wholesalers</td>
</tr>
<tr>
<td>(c) Services-related manufacturing</td>
<td>[323] Printing and related support activities; [334] Computer and electronic product manufacturing; [45431] Direct selling establishments; [4931] Warehousing and storage (includes 484); [5111] Newspaper, periodical, book, and directory publishers; [551114] Corporate, subsidiary, and regional managing offices</td>
</tr>
<tr>
<td>(d) Services-related wholesalers</td>
<td>[4234] Commercial equip. merchant wholesalers; [4242] Drugs and druggists' sundries merchant wholesalers</td>
</tr>
<tr>
<td>(g) Agriculture manufacturing</td>
<td>[311] Food manufacturing; [312] Beverage and tobacco product manufacturing</td>
</tr>
<tr>
<td>(h) Agriculture wholesalers</td>
<td>[4244] Grocery and related product merchant wholesalers; [4245] Farm product raw material merchant wholesalers; [4248] Beer, wine, and distilled alcoholic beverage merchant wholesalers</td>
</tr>
<tr>
<td>(l) Wood products wholesalers</td>
<td>[4232] Furniture and home furnishing merchant wholesalers</td>
</tr>
</tbody>
</table>

Notice: Numbers in the brackets are NAICS codes.
NAICS: North American Industry Classification System.
d) Service-related wholesalers: 22% transported by air cargo and 39% selected parcel services.

e) Metals manufacturing group: Constitutes approximately 10% of the entire cases. It seems that there is no predominate mode to transport these shipments, while, air cargo carried 27% followed by parcel services by 16% of the light goods in the group related to the electrical, appliance, and components. The truck-related modes such as truck, truck-rail, and truck-water transported the heavy shipments contained in the group by 16%, 15% and 10 respectively.

f) Metals wholesalers group: about 13% of the total cases, and the related shipments transported with various modes remain relatively constant among such desirable modes.

g) Agriculture group: Roughly 6.3% of the observation. Selected truck-rail and truck-water for 51% of its total shipments, which might be related to their economical for long-distance and its ability to deal with refrigerated containers due to the perishable nature of these products.

h) Agriculture wholesalers: Constitute nearly 9.6% of the entire observations. There is a tendency to select maritime options, i.e., 30% and 26% of the selected services are water and water-truck. Interestingly, the other-mode play significant role in transporting these shipments with around one quarter of the total observations.
i) Textiles, apparel and paper manufacturing: Constitute about 18% of the total cases, and statistics indicate preference to select rail and rail combined with the truck in this group by 28% and 15% respectively, while almost 25% of the commodity is carried by pipeline.

j) Textile, apparel, and paper wholesalers: Constitute almost 3.4% of the observation, truck and parcel transport more than 61%, followed by other-mode 15%, and the rest of the mode remain relatively constant.

k) Wood products manufacturing: nearly 2.6% of the whole observation; trucks selected for 25%, rail for 22% and a combination of truck-rail for 22% of its shipments. This expected, because railways are economical and best suited for bulky goods over long distances.

l) Wood products wholesalers: barely 0.62% of the entire observation; most shipment carried by certain modes, such as truck-water 36%, truck 29%, parcel 25%, truck-rail 10%, and modes such as, water, air-pipeline and other-mode in many cases, are not even an option to transport these commodities.

The following section describes the economic approach followed to understand freight mode choice with industry clusters.

2.4: Econometric Approach

Discrete choice models provide an econometric framework appropriate to model the freight mode selection. With various assumptions regarding error structure, a broad range of discrete choice models exist in the family of random utility theory. In
passenger and freight applications, the MNL model is commonly used. As shown in (Section 1.5) there is notable limitation associated with using such a model and it is very likely that the unobserved factors are shared by certain outcomes.

The MNL with random parameters overcomes that limitation. It also considers random test variations, and controls problems related to correlation of unobserved factors, and restrictive substitution patterns mostly generated by standard MNL. The utility \( U_{ni} \) of shipment \( n \) selecting alternative \( i \) is presented in Equation (2-1), where \( \beta \) is a vector of estimated parameters, \( X_{ni} \) is a vector of variables, and \( \epsilon_{ni} \) is a random term following a type I (iid extreme value distribution).

\[
U_{ni} = \beta' X_{ni} + \epsilon_{ni} \quad \forall i \in I, \forall n \in N
\]  

Equation (2-2) describes the probability \( L_{ni}(\beta) \) of selecting alternative \( i \in I \), where \( (I) \) is the set of available freight modes, in case \( (n \in N) \), where \( (N) \) is CFS dataset for mode choice, conditional on \( (\beta) \).

\[
L_{ni}(\beta) = \frac{e^{\beta' X_{ni}}}{\sum_{j \in I} e^{\beta' X_{nj}}} \quad \forall i \in I, \forall n \in N
\]  

From the random parameters perspective, Equation (2-3) describes \( P_{ni} \) as the unconditional probability that integrates the corresponding product over all the values of \( (\beta) \), where \( f(\beta) \) is the continuous density function of \( (\beta) \). \( f(\beta) \) can follow different distribution patterns, e.g., lognormal, normal, triangular, uniform, among others. The estimation process requires determining a distribution \( f(\beta) \) and its
corresponding structural coefficients of, e.g., $\Phi(\mu, \sigma)$ for the normal distribution, where $\mu$ is the mean of the random parameter and $\sigma$ the (standard deviation).

$$P_{ni} = \int L_{ni}(\beta)f(\beta)d\beta$$  \hspace{1cm} (2-3)

Estimating the MNL with random parameters involve computing $L_{ni}(\beta)$ with draws of $(\beta)$ produced from $f(\beta)$. Sufficient numbers of draws are required to obtain a simulated $P_{ni}$. The likelihood function is computed using simulated $P_{ni}$, and maximized to best estimation of $(\beta)$. Train (2000), and, Bhat (2003) reported that Halton draws is the most popular and efficient approach. The following references provide more details about simulation-based maximum likelihood methods for estimating mixed logit models: (Brownstone and Train, 1998; Geweke et al., 1994; McFadden and Ruud, 1994; Stern, 1997).

$$ME_{X_{nit}}^{P_{i}} = \frac{\delta P_{i}}{\delta X_{nit}}$$  \hspace{1cm} (2-4)

Marginal effects $\text{ME}_{X_{nit}}^{P_{i}}$ can be computed after model estimation to describe how unitary changes in the variables $X_{nit}$ affect the outcome probability $P_{i}$. Equation (2-4).

The next section presents and discusses the results after applying the mixed logit model and marginal effects.
Table 2-4: MNL Model with Random Parameters for mode choice: Truck mode only (base utility).

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<tr>
<th>Variable</th>
<th>Rail Coeff.</th>
<th>t-stat</th>
<th>Water Coeff.</th>
<th>t-stat</th>
<th>Air Coeff.</th>
<th>t-stat</th>
<th>Pipeline Coeff.</th>
<th>t-stat</th>
<th>Parcel Coeff.</th>
<th>t-stat</th>
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<th>Truck-Water Coeff.</th>
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45000 Observation. / Notation: uE = β = a + bα200.
Random parameters normally distributed and estimated with 200 Halton draws.
Log likelihood at convergence = -6733.165. Log likelihood at zero=-9887.511 / p² = 0.31902 / Adjusted p² = 0.31720

36
Table 2-5: Marginal Effects for Attributes in the (MNL) Model for Mode-Choice.

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<th>Variable</th>
<th>Rail Avg. ME (%)</th>
<th>Water Avg. ME (%)</th>
<th>Air Avg. ME (%)</th>
<th>Pipeline Avg. ME (%)</th>
<th>Parcel Avg. ME (%)</th>
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<th>Truck-Water Avg. ME (%)</th>
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<td></td>
<td></td>
<td>2.39E-01</td>
</tr>
</tbody>
</table>

ME: Marginal effect.
<sup>a</sup>: Distance in miles. <sup>b</sup>: Binary variables. <sup>c</sup>: ($ per lb.). / (NAICS) North America Industry Classification.
2.5: Estimation Results

This section presents and discusses the estimation of results of the MNL model with random parameters for freight mode choice considering holistic regions of the U.S. using the public available data CFS 2012. The estimation process involved two stages: (1) estimation of the standard MNL model, for variables related to shipment characteristics and industry clusters Table 2-4 based on statistical significance and intuitiveness; and (2) testing the random parameters. After several iterations for different model structures, the MNL with random parameters which represents the best specification for freight mode selection is shown in Table 2-4. The software LIMDEP 10 (NLOGIT 5) is used for this model estimation. The truck mode is the based case in the model; hence, the estimated coefficients are contrasted against the truck mode (base).

The variables in the final estimated MNL model with random parameters show similar results to previous models. Table 2-4 shows parameters are statistically significant and have intuitive signs. The random variables follow standard normal distribution. For random parameters, Table 2-4 presents the mean value above the corresponding standard deviation (in parenthesis). Likelihood ratio test is used to assess the overall significance of the MNL with random parameters, i.e., unrestricted model (labeled U), over the corresponding standard MNL, i.e., restricted model (labeled R). Equation (2-5) represents the likelihood ratio test statistic, where
LL(\(\beta_R\)) = −6733.165 is the log-likelihood at convergence of the MNL with random parameters, and where \(LL(\beta_U) = −6897.109\).

\[
\chi^2 = −2[LL(\beta_R) − LL(\beta_U)]
\]  

(2-5)

Thus, the Chi-squared \(\chi^2 = 327.888\) is distributed with six degrees of freedom (six more parameters estimated in MNL with random parameters model, i.e., standard deviations of random parameters). Thus, with at least a 99% level of confidence, the MNL can be rejected and the MNL with random parameters is preferred.

Table 2-5 presents the corresponding average marginal effects, used to quantify the effect that a unitary change in each variable has in the mode choice probability. The MEs are computed to provide a better understanding on how each variable impacts freight mode choice. In the following analysis, variables are classified in two groups related to shipment characteristics and industry clusters.

2.5.1: Shipment characteristics

The first group of variables is shipment characteristics, which is presented and explained below to better understand their impact on mode selection.

2.5.1.1: Shipment distance (geographic)

The distance from origin to destination is measured using the geographic distance in miles, i.e., direct distance connecting the two points. Although on-route distance is provided for each shipment, it cannot be compared with other modes because there is no information about the shipper’s choice set. Therefore, the distance on other
possible modes is not available. In general it is observed as the geographic distance between origin and destination increases, the probability of selecting modes other than truck increases, i.e., 21.6% truck-rail, 18.4% truck-water, 12.2% air cargo, 12.1% rail, 9.21% parcel services, 8.49% other-modes, and 5.23% water (Table 2-5). The largest increments, i.e., truck-rail, truck-water, and air, might be related to long international shipments that are mainly possible through these modes, which increases their attractiveness.

A different trend is observed for pipelines, where their selection probability in average decrease with respect to geographic distance, i.e., in average 1.28% reduction per additional mile (Table 2-5). The parameter associated with pipeline distance is random. Random effects indicate for 40.98% of the observation as the geographic distance increases, the probability of selecting pipeline increases. On the other hand, for 59.02% of the observations geographic, distance increments reduce the probability of selecting pipelines. Although crude petroleum highly uses pipelines for long distance, this commodity is not captured in the survey. Therefore, results only illustrate the behavior of other pipe-line oriented goods, like chemicals, petroleum products, among other, which are observed to be more short-distance oriented than regular truck shipments. Intuition behind the preference for short-distance shipments include coagulation of liquids related to petroleum and chemicals products for long distances, increased exposure of pipelines to obstruction, and
security issues in remote areas, among others. The parameter related to the combination of truck-water is also random.

For 74.33% of the observations as distance increases, the probability of choosing truck-water also increases. However, for 25.67% of the observations such probability decreases. The large increments might be related to the combination of flexible trucks with line-haul economies of water cargo for long distances. On the other hand, the small portion of reduction can be related to utilization of truck-water in inland water such as rivers or Great Lakes which are naturally short distances. Also, the location of major ports mostly in or suburbs of big cities which mainly the final destination of most shipments in which considered inherently as short distance.

The parameter for selecting other-mode for long distance is random. For 78.62% of the observation increments in geographic distance increase the probability of selecting other-modes, and for 21.38% of the observation the probability is decreased, both at different scales (normally distributed). The highest increments of selecting other-mode might be associated with the utilization of Multimodal transport such as, rail-water, which are typically two modes heavily utilized for long distances. Additionally, employing more than two modes of transport which allow the customer to cost-effectively manage shipments from start-to-end, ensures optimum care and efficiency every step of the way which can also explain this result. The lower reduction might be related to walking, carrying or bicycle which is mentioned in the
dataset attracting light shipments for short distance that generally require delivery inside the building.

2.5.1.2: International shipment

From the perspective of the international shipment, if the final destination of the shipment is Canada, on average it increases the probability of selecting other-mode by 1.24%, rail 0.80%, truck-water 0.59%, truck-rail 0.44%, and air cargo 0.22%, which indicate that there is possibility to use most of the available freight modes to Canada. Indeed, Canada and the U.S. share the longest land and sea borders that facilitate the utilization of any mode. If the final destination is Mexico, in average the probability to selecting different freight modes increases 0.84% for rail, 0.59% for truck-rail, 0.09% for other-modes, 0.06% for water and 0.04% for air cargo. The higher tendency of selecting rail and truck attached modes highlighted the importance of these modes for border crossing, especially Canada and Mexico in which shippers can reduce travel time and cost. On average, longer journeys tend to be less expensive by rail, and shorter journeys are less costly by road. On the other hand, the mode selection is governed by many factors which are route and commodity specific. If the final destination is other-country, the probability of selecting truck-water in average increases by 3.64%, and water by 1.77%, which highlights the importance of water for international shipments. Moreover, it is obvious that the U.S. has borders with few countries, so, few alternatives are available. Thus, the selection of water or water combined with truck might be related
to its widespread availability along the east coast, west coast, or Gulf of Mexico which makes it a practical option. Additionally, if other-country is the final destination the probability of selecting air cargo in average increases by 5.77%. The higher ME for air cargo might be related to its widespread availability and scope. Increased probability of selecting railway and rail attached with truck by 0.26% and 4.96% respectively, indicates that rail still is the valuable option for shipments destined to Central America through Mexico lands.

2.5.1.3: Unitary value of shipment

This variable captures the shipment unitary value, which is the ratio of shipment value to shipment weight. A mode offering high capacity and low transit time usually generates low unitary shipment costs that might attract commodities with low unitary value. This is supported by negative signs of the parameters for the corresponding variable in the model. On average, a $ 1 per lb. increment in shipment unitary value decreases the probability of selecting rail by 0.53%, truck-water 0.47% and water 0.32%; thus, these modes are less desirable for high-value shipments.

The parameter related to selection of truck-rail to carry high value shipments is random. In average, the probability of selecting truck-rail decreases by 0.07% for a unitary increase of shipment value. Random effects for 46.73% of the observations indicate the selection probability increases, and for 53.27% decreases, both at different scales (normally distributed). Although railways are fast for long-hauls and trucks increase speed for last mile deliveries, other elements of truck-rail might
decrease its desirability for the majority of high-value shipments, i.e., handling at intermodal facilities, restrictions related to fixed schedules for rail, damages, delays, potential vandalism, among others. On the other hand, some high-value shipments might have found a good way to exploit the advantages of each mode, and, hence, make this synergy more desirable. Additionally, the parameter for selecting air cargo to transport high-value shipments is also random.

The probability of selecting air cargo in average increases by 22.8% for a $1 increment per lb. Random effects indicate that almost 66.02% of the observations have air cargo probability selection increments and nearly 33.98% reductions, both at different scales (normally distributed). Similarly, the parameter associated with selection of parcel delivery services is random. In average, for 66.94% of cases parcel selection increases as the unitary value of shipments increases, and for 33.06% of the cases the probability decreases. The high increments associated with selecting air cargo and parcel delivery is expected because their practicality for direct shipment and express delivery, which make them more attractive for high-value shipments, despite its expensive shipment cost compared to other modes. This also highlights the importance of reliability for shippers, who are willing to pay more in order to avoid delay associated with some freight modes. The high increments associated with selecting parcel delivery is expected because of their practicality for direct shipment and express delivery. Moreover, air freight serves markets and supply chains that demand speed, which make them more attractive for high-value shipments. The
selection reduction for both modes might be related to the expensive shipping cost compared to other modes. This factor also highlights the importance of reliability for shippers, who are willing to pay more in order to avoid delay associated with some freight modes.

2.5.1.4: Hazmat (flammable liquids) shipments

Shippers with shipments carrying hazardous materials prefer modes that maintain certain levels of safety in their equipment and/or operation. This is supported by the positive parameters to the corresponding variable in the model. On average, hazmat shipments tend to increase the probability of selecting the following modes with respect to trucks: pipeline by 11.4%, water by 5.37%, rail cargo by 1.45%, and truck-water by 0.04%. Intuitively, the high increments in selecting pipelines to transport flammable and explosive chemical materials possibly relate to the satisfactory safety levels associated with this mode (accidents are rare in pipeline transportation). The increased desirability of water might be related to the evolving of tanker vessels that are a preferred mode of transport for the movement of high volume and heavy shipment such as, petroleum products, petrochemicals, among others which would be impossible to move by other modes especially international shipments. The attractiveness for the rail system might be related to the widespread availability of tank cars that are designed to carry flammable gases and hazardous materials directly to industrial locations. The lower ME in selecting the combination of truck-water might be related to the transference process between the patterns, but it still remains
as a practical option in many cases. On the other hand, the probability of selecting air cargo and parcel services to carry hazardous materials in average, it goes up by the order of 0.001%. Despite the security measures and special cargo handling associated with these modes, the shippers are aware of the risks of these shipments when selecting them. Therefore, they may be suitable to transport the hazardous dry materials in limited quantities. Additionally, the probability of choosing truck-rail to carry flammable liquid shipments on average decreases up by the order of 0.001%. Interestingly, the unattached rail is desirable to transport such loads, but adding trucks makes multimodal services undesirable. Increased shipment handling can be unsafe for hazmat shipments and promotes negative attitudes towards the truck-rail mode.

2.5.1.5: Temperature controlled

In average, the probability of selecting truck-water for shipments that require temperature-control increases by 1.48% with respect to trucks. The increments might be linked to the advantage of utilizing specialized containers (refrigerated-container) in low-cost modes for long-hauls, i.e., water, and trucks for last miles. Similarly, the positive signs in the model indicate that the probability of selecting air cargo increases by 0.21% with respect to trucks. The increment might be related to certain advantages, e.g., direct shipping and constant temperature control along the transporting process, among others. Also, despite its high cost, the air freight remains in many cases, it is the only feasible option. In average the probability of selecting
pipeline decreases by 0.43% with respect to trucks, followed by 0.18% for water, 0.15% for the railway system, 0.13% for truck-rail, and 0.13% for parcel services. Different factors affect the desirability of selecting such modes: Inability to protect against natural factors during the transfer process for pipeline mode, unavailability of particular types of temperature-controlled equipment during distribution for parcel service, and expensive storage cost along the railway track. These significant factors make those modes less desirable.

Shipments requiring some level of temperature control in average have the highest probability of selecting other-mode by 2.50%. Interestingly, despite other-mode containing a mixture of transport patterns, it is still ambiguous which mode is suitable for these shipments. Since details on other-modes are not available in the dataset, additional investigations are required to better understand this trend.

2.5.2: Industry clusters

The second group of variables is related to industry clusters, on which several industry types have strong economic interdependencies Mesa-Arango and Kumar (2017). The following analysis expands cluster to account for manufacturing and activities within each group.

2.5.2.1: Raw materials manufacturing

For the manufacturing of raw materials, shippers tend to prefer modes serving regular routes. The positive signs in the model indicate that the probability of selecting modes increases with respect to trucks as the carrying capacity increases. In average,
the probability of selecting water increases by 8.89% with respect to trucks, pipeline by 6.25%, other modes by 4.56%, railway by 3.22%, truck-rail by 1.65% and truck-water by 0.76%. Undoubtedly, ships and railways have been used to transport a variety of unpackaged raw materials for a long time, i.e., chemicals, petroleum products, and bulk cargo such as coal, iron ore, cereals, and bauxite. Additionally, pipelines are developed to transport the bulk of raw materials, such as natural gas and petroleum products, which has a distinctive and well-defined uses. On the other hand, despite the advantage of multimodal transportation, which enhances the economic performance of transportation chains, the lower ME for selecting the combination of truck-rail and truck-water, might be related to the additional costs involved in using more than one freight mode.

2.5.2.2: Raw Materials wholesalers

The primary crude petroleum is not covered in the survey; therefore, the CFS surveyed petroleum refining firms and deal with it as petroleum and petroleum-related products. In fact, petroleum products are the main engines of modern life and involve in various aspects of the economy, which require distribution to many different places. Undoubtedly certain freight modes with the largest capacity to reduce more frequent delivery and highest satisfaction levels safety will most likely to be selected. The probability of choosing water cargo in average increases by 0.56% for industries in the raw materials wholesalers clusters. Water transport is expected to increase the shipment quantities which might reduce the transport frequency, and
thus enhance the safety. Moreover, its large capacity offers both cost savings and long distance scope due to the high demand for related shipments. Notice that the widespread availability of seaports along the U.S. coasts might be other reason to make it the most practical option for such shipments.

2.5.2.3: Service-related manufacturing

In average, the probability of selecting air cargo to carry shipments related to service manufacturing increases by 5.74%. Air freight offers certain advantages which align with shipping requirement for commodities in this cluster, e.g., unmatched speed, and global shipping flexibility, for, shipment related to printing, newspaper, periodical, book, directory publishers shipments. Also, air cargo requires less need for warehousing and reduced risk of theft and damages for shipment related to computer and electronic product manufacturing. Furthermore, the probability of selecting parcel services in average increases by 3.87% for service-related manufacturing. The parcel services provide speedy delivery and door-to-door services that include local, regional, or international delivery which provide transportation solutions to businesses especially for corporate, subsidiary, and regional managing offices and other shipments in general.

2.5.2.4: Service-related wholesalers

From the marginal effects computed in Table 2-5, it is observed that service related wholesale groups increase the probability of selecting the same predominant modes during manufacturing, i.e., parcel by 1.16% and air 0.91%; the rest of the freight
patterns are not desirable for these shipments. The features associated with parcel delivery services are mostly compatible with the requirement for shipping commodities in this group such as the flexible schedule for drop-off and pick-up, door-to-door services, accelerated deliveries, that make parcel uniquely desirable for service-related wholesale. The increment for selecting air cargo might be related to drugs and druggists' sundries shipments. These features and systematic temperatures during the transfer process make it distinctive transport mode and in many cases, the only option for such shipment.

2.5.2.5: Metals manufacturing

This group gather industries like, primary metal, fabricated metal, machinery, electrical equipment, appliance, transportation equipment, which are highly sensitive to timely delivery, quality, and service flexibility. Likewise, this products have broad scope and need to be distributed to many different places. This seems to be reasonable and modes have the highest satisfaction levels for shipping the high-value commodity with more frequent delivery will most likely to be selected. The probability of choosing air cargo in average increases by 2.53% for industries in the metals manufacturing cluster. This is because air freight meets the shipper's demand in term of efficient, quick transport services, and safety which is required for light package further expediting the process of shipping. The all given attributes might be related to electrical equipment, appliances and components, and machinery. On the other hand, the probability of selecting water cargo increases by 0.08%, which might
be related to commodities in this group such as primary metal, fabricated metal, machinery manufacturing and transportation equipment. In many cases, the shippers prefer to ship using maritime cargo for large quantities of heavy and bulky goods traveling long distances, in which the cost of transportation is meager compared with other freight patterns. On the other hand, the probability of selecting truck-rail and truck-water increases by 1.38% and 0.08% respectively, which might be related to commodities in this group such as primary metal, fabricated metal, machinery manufacturing and transportation equipment. In many cases, the shippers prefer to ship using maritime cargo and railway system for large quantities of heavy and bulky goods for long distances, in which the cost of transportation is meager compared with other freight patterns. While the efficiencies of trucks provide flexible local pickups and deliveries.

2.5.2.6: Metals wholesalers

In the results, it is obvious that the selection of freight mode for distribution the wholesalers clearly differs from the initial stage (manufacturing), possibly due to the nature of the industrial activities. The probability of choosing freight modes which is widely regarded as the most critical for on-time delivery such as air cargo and parcel services in average increases by 3.04% and 2.84% respectively. The increments of air cargo and parcel service selection might be related to a certain segment of the metal wholesalers group, i.e., electrical, electronic goods, machinery, equipment, and miscellaneous durable goods which constitute commodities that are
highly sensitive to service quality and service flexibility attributes. The features associated with these modes related to understanding that the more times a package is handled or changes hands, the greater the risk, so the shipments undergo only minimal handling and certain regulations which make them more desirable of such shipments. On the other hand, on average the probability of selecting truck-rail increases by 1.50% with respect to trucks, truck-water by 0.53% and water by almost 0.17%. As expected the selection of truck-rail and truck-water increment could be attributed to many advantages required to transport the high volume of motor vehicles and parts and more sizable capability to carry heavy tonnage of metal, mineral, plumbing, lumber, and construction materials. The high-capacity for long distances covered by rail and water modes and the flexibility is one of the unique features for the truck transport regarding delivering to the final destination and volume of goods to be transported.

2.5.2.7: Agricultural manufacturing

Shippers with shipments associated with some level of regulations restriction for the entire process prefer freight modes that are flexible to changes in capacity and/or equipment. This is supported by the positive parameters of the corresponding variables in the model. In average, the probability of selecting truck-rail increases by 1.24% with respect to trucks for industries in the agricultural manufacturing cluster. In this case, the inspection required for shipments related to food, beverage, and tobacco products make certain modes appropriate for transport such shipment. The
increment may be connected to the rules, regulations, and licenses required by truck and combined with regular inspections for truck-trailer containing such shipments make truck-rail more desirable for such shipments. Moreover, railways are economical and best suited for bulky goods over long distances, in which food cost is maintained at a low level.

2.5.2.8: Agricultural wholesalers

The groups of grocery and related products, farm products, beer, wine, and distilled alcoholic beverages tend to increase the probability of selecting certain freight patterns to transport their commodities, and on average, it increases the probability of selecting unattached water by 3.24% and water combined with trucks by 1.11% with respect to trucks. Waterborne freight covers domestic commerce and international trade and offers cost-effective ways to move large quantities of low-value shipments for long distances. Additionally, the combination of truck-water makes transport of the specialized containers (refrigerated containers) for food transportation more practical. In general, food shipments are more sensitive to both cost and time; thus, using large capacity by water combined with a large fleet of refrigerated vehicles makes a big difference in timing, and it, becomes more desirable to transport food-related shipments.

2.5.2.9: Textile/apparel and paper manufacturing

Seemingly, railway and truck-rail are more attractive to transport most commodities in this group. The positive signs in the model indicated that the probability for
railway and truck-rail to be selected increases by 5.08% and 2.75%, respectively. Rail offers consistent and reliable schedules for production and distribution with required capacity for commodities such as leather, apparel, and textiles, which are desirable features for these shipments during the manufacturing process. Moreover, the railway system is the primary land transport mode for large quantities of low value-per-ton-goods, and the efficiencies of trucks provide flexible door-to-door delivery services which might be appropriate to transport shipments related to paper, chemicals, and plastics and rubber products manufacturing. On the other hand, the probability of choosing air cargo and parcel services increases by 1.95% on average each, which might be related to segments of textiles, apparel, and leather shipments mostly having high-value and generally requiring express delivery, which is the main feature of such modes. Additionally, the probability of selecting pipeline in average increases by 3.79%, and primary chemicals and their chemical products exist in this group. It is clear that pipes are the most convenient, efficient, and economical mode to transport liquids.

2.5.2.10: Textile/apparel and paper wholesalers

This group combines industries such as paper and paper products, apparel, piece goods, chemicals, and miscellaneous nondurable goods, which in are need of time-critical delivery requiring capable modes providing delivery within certain times. In this case, shippers are looking for reliable service, and they would pay more to receive the items based on expected delivery time. The probability of choosing
parcel services in average increases by 1.51% for industries in this cluster. Parcel service provides features to facilitate the shipping process between the parties from door-to-door in a timely manner that might be desirable attributes for these shipments. On the other hand, the probability of selecting air cargo in average increases by 0.001%, which might include expensive items in this group, such as apparel, piece goods, miscellaneous nondurable goods, among others. Those shipments usually represent a small percentage; however, they require special services which are compatible with air freight operations. Moreover, air cargo might be more attractive to international segments required for such shipments.

2.5.2.11: Wood products manufacturing

Interestingly, wood, furniture, and related products lean heavily toward the railway as the preferred mode of transportation. The probability of choosing unattached rail and rail combined with truck in average increases by 0.41% and 0.31% for industries in the wood manufacturing cluster. The flexible capacity of railway cars is expected to enhance the performance and increase the capacity, which might reduce the trip frequency. Moreover, the railway is expected to be selected, due to its widespread, and it seems to be the most practical option for such shipments. On the other hand, trucks are still indispensable for short distance delivery. The truck offers a wide range of features which might be required for such shipments, i.e., flexible capacity, and utilization of a wide variety of equipment that makes it a more desirable mode with railway system.
**2.5.2.12: Wood products wholesalers**

In average, the probability of selecting parcel services to carry shipments related to wood products wholesalers increases by 0.24%, which might be related to shipment contents of furniture and home furnishing goods. Parcel provides features like shipment tracking and door-to-door delivery that might be desirable attributes for these shipments. Recently, an increase in the online shopping make parcel services more practical options for delivering such shipments. On the other hand, there is a tendency to select intermodal carriers to carry the related shipments with in average increases by 0.02% for both truck-rail and truck-water. Several attributes might make intermodal more desirable for such shipments. For example, high capacity and low transit time of rail and water offer both cost savings and long distance scope for their related shipments; truck provides flexibility and availability for short distances; water might be more attractive for international segments to transport such shipments.

**2.6: Numerical example**

The hypothetical example is presented to illustrate the application of the MNL mode with random parameters and its importance for shipper and carriers. Professionals in charge of transportation systems for their companies are considering the 2012 CFS data for strategies that allowing understanding the best freight modes for their shipments’ characteristics which are summarized in Table 2-6. Their plan is to
understand the possible freight modes which fit their shipment before procuring the transporting services from the candidate carriers.

### Table 2-6: Numerical example: attributes of shipment

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Origin</th>
<th>Destination</th>
<th>Value ($)</th>
<th>Weight (lb.)</th>
<th>Distance (mi)</th>
<th>Temperatures</th>
<th>Hazmat</th>
<th>Export / Import</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food manufacturing</td>
<td>U.S.</td>
<td>U.S.</td>
<td>VA</td>
<td>VA</td>
<td>UND</td>
<td>YES</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mining manufacturing</td>
<td>U.S.</td>
<td>U.S.</td>
<td>VA</td>
<td>VA</td>
<td>UND</td>
<td>-</td>
<td>NO</td>
<td>O-C</td>
</tr>
<tr>
<td>Hazmat materials</td>
<td>U.S.</td>
<td>U.S.</td>
<td>VA</td>
<td>VA</td>
<td>248 mi</td>
<td>YES</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electrical/electronic/machinery wholesalers</td>
<td>U.S.</td>
<td>U.S.</td>
<td>200,130</td>
<td>VA</td>
<td>UND</td>
<td>-</td>
<td>NO</td>
<td>O-C</td>
</tr>
</tbody>
</table>

VA: Varies. / O-Country: Other-country except (Canada and Mexico). UND: undefined average distance between origin and destination (miles).

Based on the above data, the professionals considered the most available freight modes in the U.S., but they differ from one company to another. Nine freight modes are candidate carriers (truck, rail, water, air, parcel, pipeline, truck-rail, truck-water and other-mode).

The utility functions are estimated through Equation (2-6), which presents the econometric specification of the model in Table 2-6, where $U_i$ is the utility of selecting the freight modes. The average utility function $U_i$ is associated with freight modes $i \in \{\text{Truck (T), rail (R), water (W), Air (A), pipeline (P), parcel (PA), truck-rail (TR), truck-water (TW), and other-mode (OM)}\}$. Variables related to the alternative $i$ are: the shipment distance (route) $x_i^d$ (miles), the unitary value $x_i^{u-value} = \text{shipment value divided by shipment size (\$ per lb.)}$, and binary indicator variables, such as $x_i^{\text{Canada}} = 1$ if the final of destination of the shipments is Canada; $x_i^{\text{mexico}} = 1$ if Mexico is the final distance; and $x_i^{\text{O-Country}} = 1$ if Other-country is final destination. Other variables include $x_i^{\text{temp}} = 1$ if the shipment requires
temperature control, and \( x_{i}^{\text{hazmat}} = 1 \) if the shipment contains flammable materials. If the commodity is related to any clusters, then: \( x_{i}^{\text{rm}m} = 1 \) if the commodity is raw materials manufacturing; \( x_{i}^{\text{rm}h} = 1 \) if the commodity is raw materials wholesalers; \( x_{i}^{\text{s-rm}} = 1 \) if the shipment is services-related manufacturers; \( x_{i}^{\text{s-rh}} = 1 \) if the shipment is services-related wholesalers; \( x_{i}^{\text{mm}} = 1 \), if the commodity is related to metals manufacturing; \( x_{i}^{\text{mh}} = 1 \), if the commodity is metals wholesalers; \( x_{i}^{\text{am}} = 1 \) if the commodity is agriculture manufacturing; \( x_{i}^{\text{ah}} = 1 \) if the commodity is agriculture wholesalers; \( x_{i}^{\text{tapm}} = 1 \), if the shipment is related to textile/apparel/paper manufacturing; \( x_{i}^{\text{tap}} = 1 \) if the shipments related to textile/apparel/paper wholesalers; \( x_{i}^{\text{wpm}} = 1 \) if the shipment is wood products manufacturing; and \( x_{i}^{\text{wph}} = 1 \) if the shipment is wood products wholesalers.

\[
U_{i} = (\text{Constant}_{i} + \beta_{i} x_{i}^{d} + \beta_{i} x_{i}^{\text{u-value}} + \beta_{i} x_{i}^{\text{Canada}} + \beta_{i} x_{i}^{\text{Mexico}} + \beta_{i} x_{i}^{\text{o-country}} + \beta_{i} x_{i}^{\text{tem}} + \beta_{i} x_{i}^{\text{hazmat}} + \beta_{i} x_{i}^{\text{rm}m} + \beta_{i} x_{i}^{\text{rm}h} + \beta_{i} x_{i}^{\text{s-rm}} + \beta_{i} x_{i}^{\text{s-rh}} + \beta_{i} x_{i}^{\text{mm}} + \beta_{i} x_{i}^{\text{mh}} + \beta_{i} x_{i}^{\text{am}} + \beta_{i} x_{i}^{\text{ah}} + \beta_{i} x_{i}^{\text{tapm}} + \beta_{i} x_{i}^{\text{tap}} + \beta_{i} x_{i}^{\text{wpm}} + \beta_{i} x_{i}^{\text{wph}}) (2-6)
\]

The probability \( P_{i} \) of selecting freight mode \( i \) is determined by logit formula presented in Equation (2-7). The probabilities are computed for 900 observations, in which sampling from the original dataset is completed before the model is estimated. The main reason is to confirm that the first sampling represents the entire dataset and results are not be biased toward the model dataset. Each freight mode is described by
100 observations, taking into account the same considerations in sampling the data for the model stage.

\[ (P_i) = \frac{e^{U_i}}{\sum_{j \in \{T,R,W,A,P,PA,TW,OM\}} e^{U_j}} \]  

(2-7)

The first scenario related to a food company requires freight service for shipments from different locations to its manufacturer's facilities. The detailed information in Table 2-6 indicates that all facilities are in the U.S., the shipments need temperature control, but distance and weight vary from one shipment to another. The primary hypothesis is that all shipments to which these specifications are applied in the dataset will be considered as the shipments to be transported, and will take into consideration all freight modes available.

Figure 2-2: Probability of selecting freight transport for food company

From the dataset, with the absence of the certain attributes such as travel time and shipping cost, the freight professional will consider the distance as a major
variable to determine the appropriate freight mode. In average, the selection probabilities are 24% for the truck for short distances, and the probability decreases as the distance increases. The shipping cost associated with trucks can increase significantly concerning distance, and make it more undesirable. The probability of selecting railway remains constant to almost 10%, despite distance change. In cases of intermodal shipment, truck-rail and truck-water, the selection probability increases as the geographic distance increases. The selection probability is reached 34% for truck-rail and 41% for truck-water for long travel shipments. The high performance of rail and water are attributed to the combination of low-cost prices with fast delivery and utilization of containers. Although truck has less desirability for long distances, it is the better option in combination with other modes because of its availability and higher maneuverability for loading and unloading. Interestingly, it is observed from the probabilities computed for this scenario Figure 2-2, that the other-mode play a significant role in food transport, in which the selection probability is more than 45% for short distances and decreases as the distance increases.

In the second scenario, a Mining Company requires freight services for its products, which include metallic ores, coal, and non-metallic mineral products. The company is needs to understand the effect the distance for both the final destination and daily production. Table 2-6 has the information about the company' activities and nature of service required.
Figure 2-3: Probability of selecting freight for bulky mining shipment

Using the same hypothesis as in the first scenario, commodities that have the same characteristics in the dataset will be considered as shipments to be transported. In average, the selection probabilities related to short distances, which are less than 50 miles, are 27% for water, 22% for other-mode, 14% for the pipeline, 13% for the railway, 12% for the truck, 7% for truck-rail, for 4% for truck-water, and almost 1% for parcel. It is observed that the desirability to choose the truck and pipeline modes decreases with increasing distance to reached almost zero for specific distances. Moreover, the selection of rail and water remain relatively constant as the distance increases. On the other hand, truck-rail and truck-water are more desirable as distance increases because they offer high capacity and lower price for long distance. The effect of these attributes is sufficient to show other positive features, such as large and newer fleets for trucks showing better performance with the high capacity by water and consistent schedule by rail. Furthermore, the pipeline is highly
unattractive for long distances because it is not flexible and its capacity cannot be increased once it is laid, which gives unsatisfactory experiences with such commodities. The computed probabilities for this scenario are presented in Figure 2-3.

The third scenario relates to a giant petrochemical company that has several branches in the U.S. The company hired transportation professional firms to submit a report for seeking to own its transport fleet, suitable for the various goods manufactured varying between basic chemicals, other chemical products and preparations, and petroleum products. The shipments characteristics are presented in Table 2-6, but the important aspect in these cases is that the average distance between the shipment origin and destination is about 248 miles.

![Figure 2-4: Probability of selecting freight for hazmat materials](image)

Here, with the utilization of the same hypothesis as in the first scenario, the average selection probability is 2% for the truck, and it is almost constant with
distance. On the other hand, it is obvious that the distance has a positive effect on the selection of freight modes, such as rail, water, truck-rail, truck-water, and other-mode. In cases of railway and water, the effect is more evident with the increment from 5% rail and 2% for water, to reach 62% and almost 16% respectively, concerning the distance. The increment of the selection probabilities related to truck-water and other-mode are not significant. In cases of truck-rail, it is higher by 12% on average. Evidently, there is a preference for selecting pipeline by almost 90%, which makes it the most desired mode. The high tendency to select pipeline can be attributed to the positive values of safety measures associated with the operation process, especially for such commodities. The results for the simulated probabilities from this scenario are presented in Figure 2-4.

![Graph showing selection probabilities for different modes](image)

**Figure 2-5: Probability of selecting freight for electrical/electronic/machinery wholesaler’s shipment**
The last scenario is for a company selling electronics and electrical tools, which requires understanding the suitable freight modes which align with the nature of its shipment. The main concerns of the company are the value of the shipments, which are about $200,130, and more details about the shipments are provided in Table 2-6. It is observed in Figure 2-5 after applying the same hypothesis in the first scenario, that the average selection probabilities with respect to short distance are 21% for the parcel, 19% for truck-rail, 16% for the truck, 12% for truck-water, 10% of other-mode, 9% for air cargo, 7% for rail, and 6% for water. These probabilities for most of the freight modes decrease as the distance increases, in which might be related to two reasons. First is the nature of these commodities and import shipments. Noticeably, there is a preference for selecting air cargo reaching almost 100% for the long distance that might be related to shipments from other-country in which the shipping options are limited, but still, there is a significant chance to select other freight patterns for short distance shipments. In this scenario, air cargo is in the first position for long distance, mainly because of its attractive features, such as unmatched speed, higher standards of security, global shipping flexibility, and reliable schedules.

The numerical example shows that the results mostly are identical with the outcome from the model estimated. On the other hand, this proves the model's flexibility for the shippers.
The next section summarizes the mode choice investigation and its key findings. Likewise, it discusses limitations and future research directions.

2.7: Conclusion

Freight mode choice models are important for decision-making by the public and private agencies. This chapter employs econometric modeling to understand and analyze freight mode choice in the U.S.

The 2012 CFS—one of the most comprehensive databases on intercity freight movements in the country—is the cornerstone of the current research effort. However, during the analysis and discussion, the high number of the commodities in the dataset become unmanageable, and understanding all of them together is cumbersome and difficult to fully explain. Therefore, economic clusters is a well-structured and consistent economic approach to aggregating various industry types into groups. Thus, this chapter employs a novel clustering approach revealed by Mesa-Arango and Kumar (2017), in which clustering freight transportation modes and freight supporting activities and other industry sectors that have strong economic linkages and interdependencies are grouped into logistics clusters. Moreover, the industry clusters are aggregated into clusters following the taxonomy developed by Mesa-Arango and Kumar (2017) using NAICS codes to describe industries.

A multinomial logit model with random parameters is estimated to determine the variables that affect the mode choice presses. Variables like route distance, unitary value, shipments requiring temperature control, hazardous shipments, and
international shipments, are found to be significant. Industries clusters based on NAICS for both (manufacturing and wholesales) activities are found to be intuitive and significant. These findings align with previous results in the literature.

Furthermore, new findings related to the effect of logistic clusters on freight mode choice add novel insights on the freight mode choice process. It is obvious that those homogeneous shipments that are behaviorally classified, are based mainly on several consignment characteristics rather than commodity type, as seen in the real world adding value during transportation. This result suggests that the traditional commodity-type based segmentations do not fully accommodate the heterogeneity in shippers’ freight mode choice behavior. Rather, behaviorally homogeneous segments are defined by a combination of attributes of the shipment. For example, clusters associated with manufacturing shipments, and others related to wholesalers’ activities have been determined and satisfactorily incorporated into the estimated freight mode-choice model for the first time.

MEs are used to rank the importance of modes with respect to their selection probability. All the industry clusters in the discrete choice model are found to be significant and associated with intuitive signs for various freight modes.

The results herein are of vital importance concerning freight transportation, logistics, and supply chain management. The contributions of the chapter are: (1) Studying the general behaviors behind using the CFS 2012 data of the freight service by shippers that select transport mode at all holistic regions in the U.S., (2) Testing
a set of industry clustering attributes to facilitate the analysis and to clearly understand freight mode-choice, (3) Proposing multinomial logit mode with a random parameter to identify the main variables determining the choice of freight mode at strategic macroscopic level, and (4) providing a discussion on how these variables affect mode choice. Decision makers can use the results from this model to better understand freight mode selection and the key components driving this decision.

3.1: Introduction

This chapter develops a joint mode-choice and shipment-size freight transportation macroscopic model for the United States. The methodology follows a discrete-continuous econometric framework that addresses the selectivity bias problem related to the joint mode-choice/shipment-size decision. Public data from the Commodity Flow Survey 2012 is used to estimate the model. Aggregating of firms into ad-hoc classifications follow well-structured approaches that are economically consistent indeed important to understanding the freight mode selection. Numerical results show that variables related to the commodities transported, underlying industrial clustering activities, and geography distribution of shipments, play an important role in the joint decision.

This chapter develops a freight transportation planning tool to understand and model joint mode-choice and shipment-size decisions at a macroscopic level. The essence of planning is the comprehensive analysis of the impacts of policies, programs, and projects upon both systems under consideration and its socioeconomic environment. In freight transportation planning, this philosophy translates into the consideration of the interactions among multiple freight modes, land uses, the economy, and the environment. Freight models are important to assess the impacts
of proposed and planned alternatives resulting from the complex combination of multiple factors. However, modeling freight transportation is challenging for multiple reasons, e.g., lack of awareness of the importance of freight transportation, the inherent complexity of freight movement, sequential modeling structures that cannot capture simultaneous logistics decisions, among others. Therefore, there is a great need to have a rigorous understanding of the behavior of decision makers in freight transportation markets.

This work contributes to the freight transportation and logistics literature by (1) studying the general behaviors behind the selection of the freight service by shippers that move commodities, (2) Using the discrete-continuous approach to analysis freight mode choice with aggregated data such as 2012 CFS for strategic decision, and (3) testing the effect of aggregate industry type into logistics clusters on freight mode choice to explain the general trend of freight movement at the national level.

The rest of the chapter is organized as follows. Section 3.2 provides a comprehensive review on joint mode-choice and shipment size research. Section 3.3 clearly defines the problem to be solved. Section 3.4 describes the datasets used in the current chapter. Section 3.5 presents the discrete-continuous econometric approach followed in the chapter to estimate shipment-size and mode choice. Section 3.6 presents the model estimation results and discusses key findings. Section 3.7 concludes and summarizes the work.
3.2: Background of mode choice and shipment size model

This section presents a literature review of previous works related to freight demand modeling focusing on mode choice and shipment size. The review illustrates the gap related to the use of joint mode-choice and shipment-size macroscopic models that use aggregated data CFS 2012 for holistic regional analysis. First, mode choice will be reviewed and the lack of joint models that consider shipment size will be highlighted. Then, models for joint estimates are reviewed and the gap on macroscopic models that aggregate industry type into logistics clusters for regional analysis is illustrated. Additionally, attributes that were considered to explain similar choices are summarized in order to postulate a set of covariates that will be used to explain this behavioral phenomenon.

There are mixed opinions about the role between shippers and carries on the decision of shipment size and mode choice. A group of researches (Catalani, 2001; Golias and Yannis, 1997; Kim, 2002; McGinnis et al., 1981; Nam, 1997; Train and Wilson, 2006; Wisetjindawat et al., 2005), argue that shipment size does not affect mode choice, i.e., shippers take this decision based only on mode-related attributes like transportation and inventory costs, travel time, accessibility, reliability, transit time, travel cost, security, service level, frequency of service among others. Several works make this assumption in the context of multiple mode alternatives. This branch of research is recently exemplified by several works that have been used to understand the behavior of shippers selecting truck types, e.g., (Cavalcante and
Roorda, 2013; Mesa-Arango and Ukkusuri, 2014; Shah and Brueckner, 2012), and more general multimodal choices (Anderson et al., 2009; Arunotayanun and Polak, 2011; Banomyong and Supatn, 2011; Brooks et al., 2012; Danielis and Marcucci, 2007; Hensher et al., 2013; Larranaga et al., 2017; Patterson et al., 2010; Puckett et al., 2011; Wilson et al., 1986; Zamparini et al., 2011). However, not considering shipment size is problematic because there is a clear relationship between shipment size (among other attributes), and mode choice. This idea is supported by several works reviewed next.

A significantly large group of researchers agrees that shipment size affects mode choice. Thus, there are two approaches to incorporate shipment size into mode choice, i.e., exogenously or endogenously determined by the shipper/carrier interaction. Models that consider shipment size to be exogenously determined assume that shipment size determines mode choice but not the opposite (Arunotayanun and Polak, 2007; Jiang et al., 1999; Norojono and Young, 2003). However, this is a problematic assumption because usually shipment-size and mode-choice are joint decisions based on the interaction and experience between shippers and carriers. For example, Samuelson (1977) argues that shipper-carrier interactions jointly determine freight mode choice. Likewise, Holguín-Veras et al., (2011) support the cooperative interaction between shippers and carriers for these decisions. Consequently, several models have been developed to understand the joint shipment-size/mode-choice decision with endogenous assumptions. (Abdelwahab and
Sargious, 1992; Abdelwahab and Sayes, 1999; Holguín-Veras, 2002; McFadden et al., 1985) Studying this joint decision requires the use of discrete-continuous joint models, which will be reviewed next.

Few models have been proposed in the literature of freight transportation to consider join discrete-continues choices for mode-choice and shipment-size and most of them have been developed to understand this behavior from a microeconomic perspective, i.e., mode/shipment-size selection at the firm level. There are two fundamental distinctions between such microeconomic models: (i) inventory-based models, where this decision depends on operational characteristics of the firm (Chiang et al., 1981; Daughety, 1979; Daughety and Inaba, 1977; Hashemian, 1982; McFadden and Winston, 1981), and (ii) behavioral-based models which capture unobserved behavioral attributes in the shipper/carerrier interaction as well as incomplete/imperfect operational information Baumol and Vinod (1970), and Constable and Whybark (1978). From an inventory perspective, Abdelwahab and Sargious (1992) integrate mode choice with production decisions like shipment size. On the other hand, from a behavioral perspective Winston (1983) focuses on mode choice. McFadden et al., (1985) derive a joint mode choice/shipment size model to establish the simultaneous nature of the firm’s choice of mode and shipment size for freight transported by truck and rail. Abdelwahab and Sargious (1992) use the same formulation of the firm's simultaneous decision process. However, the applicability of this model is rather limited when decision makers have to choose from more than
two mode alternatives. Holguín-Veras (2002) considers freight and vehicle choices as part of a discrete-continuous choice problem in which the shipment size is the continuous variable and mode choice is the discrete variable. Abate and De Jong (2014) investigate how variations in route/haul, carrier and vehicle characteristics affect the optimal vehicle size choice and the associated choice of shipment size. Johnson and De Jong (2011) take a similar approach, which yielded similar qualitative results, but they model the discrete choice component with different mode choices. A common feature of these works is the use of disaggregated data (at the firm level) to understand the discrete-continuous mode choice for microscopic/microeconomic decisions. Micro-level models are very useful to analyze individual firms when proprietary data about their logistics and operations are available. However, this information is not always available for regional modeling, when researchers/agencies need to understand and predict freight activities at a macroscopic level suitable for holistic decision making.

Both microscopic (disaggregated) and macroscopic (aggregated) models are important for freight transportation research. Several papers focus on macroscopic approaches because such resolution is frequently required for transportation planning purposes (De Jong et al., 2004; Rich et al., 2009; Veldman et al., 2011; Winston, 1983). Macroscopic models are important to understand and predict the regional distribution of commodity flows among different freight modes, and to analysis the impact of socioeconomic conditions in this phenomenon (Pendyala et al., 2000).
Earlier al 1990s Abdelwahab and Sargious (1992) utilized Commodity Transportation Survey to develop aggregate model by combines the two decisions on shipment size and mode choice. They used the same amount and quality of data as the one required to build a standard disaggregate mode choice model. Windisch et al., (2010) developed an aggregate model based on Swedish National Commodity Flow Surveys (SNCS) and incorporated logistics costs which yield accurate freight model estimation. Their empirical results indicate that disaggregate model can help to understand the parameters and their ability to predict choices of freight mode. Abate et al., (2014) use the same public data (SNCS) to update the current deterministic Swedish National Freight Model System to a stochastic one. The only macroscopic model that considers the joint mode-choice/shipment-size decision is the work by Pourabdollahi et al., (2013), which uses data from a large-scale establishment survey and develops a disaggregated model with detailed information about establishments, i.e., industry type and employee size. The study uses a copula-based discrete-discrete choice model where both mode choice and shipment size are considered as discrete choices. From a methodological perspective, using a discrete-discrete type of model for this decision is counterintuitive because shipment size is a continuous variable (not discrete), and its continuous property is clearly supported by the large majority of microscopic models reviewed before. Therefore, there is a gap in freight transportation literature related to the macroscopic discrete-continuous mode and shipment-size choice models that incorporate behavioral and operational
attributes as well as logistical clusters. To the best of the authors' knowledge, no work explicitly considers discrete-continuous of shipment-size and mode choice model that utilizes aggregated data for the holistic regional analysis in the U.S. and encompasses also all available freight transportation modes. Such a gap is narrowed with the current chapter, which uses regional data from the 2012 CFS and industry clusters develop by Mesa-Arango and Kumar (2017) to develop a discrete-continuous econometric choice model. The data and methodological approaches used to achieve this goal are reviewed in (Sections 3.4 and 3.5).

Furthermore, it is important to review variables that have affected this decision in previous research in order to assess data requirements for model development. Table 3-1 summarizes attributes considered for choice of mode/vehicle and shipment size in previous freight transportation studies. Identifying these variables is important to postulate a set of attributes to understand the behavioral shipment-size/mode-choice selection proposed in this chapter. In general, attributes related to commodity type, shipment volume, availability of transportation mode, commodity weight, and distinction of commodity being transported are regularly considered. Abate and De Jong (2014) investigate additional attributes related to vehicle characteristics, age, operating cost per ton, and vehicle class. Their work also includes carrier characteristics (e.g., carrier type hire or own and fleet size). Additionally, De Jong and Ben-Akiva (2007) show that logistics costs significantly influence shipper’s decision, i.e., total annual logistics costs, transport, consolidation and distribution
costs, order costs, cost of deterioration, capital costs of goods during transit, storage costs, capital costs of inventory, stockout costs and damage during transit.

Holguín-Veras (2002) uses a survey that gathers data from truck drivers randomly selected, and finds that the type of economic activities at the trip origin and the destination are important for freight decisions. The study suggests that such variables need further explorations and have potential to provide enhanced representations of the economic linkages that determine freight demand. Therefore, increasing utilization and integrating the non-monetary attributes in freight-service modeling reflect the level of importance that the users of the transport services attach to these attributes and that constitute a strong support towards priorities related to transport infrastructure planning and investments.

3.3: Problem definition

Shipment size and mode-choice are among the most critical decisions in logistics, which are commonly studied using independent models. Limited data on commodity movements has been a key obstacle to the development and application of simultaneous freight demand models. Previous research studied the competition among different transportation modes using different procedures to understand freight movements.
### Table 3-1: Attributes for Shipper-Carrier Interaction

| Data           | Category | Mode | Commodity Type | Commodity Value | Commodity Weight | Shipment Size | Distance | Frequency | Reliability | Inventory Cost | Loading/Unloading | Track Type | Vehicle age | Transport time | Operational Cost | Vessel | Damage | Employment Size | Industry Type | Activities OD |
|----------------|----------|------|----------------|-----------------|------------------|---------------|----------|----------|------------|-------------|-----------------|-----------------|------------|-------------|----------------|-----------------|--------|--------|----------------|---------------|----------------|
| Wisetjindawat (2005) | TMGMS    | I    | X              | X               | X                | X             | X        | X        | X          | X           |                |                |            |             |                |                 |        |        |                |               |                |
| Abdelwahab & Sargious (1992) | CTSU    | CC   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| Abdelwahab (1998)      | CTSU    | CC   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| Holguín-Veras, J (2002) | S        | CC   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| Holguín-Veras et al., (2011) | S        | CC   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| Combes, F (2012)       | ECHO    | CC   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| Abate & De Jong (2014) | CFSS    | CC   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| Abate et al., (2014)   | CFSS    | CC   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| De Jong and Ben-Akiva (2007) | CFSS    | CD   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| De Jong & Johnson (2009) | CFSS    | CD   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| Windisch et al., (2010) | CFSS    | CD   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |
| Pourabdollahi et al., (2013) | S        | CD   | X              | X               | X                | X             | X        | X        |            |             |                |                |            |             |                |                 |        |        | X              |               |                |

* I: Shipment size not considered (Independent), S: Shipment size is exogenous (Sequential), CC: Shipment size is continuous (Cooperative), CD: Shipment size is discrete (Cooperative).
* Availability of alternative mode of transportation
* Origin/ Distance of Commodity
* Storage costs, Capital of inventory, Stockout costs, ordering costs, holding costs and Storage time
* Transit time, Waiting time and Travel Time
* Cost of deterioration and damage during transport
The resulting freight trends are important to understand how freight operators choose specific transportation modes, how goods are shipped between origins and destinations, and how mode choice and shipment size vary as a function of policy interventions, e.g. change in the permissible payload. Although it is easy to assume that freight-related decisions are purely driven by monetary attributes, e.g., costs, or prices, previous works demonstrate that other attributes should be considered, e.g., transit time, reliability, safety, frequency, among others.

Many decisions in the real world are interconnected and require to be taken sequentially or simultaneously. The review illustrates the gap related to the use of joint mode-choice and shipment-size macroscopic models is still missing from the literature. Thus, an attempt to bridge the gap, this work presents a freight mode choice model that: (i) combines the two decisions related to shipment-size and transport mode; (ii) use the publicly available data to develop an aggregate mode-choice model and (iii) understanding the effect of industry clusters in freight mode selection.

3.4: Data representation and related variables

As shown in (Section 1.6) the primary data source for this research is the Commodity Flow Survey 2012. Also, as shown in (Section 2.3) applying this model on the large dataset such as the CFS using standard commercial software can be challenging. Therefore, in practical applications, a sufficient amount of observations to build a sample is required. Indeed in this model, we are limited by constraints of both
feasibility (that is the appropriate sample size) and time concerns (the reasonable
time for the computer to run the model). As such, we are motivated to extract as
much meaningful information as possible, but it would probably subject the
particular bias results toward the tracking and parcel mode. Methodologically,
(Section 2.3) described the sampling process and software used. The sampling
process precisely occurred in both truck and parcel modes with a total number of
observations for each mode in 100,000 cases, and the rest of the modes in the dataset
remaining the same. Finally, nine modes considered in the study were analyzed with
a total of 300,804 cases.

3.4.1: Summary statistics for related variables

Table 3-2 presents summary statistics for selected attributes related to shipments
characteristics covered by the dataset and industry clusters which have economic
interdependencies between freight transportation modes that highly interconnected
with industry sectors. Notice that the statistics provide general insights but specific
conclusions can only be drawn from the final model developed in (Section 3.6).
Furthermore, these summary statistics should be analyzed delicately from the context
the experiment itself. The following trends are observed in the dataset.

   a) Shipment route distance: the average route distance between shipment origin
and destination utilizing air cargo is highest among all freight modes with
almost 1,300 miles, and it is similar with the combination of truck-rail and
truck-water at roughly 1,300 miles. The average traveling distance by railway
system and parcel services is about (850 miles in average each), followed by other-mode 660 miles, unattached water 460 miles, and truck 320 miles.

b) Shipments the final destination Canada: General statistics indicate that 2.7% of the cases are shipped to Canada, 36% of those shipments are moved by other-mode, 23% by railway, and 13% for both truck-water and air cargo. Freight modes like water cargo and pipeline have the lowest representation among other modes.

c) Shipments the final destination Mexico: barely 0.89% of all observation is shipments occur between the U.S. and Mexico, which is comparatively small to other destination. It is noticed that railway system seems to be the predominated mode with almost half of the observation and railway companies with the truck to reach almost 70% of the total shipments between the two countries.

d) Shipment the final destination other countries: About 12% of the cases are shipments heading to other countries. The geographical impediments of the U.S location prioritizing air shipments by 41% and the combination of truck-rail and truck-water with almost 40%.
Table 3-2: Summary Statistics for Selected Variables for Shipment-Size

<table>
<thead>
<tr>
<th>Variable</th>
<th>Truck</th>
<th>Rail</th>
<th>Water</th>
<th>Air</th>
<th>Pipeline</th>
<th>Parcel</th>
<th>Truck-Rail</th>
<th>Truck-Water</th>
<th>Other-Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
<td>S.D.</td>
<td>Mean</td>
</tr>
<tr>
<td>Shipment characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shipment distance route $^a$</td>
<td>6.8E+03</td>
<td>3.1E+02</td>
<td>5.3E+02</td>
<td>8.4E+02</td>
<td>7.1E+02</td>
<td>6.9E+02</td>
<td>2.0E+02</td>
<td>8.4E+02</td>
<td>1.2E+03</td>
</tr>
<tr>
<td>Destination – Canada $^a$</td>
<td>2.7E-02</td>
<td>4.4E-02</td>
<td>3.0E-02</td>
<td>2.3E-01</td>
<td>7.6E-02</td>
<td>0.0E+00</td>
<td>0.0E+00</td>
<td>1.3E-01</td>
<td>5.8E-02</td>
</tr>
<tr>
<td>Destination – Mexico $^b$</td>
<td>8.9E-03</td>
<td>7.4E-02</td>
<td>2.6E-02</td>
<td>2.6E-01</td>
<td>6.5E-02</td>
<td>2.8E-02</td>
<td>4.8E-02</td>
<td>2.1E-02</td>
<td>0.0E+00</td>
</tr>
<tr>
<td>Destination- Other-country $^b$</td>
<td>1.2E-01</td>
<td>9.9E-03</td>
<td>3.3E-02</td>
<td>2.6E-02</td>
<td>5.4E-02</td>
<td>1.0E-01</td>
<td>1.1E-01</td>
<td>4.1E-01</td>
<td>2.1E-01</td>
</tr>
<tr>
<td>Unitary value of shipments $^c$</td>
<td>6.6E+02</td>
<td>1.1E+01</td>
<td>4.5E+01</td>
<td>5.7E-01</td>
<td>1.6E+00</td>
<td>5.3E-01</td>
<td>3.1E+00</td>
<td>1.2E+00</td>
<td>6.2E+00</td>
</tr>
<tr>
<td>Hazmat shipment $^d$</td>
<td>1.5E-01</td>
<td>4.7E-02</td>
<td>9.7E-02</td>
<td>1.2E-01</td>
<td>1.3E-01</td>
<td>1.7E-01</td>
<td>1.8E-01</td>
<td>1.7E-01</td>
<td>2.6E-02</td>
</tr>
<tr>
<td>Temperature controlled $^d$</td>
<td>1.5E-01</td>
<td>1.8E-02</td>
<td>5.2E-02</td>
<td>8.7E-02</td>
<td>1.1E-01</td>
<td>8.3E-02</td>
<td>3.2E-02</td>
<td>2.1E-01</td>
<td>9.9E-03</td>
</tr>
</tbody>
</table>

| Industry type (NAICS) cluster |       |      |       |     |          |        |            |             |            |
| Raw materials manufacturing | 1.6E-01 | 3.8E-02 | 9.5E-02 | 1.2E-01 | 1.5E-01 | 2.3E-01 | 2.1E-01 | 9.4E-03 | 4.2E-02 |
| Raw materials wholesalers | 3.9E-02 | 1.1E-01 | 6.1E-02 | 3.9E-02 | 3.0E-02 | 5.6E-01 | 1.4E-01 | 0.0E+00 | 2.1E-01 |
| Services-related manufacturing | 1.4E-01 | 1.1E-01 | 6.5E-02 | 5.5E-02 | 3.7E-03 | 2.8E-02 | 3.3E-01 | 1.5E-01 | 2.8E-01 |
| Services-related wholesalers | 2.7E-02 | 8.8E-02 | 4.7E-02 | 2.1E-02 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 3.9E-01 | 9.8E-02 |
| Metals manufacturing | 1.4E-01 | 1.6E-01 | 9.3E-02 | 4.3E-01 | 6.8E-02 | 2.7E-01 | 1.6E-01 | 0.0E+00 | 1.4E-01 |
| Metals wholesalers | 1.1E-01 | 1.7E-01 | 5.5E-02 | 9.8E-02 | 5.6E-02 | 8.7E-02 | 1.6E-01 | 0.0E+00 | 1.5E-01 |
| Agriculture manufacturing | 7.1E-02 | 1.2E-01 | 8.1E-02 | 1.9E-01 | 1.5E-01 | 7.6E-03 | 2.1E-02 | 0.0E+00 | 1.1E-02 |
| Agriculture wholesalers | 9.9E-02 | 7.3E-02 | 8.0E-02 | 7.9E-02 | 2.9E-02 | 1.6E-01 | 1.9E-02 | 4.2E-02 | 2.5E-01 |
| Textile/apparel manufacturing | 2.0E-01 | 8.2E-02 | 1.1E-01 | 2.4E-01 | 2.0E-01 | 3.8E-02 | 8.3E-02 | 8.6E-02 | 6.2E-02 |
| Textile/apparel wholesalers | 3.1E-02 | 3.1E-01 | 1.0E-01 | 1.6E-02 | 2.6E-02 | 3.2E-02 | 3.3E-02 | 2.6E-02 | 6.5E-03 |
| Wood products manufacturing | 2.9E-02 | 2.6E-02 | 8.1E-02 | 2.3E-01 | 7.6E-02 | 0.0E+00 | 0.0E+00 | 5.4E-02 | 2.5E-02 |
| Wood products wholesalers | 6.1E-03 | 2.8E-01 | 4.2E-02 | 5.7E-03 | 2.6E-02 | 0.0E+00 | 0.0E+00 | 3.9E-02 | 1.1E-01 |

S.D.: Standard deviation.
$^a$: Distance in miles. $^b$: Binary variables. $^c$: (S per B.).
$^d$: (NAICS): Based on the North America Industry Classification System

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e) The average value of the shipments transported by air cargo is $400 per lb., in which consider is the highest value among all modes. The parcel services are in the second position by roughly $250 per lb. Then, the average unitary value for truck-related modes, truck, truck-rail, and truck-water, in the best case does not exceed $11 per lb.

f) Hazmat shipment: about 15% of the total freightage are hazardous materials and flammable liquids; slightly more than half of them are transported by pipelines, 17% by maritime, and 12% by the railway system. The rest of the freight modes are carrying portions that almost equally.

g) Temperature controlled shipments: 15% of the entire haulages are associated with some level of temperature-controlled shipment; 32% of them are shipped via air cargo, 21% via truck-rail, 14% via track-water and 11% other-mode, the remaining observations distribute evenly throughout other modes.

h) Raw materials manufacturing: Constitutes approximately 16% of the entire cases. It seems that no predominate mode to transport such shipments, pipelines carry 24%, water cargo 23%, other-mode 19%, and rail 12%.

i) Raw materials wholesalers: Nearly 3.9% of all cases are shipments related to petroleum and petroleum products merchant wholesalers. It is observed that majority of the cases are shipped by maritime 55% and truck 11%.

j) Service-related manufacturing: Constitute about 14% of the total cases. Shipments related to computer, electronic, printing and newspaper most
sensitive to delivery time, in the many cases 33% shipped by air cargo and 28% required parcel services. These modes offer services which potentially related to the minimum time delivery expected.

k) Service-related wholesalers: Constitute almost 2.8% of the observations. Freight modes such as parcel service transported more than 39%, followed by air cargo 23% and other modes as railway, water, and the pipeline are not even an option to transport these commodities.

l) Metals manufacturing group: 27% transported by air cargo, 16% selected parcel services, and truck-related modes such as truck, truck-rail, and truck-water which accounted for 42% of the total shipments.

m) Metals wholesalers: Nearly 11% of the whole observation; trucks selected for 17%, air cargo 16%, parcel 15%, and the combination of truck-rail and truck-water 13% in average each) of its shipments, and the rest of the modes remain relatively constant.

n) Agriculture manufacturing group: Roughly 7.1% of the cases. Noticeably, in the cases of food, beverage and tobacco products the selection of intermodal such truck-water and truck-rail reached 61% of its entire shipments. The higher selection might be related to the utilization of containers.

o) Agriculture wholesalers group: Almost 9.9 % of the observations are shipments related grocery, alcoholic beverage, and farm products merchant wholesalers. Although different modes are utilized to convey them, the
maritime is still the predominant mode with 30% for unattached water and 29% for water combine with the truck.

p) Textiles, apparel, and paper manufacturing: 20% of the observations are shipments related to textile, apparel, leather, plastics and rubber products community.

q) Textiles, apparel, and paper wholesalers: In cases of paper, garments, pieces goods, and miscellaneous goods merchant, in the majority of the cases 32% select truck, 22% required parcel services, and 15% shipped by other-mode, the remaining cases distribute evenly throughout other modes.

r) Wood products manufacturing group: Constitute nearly 2.9% of the whole observations. Remarkably, trucks and rail are the most selected modes, which trucks carried 26%, rail 23% and the combination of truck-rail 22% of its shipments. This is expected, because of the nature of wood manufacturing which required elastic capacity that offered by the selected modes.

s) Wood products wholesalers: only 0.61% of all cases, which is relatively small compared to other groups. It is observed that most shipment carried by specific modes, i.e., truck-water 36%, truck 28%, parcel 25%, truck-rail 10%, rail 0.57% and the rest of the modes out of the scope for this selection.

The following section describes the econometric approach followed to understand carrier selection.
3.5: Methodology and Model Description

There is a significant amount of literature review dealing with choice issues in which decision makers’ choices between a discrete choice set, i.e., transportation mode and a continuous variable, i.e., shipment size. These problems are referred to as discrete-continuous. Freight mode choice is part of a larger joint interaction decision process that includes choice of shipment size. In order to develop a discrete-continuous equation, a structure to link the continuous with discrete components is needed. In the freight conceptual, two distinct approaches have been developed to deal with this phenomenon. (i) The first approach ensures economic consistency, in which implied demand functions is defined by Roy’s Identity. (ii) The second, a reduced form structure, this approach is based on overall utility (decision between shippers and carriers is formulated as joint interaction and some extend base on previous experiences).

Note, that selectivity problems that evolve from interrelated discrete/continuous choices give rise to a challenging econometric problem. In this case, interrelationship involvement as the outcome of one clearly affects the other because of the possibility that the transportation planner makes a choice between transportation mode and simultaneously decides the shipment size to load on the chosen mode. Clearly, then, the two decisions are interrelated since mode choice and shipment size are generated using the same optimization problem, in which considering that the error terms are more probable to be correlated. If this interrelationship between mode choice
(discrete) and shipment size (continuous) is ignored, a specification bias will result in the model estimation. For this reason, we need to model mode and shipment size choice using a discrete-continuous model.

Both are economically consistent and reduce form models have shared widespread use. (Dubin and McFadden, 1984; Hanemann, 1985, 1984; Train, 1986); in early studies applied economically consistent structures. On the other hand, reduced form structure have been used by; (Chiang et al., 1981; Holguín-Veras, 2002; McFadden et al., 1985). In choosing between the two approaches, Mannering and Hensher (1987)’s argue that the economically consistent models relied too heavily on theoretical ground and involved highly non-linear function structures of either demand equations or utility forms, making estimation difficult. On the other hand, the reduced form model is selected in this model, due to being more easily estimated and dispute the relationship between discrete and continuous variables is in general arbitrary.

As described earlier, freight mode choice is part of a larger joint decision process that includes shipment size choice. Building on this insight, this section presents a discrete/continuous equation system, in which it provides the construct to link the discrete and continuous components. A reduced form is the most obvious of the two constructs and the approach is followed in this chapter. Starting with the discrete model is the common way to implement a reduced form. The utility of choice of freight mode can be represented as:
\[ U_{in} = \beta_i X_{in} + \theta_i Z_{in} + \varepsilon_i \]  

(3-1)

Where \( U_i \) = the reduced-form utility associated with the net-benefit from the choice of different transport mode \((i = 1 \ldots I)\) for observation \( n \), \( X_{in} \) = vector of the observable characteristic (covariates) that determines discrete outcomes for observation \( n \), \( \beta_i \) = a vector of estimable parameters associated with \( X_i \); \( Z_{in} \) = the corresponding continuous variables in discrete-continuous modeling system (shipment size), \( \theta_i \) = parameter associated with shipment size; \( Z_{in} \) and \( \varepsilon_i \) = disturbance term accounting for unobserved effects. Let the corresponding continuous equation be the linear function and defined as:

\[ Z_{in} = \varnothing_i W_{in} + v_{in} \]  

(3-2)

Where \( \varnothing_i \) = vector of estimable parameter for continuous variable observed for discrete outcome mode \( i \), \( v_i \) = disturbance term and \( W_{in} \) = is a vector of the observable characteristics (covariates) that determine \( Z_{in} \). Note, to capture the effect of these (varieties) variables, \( X \) includes shipment characteristics, commodity types (NAICS and STAG) and socioeconomic characteristics. This question showed that the shipment size and mode choice depends on the same variables, both in reality with some variables having bearing on the shipment size choice only through their impact on the mode choice process. Consequently, \( Z \) includes all the variables in \( X \) and additional variables which do not come significantly in the mode choice process.
These variables are expected to play a role in the shipment size and ultimately, the freight mode choice. Among the socioeconomic characteristics, the number of establishments and number of employees per establishment is at the origin or destination of the trip. Therefore, these variables affect shipment size only through preferences for different freight transport modes. Finally, equation 2 is estimated using ordinary least squares with appropriate selectivity bias correction.

As indicated by Train (1986) and others, the major concerning issue is estimation bias, which resulted from the correlation between the continuous and discrete choice. To overcome this bias estimation two major approaches are applied. (i) Indirect methods (instrumental variables), in which the different models are estimated with exogenous variables. This first method utilizes the selection correction terms of different (alternative) choices. The instrumental variables techniques has been successfully applied to the discrete-continuous choice model by (Dubin and McFadden, 1984; Train, 1986; Train and Lohrer, 1982). (ii) Direct methods (correction term), in which one considers the (econometric) error terms interaction between continuous and discrete choice model. While the second method utilized a selection correction term of the actual choice, work on the bias correction term began early with (Barnard, 1987; Heckman, 1977, 1976; Hensher and Milthorpe, 1987; Lee, 1983; Mannering and Hensher, 1987; Westin and Gillen, 1978).
This chapter uses a direct methods approach, as described above; more specifically, the two-step estimation method is used. A multinomial logit model of freight mode choice is estimated in the first step, with nine different freight transport modes to examine the determinants of the choice process. On the other hand, the possibility to apply the advanced discrete choice model to overcome the problem of independence of irrelevant alternatives is where most of the selection model suffer from making this approach interesting. While in the second step, we estimate shipment size given the mode choice. Thus, this step includes using standard least-squares regression methods (OLS) simultaneously with aforementioned selectivity-bias correction term.

\[
E(z_n | i) = \beta_i X_n + E(\xi_n | i)
\] 

In the context of correction terms techniques, this approach is implemented by noting that \(E(z_n | i)\) is the average shipment size of observation \(n\) conditional on the chosen freight mode \(i\), \(X_n\) is the vector of observation \(n\) characteristics influencing shipment size, \(\beta_i\) is vector of estimable parameters, and \(E(\xi_n | i)\) is the conditional unobserved characteristics. As mentioned above, the two-step estimation is used to avoid the possible correlation between error terms. Therefore, application of this equation provides consistent estimates of parameter \(\beta\) and bias correction, for one reason that the conditional expectation of \(\xi_n = E(\xi_n | i)\) takes into account the non-random observed shipment size that are selectively biased by commodities self-selection choice of freight mode.
Dubin and McFadden (1984), and Hay (1981) provided the bias correction term to the problem account for multiple discrete choices. Their studies were based on the assumption that the discrete choice is represented by a multinomial logit model. The parameter estimated from the choice model is needed to construct the selectivity correction terms. The probability that freight mode is preferred is given by \( P_i \).

\[
P_i = \frac{\exp^{{t_i}}}{\sum_j \exp^{{t_j}}}
\]  

(3-4)

Then the problem becomes one of deriving a closed-form representation of \( E(\xi_n| i) \) that is used for equation estimation. Dubin and McFadden (1984), and Hay (1981) have shown such derivation in Equation (3-5). Thus, the general specification of the shipment size with the corresponding interaction terms becomes

\[
E(\xi_n| i) = (-1)^{j+1} (\sigma 6 \rho_i / \pi^2) \left\{ \left( \frac{1}{J} \right) \sum_{j \neq i} \left[ (P_j \text{LN}(P_j)) / (1 - P_j) \right] + \text{LN}(P_i) \right\}
\]  

(3-5)

Where \( P_i \) is the probability of discrete outcome, \( J \) is the total number of discrete outcomes, \( \xi \) is the conditional expectation, \( \sigma^2 \) is the unconditional variance of \( \xi \) and \( \rho_i \) is the correlation of \( \xi \) and the resulting from the differencing of \( \epsilon_i - \epsilon_j \). Thus, Equation (3-3) is estimated for each freight mode \( K \) as

\[
z_{in} = \beta_i X_n + \alpha_i \lambda_n + \mu_i
\]  

(3-6)

Where \( \alpha_i = (-1)^{j+1} (\sigma 6 \rho_i / \pi^2) \), \( \lambda_n = \left( \frac{1}{J} \right) \sum_{j \neq i} \left[ (P_j \text{LN}(P_j)) / (1 - P_j) \right] + \text{LN}(P_i) \) and \( \mu_i \) is the disturbance term. We use Equation (3-6) for estimation. (Section 3.6)
gives estimation results for different freight mode specifications based on the Washington et al., (2010) approach, which is commonly used in the literature.

The next section presents and discusses the results of the discrete-continuous choice model, and the marginal effect for section transportation services.

3.6: Estimation results

The main estimation results are based on the discrete-choice econometric model. This section presents the outcome of the estimated standard least-squares model as a part of the freight mode choice selection. Developing shipment size can provide a construct to link the discrete (mode choice) and continuous components (shipment size). Then, the shipment size is computed and discussed for selected variables based on the results of the multinomial logit model.

After several iterations, the ordinary least squares model with appropriate econometric corrections (such as adding a selectivity-bias correction term) represents the best specification for freight modes selection are presented in tables (1 to 9). The software used for model estimation is LIMDEP 10 (NLOGIT 5). Variables in these models are statistically significant and have intuitive signs. Through the model fitting process, several groups of variables were tested. As expected, a wide range of variables influenced the shipment size process. The variables are presented in groups, shipment-characteristics, such as unitary value, shipment route distance, domestic or international destinations, hazmat material, temperature controlled and logistics clusters in which includes industry type (categorized based on NAICS).
Table 3-3 through Table 3-11 present the results from OLS used to quantify the average shipment size in each variable in these models. The shipment size is computed to provide a better understanding of how each variable’s shipment quantity impacts the mode choice process. For better illustration, the intuition and findings related to the model’s variables are presented next.

Table 3-3: Standard least-squares regression model for selection variables in truck mode

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shipment characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>2.9509E+03</td>
<td>2.27E+00</td>
</tr>
<tr>
<td>Correction term.</td>
<td>8.4093E+00</td>
<td>9.12E-01</td>
</tr>
<tr>
<td>Shipment distance route (mi.)</td>
<td>3.5752E+02</td>
<td>1.55E+00</td>
</tr>
<tr>
<td>Final destination Canada (Bin)</td>
<td>9.4705E+03</td>
<td>2.52E+00</td>
</tr>
<tr>
<td>Final destination Mexico (Bin)</td>
<td>3.5571E+03</td>
<td>2.62E+00</td>
</tr>
<tr>
<td>Final destination-other-country (Bin)</td>
<td>2.1897E+04</td>
<td>5.95E+00</td>
</tr>
<tr>
<td>Hazmat shipment (Bin)</td>
<td>3.6365E+03</td>
<td>2.25E+00</td>
</tr>
<tr>
<td><strong>Industry cluster</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw materials manufacturing (Bin)</td>
<td>3.8640E+04</td>
<td>2.45E+01</td>
</tr>
<tr>
<td>Raw materials wholesalers (Bin)</td>
<td>1.5241E+04</td>
<td>5.28E+00</td>
</tr>
<tr>
<td>Metals manufacturing (Bin)</td>
<td>7.8484E+03</td>
<td>5.27E+00</td>
</tr>
<tr>
<td>Metals wholesalers (Bin)</td>
<td>2.7296E+03</td>
<td>2.17E+00</td>
</tr>
<tr>
<td>Agriculture manufacturing (Bin)</td>
<td>1.9365E+04</td>
<td>1.10E+01</td>
</tr>
<tr>
<td>Agriculture wholesalers (Bin)</td>
<td>5.3718E+03</td>
<td>3.37E+00</td>
</tr>
<tr>
<td>Textile/apparel manufacturing (Bin)</td>
<td>9.0621E+03</td>
<td>6.47E+00</td>
</tr>
<tr>
<td>Wood products manufacturing (Bin)</td>
<td>1.2082E+04</td>
<td>5.89E+00</td>
</tr>
</tbody>
</table>

Bin: binary variable. (mi): 100000 Observation
log likelihood: -1.3161E+06
R-squared:-7.8234E-03

3.6.1: Truck mode analysis

Table 3-3 presents the corresponding OLS results used to quantify the average shipment size in truck-related shipments. The overall results are consistent with the
prediction of shipment size optimization theory: shipment size increases with trip distance by $3.5752 \times 10^2$ lb. The trip distance can have a positive effect on shipment size if there are significant economies in truck operation cost, which in turn implies that shipment sizes are larger for longer trips. Looking at international shipment, if the final destination of the shipment is Canada, Mexico, and other countries, on the shipment size increases by $9.4705 \times 10^3$ lb., $3.5571 \times 10^3$ lb., and $2.1897 \times 10^4$ lb., respectively. This result implies that shippers are more likely to choose trucks, especially if they are delivering smaller orders to specific locations. This is expected because the truck is flexible in crossing borders and it is completely suitable for transporting freight over short or long distances. The parameter estimates for selecting truck to carry hazardous materials and flammable liquids are positive and highly significant. This is partly due to the fact that tanker vehicles are designed and usually equipped with better technological capabilities to carry single or multiple loads (often by means of internal divisions in their tank). From the industry type perspective. The effect of cargo density (i.e., the raw material for manufacturing) is significant and increase the shipment size by the $3.8640 \times 10^4$ lb. This is an expected result, because heavier vehicle are more likely to be preferred for dense or bulk cargo. As shown, selecting truck to carry petroleum and petroleum products merchant wholesalers in average increase the shipment size by the $1.5241 \times 10^4$ lb. In conformity with our earlier finding, an increase in shipment size (to carry hazmat shipments) implies a preference for trucks as it maintains a certain level of safety.
rules in their equipment and or operation. The estimates for metals manufacturing and wholesalers show that they are statistically significant, and, on average increase the shipment size by 7.8484E+03 lb., and 2.7296E+03 lb., respectively. This is expected because the truck is more capable of aggregating loads from various commodities for a given trip, which explains the shippers' preference to select truck for these industry clusters. The average shipment size of commodities related to agriculture manufacturing and wholesalers increase with the selection of the truck mode by 1.9365E+04 lb., and 5.3718E+03 lb., respectively. This is expected results because refrigerated vehicles are more likely to be preferred for transporting perishable cargo. The refrigerated trucks offer solution needed to protect the products and maximizes perishable cargo with the variety of sizes and adjusted temperature from single, mid and deep-frozen applications which regulated to transporting such shipments. Commodities-related to textile/apparel manufacturing on average increase the shipment size to reach 9.0621E+03, which implies elasticities the proportionate change in the probability of choosing a vehicle for a proportionate change in the required capacity to transport these shipments. As expected, the estimates for wood manufacturing increase the probability of choosing the truck with average shipments size 1.2082E+04 lb. The truck offers a wide range of features might be required for such shipments, i.e., elastic capacity, equipped with wide variety of equipment and flexibility of heavier vehicles in the field.
### Table 3-4: Standard least-squares regression model for selection variables in rail mode

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>6.3667E+07</td>
<td>3.83E+01</td>
</tr>
<tr>
<td>Correction term</td>
<td>2.1852E+07</td>
<td>4.93E+01</td>
</tr>
<tr>
<td>Shipment distance route (mi.)</td>
<td>2.5703E+05</td>
<td>1.19E+01</td>
</tr>
<tr>
<td>Final destination-other-country (Bin)</td>
<td>2.0233E+07</td>
<td>9.87E+00</td>
</tr>
<tr>
<td>Unitary value of shipment ($ per lb.)</td>
<td>-1.6952E+05</td>
<td>-1.08E+01</td>
</tr>
<tr>
<td>Hazmat shipment (Bin)</td>
<td>6.6298E+05</td>
<td>5.92E+00</td>
</tr>
<tr>
<td><strong>Industry cluster</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture wholesalers (Bin)</td>
<td>2.0216E+05</td>
<td>1.51E+00</td>
</tr>
</tbody>
</table>

*Bin: binary variable.*

38458 Observation

log likelihood: -6.5992E+05

R-squared: 1.4701E-01

### 3.6.2: Rail mode analysis

The estimates from the railway selection model in Table 3-4 were used to estimate the conditional shipment size for each variable that affecting the choose. The result indicated that the shipment size increases 2.5703E+05 as the trip distance increase. Distance, as used here, refers to shipment route distance. Modal shares of freight vary considerably by distance. The rail is the dominant mode by tons and ton-miles of shipments transported between 750 to 2,000 miles USDOT BTS (2017) and FHWA (2017). If the final destination of the shipments is the other countries the average shipment size increases by 2.0233E+07 lb. This is an expected result, the railway transport occupies a significant role in the foreign trade because it facilitates long-distance travel and transport of bulky goods. For instance, shippers have a strong incentive utilized for freight rail to remain competitive in the marketplace due
Its large capacity offers both cost savings and long distance scope for their related shipments. In terms of shipment unitary value, on average, a $1 per lb. increment in shipment unitary value decreases the shipment size in rail-related shipment by 1.6952E+05 lbs. The high capacity, dependable and long travel distance generates a low unitary shipment cost and attracts commodities with low unitary value to use it with large quantities. The railway is the safest mode of transport.

**Table 3-5: Standard least-squares regression model for selection variables in water mode**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shipment characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>7.5849E+06</td>
<td>7.27E+00</td>
</tr>
<tr>
<td>Correction term</td>
<td>2.6293E+06</td>
<td>6.55E+00</td>
</tr>
<tr>
<td>Shipment distance route (mi.)</td>
<td>4.3643E+05</td>
<td>3.36E+00</td>
</tr>
<tr>
<td>Final destination Canada (Bin)</td>
<td>1.1768E+07</td>
<td>3.08E+00</td>
</tr>
<tr>
<td>Final destination Mexico (Bin)</td>
<td>2.1709E+07</td>
<td>7.56E+00</td>
</tr>
<tr>
<td>Final destination-other-country (Bin)</td>
<td>1.0961E+07</td>
<td>1.40E+01</td>
</tr>
<tr>
<td>Unitary value of shipment ($ per lb.)</td>
<td>-1.3154E+05</td>
<td>-1.92E+00</td>
</tr>
<tr>
<td>Hazmat shipment (Bin)</td>
<td>6.3851E+06</td>
<td>7.08E+00</td>
</tr>
<tr>
<td><strong>Industry cluster</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw materials wholesalers</td>
<td>1.5490E+07</td>
<td>6.45E+00</td>
</tr>
<tr>
<td>Agriculture wholesalers</td>
<td>2.9765E+06</td>
<td>4.15E+00</td>
</tr>
<tr>
<td>Textile/apparel wholesalers</td>
<td>1.2754E+07</td>
<td>5.96E+00</td>
</tr>
</tbody>
</table>

Bin: binary variable.
2972 Observation
log likelihood: -6.60E+05
R-squared: -7.37E-01

The chances of breakdowns and accidents are minimal as compared to other modes of transport. This makes it more attractive for hazmat materials, for example, with the average shipment size of chemical manufacturing being 6.6298E+05. It is
observed that the average shipment size for a group of grocery, beer, wine and farm-related products increases by $2.0216 \times 10^5$ lb. Railways are economical and best suited for bulky goods over long distances, in which food cost is maintained low. For instance, there might be a tendency to use articulated containers for transporting food products that complied with transport regulation.

3.6.3: Water mode analysis

Table 3-5 presents’ parameters estimate from a discrete-continuous choice model for the maritime model. The shipment characteristic results indicated that the average shipment size increase by $4.3643 \times 10^5$ lb. as the route distance increase. In fact, the effect of the distance on shipment size associated with the cost of the movement of the ships and the total freight demand. The cost of operation of the water transport is very low, which in turn implies that larger quantities for long-distance trips. From the international shipment perspective, if the final destination is Canada, Mexico, and Other-countries the average shipment size increase by $1.1768 \times 10^7$ lb., $2.1709 \times 10^7$ lb. and $1.0961 \times 10^7$ lb. respectively. This result was expected since haulage firms are more likely to consolidate shipments and ship large quantities throughout the widespread of ports on Pacific coast, Atlantic coasts and the Gulf of Mexico which has had a major impact on all U.S.-international trade. According to the U.S. Census Bureau, water is the leading transportation mode for U.S.-international trade both in terms of weight and value. Ships moved 40.5 percent of trade value and more than 71.7 percent of trade weight in 2016 USDOT (2017). It is
observed that a $1 per lb. an increment of shipment unitary value decreases the shipment size in waterborne freight transportation shipment by 1.3154E+05 lb. The large capacity and low maintenance cost of water transport generate low unitary shipment costs that might attract commodities with a low unitary value. Flammable liquids and hazardous materials on average increase the shipment size related to water transport by 6.3851E+06 lb., as expected, increment might be related to safety measures in which risk of accidents, breakdowns, prevent damage and leaks, are minimum as compared to any other form of transport. This group related to industry clusters, in which water cargo increases the average shipment size by 1.5490E+07 lb. for shipment related to petroleum and petroleum products. In conformity with our earlier mentioned, the widespread availability of ports, high safety and cost-effective mode to move large quantities of goods for long distances, make it more desirable for such shipments. A considerable portion of the bulk cargo such as crude petroleum and petrochemicals moves predominantly through ports. Almost 69.1% of the weight of all domestic and foreign products moved by water in 2014 WCSC (2015). On the other hand, container ports provide a link between the domestic and global freight network, retailers are increasingly dependent on the utilizing the advantages of containers filled with consumer goods to their final destinations. In this regard, the water cargo increases the average shipment size for agriculture wholesalers’ commodities by 2.9765E+06 lb., in which might be related to growth in container trade and improvements in information and logistics technologies. This result implies
that shippers are more likely to choose containers, especially if the shipments are perishable. This is due to the fact that newer containers are usually equipped with better technology capabilities compline with transportation regulation for such shipments. Moreover, the estimates for textile, apparel wholesalers show that it is statistically significant to shipped by water transportation, as expected, of which might be related to the elastic capacity of containers. Note that the advantages of using the container with water transportation not only for damages protection but also largest containerships that afford greater economies of scale and cost savings.

Table 3-6: Standard least-squares regression model for selection variables in air mode

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shipment characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>5.6792E+02</td>
<td>8.63E+00</td>
</tr>
<tr>
<td>Correction term</td>
<td>1.8927E-01</td>
<td>1.25E+00</td>
</tr>
<tr>
<td>Final destination-other-country (Bin)</td>
<td>9.0448E+02</td>
<td>1.07E+01</td>
</tr>
<tr>
<td><strong>Industry cluster</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Services-related manufacturing (Bin)</td>
<td>6.8874E+02</td>
<td>7.60E+00</td>
</tr>
<tr>
<td>Services-related wholesalers (Bin)</td>
<td>6.3159E+02</td>
<td>3.83E+00</td>
</tr>
</tbody>
</table>

Bin: binary variable.
68809 Observation
log likelihood: -7.33738E+05
R-squared: 1.140E-01

3.6.4: Air mode analysis.

Table 3-6 summarizes that if the final destination of the shipment carried by air cargo is other countries increases by 9.0448E+02 lb. This result was expected since the U.S. has borders with few countries, so, few alternatives are available to export products to countries different than Mexico and Canada. Evidently, air cargo is often
used for high-value and low-volume shipments that require fast and reliable shipping. It also offers a large network of destinations, which turned to be more economic for longer distances, and, in many cases, infeasible for shorter distances. The Bureau of Transportation Statistics indicates that air and multiple modes account for 49.8% of the value of shipments moving more than 2,000 miles USDOT BTS (2017b), and FHWA (2017). The operational characteristics of the air mode makes it more attractive for light and high-value commodities. For example, the size of the following shipments in average tend to increase with the probability of selecting air cargo, i.e., printing, newspapers, book, mail-order, computers, and electronics by 6.8874E+02 lb. It appears that those commodities are time sensitive and air transportation provides reliable arrival times, reduced risk damage, security measures, and good handling. On the other hand, the average shipment size of pharmaceutical products shipped by air cargo is also increasing by 6.3159E+02 lb. Air shipping offers the reliability of schedule and special cargo handlers at airports and regulated environment during transporting increase the probability of air cargo for such shipments.

3.6.5: Pipeline mode analysis

Table 3-7 presents parameter estimates form discrete-continues choice model where it is found that a unitary mile increase on route distance between shipment origin and destination largely increase the shipment size carried by pipeline 2.5920E+05 lb.
Table 3-7: Standard least-squares regression model for selection variables in pipeline mode

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>7.0521E+05</td>
<td>1.23E+00</td>
</tr>
<tr>
<td>Correction term</td>
<td>1.8666E+05</td>
<td>1.48E+00</td>
</tr>
<tr>
<td>Shipment distance route (mi.)</td>
<td>2.5920E+05</td>
<td>3.17E+00</td>
</tr>
<tr>
<td>Final destination Mexico (Bin)</td>
<td>3.7813E+08</td>
<td>7.88E+00</td>
</tr>
<tr>
<td>Unitary value of shipment ($ per lb.)</td>
<td>-2.1281E+04</td>
<td>-1.24E+00</td>
</tr>
<tr>
<td>Hazmat shipment (Bin)</td>
<td>1.2935E+07</td>
<td>3.39E+00</td>
</tr>
<tr>
<td>Industry cluster</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw materials manufacturing (Bin)</td>
<td>4.1510E+07</td>
<td>1.49E+01</td>
</tr>
</tbody>
</table>

Bin: binary variable.
3673 Observation
log likelihood: -7.373E+5
R-squared: 7.484E-3

This is an expected result because the pipeline is the most convenient, officiant and economical mode to transport selected liquid commodities. Clearly, certain advantages associated with the pipeline, i.e., a significant reduction in transportation cost, free from obstacles in which it can be laid through difficult terrains, reliable supply, ensure supply in remote areas and non-polluting mode. From the perspective of the international shipment, if the final destination of is Mexico, on average it increases the shipment size by 3.7813E+08 lb. This is a sufficient representation that shows pipeline is a predominant mode in transporting selected products and pipeline expected to enhance the capacity performance. In terms of shipment unitary value, on average, a $1 per lb. increment in shipment unitary value decreases the shipment size in pipeline shipment by -2.1281E+04 lbs. This result was expected since the commodities carried by pipeline is fixed and it’s less likely to select pipeline for
high-value shipment. In average, shipment size related to hazardous materials increases by 1.2935E+07 lb. Several attributes might make pipeline more desirable for such shipments, but all might be associated with the satisfactory safety levels related to this mode (accidents are rare in pipeline transportation). Pipelines are developed to transport the bulk of raw materials such as natural gas and crude oil, which have distinctive and well defined uses. Thus, the average shipment size of several products and economic activities among raw materials manufacturing increased by 4.1510E+07 lb. Intuitively, crude petroleum pipelines are usually the only feasible way to transport significant volumes by land through difficult terrains for long distances. Likewise, almost all natural gas is moved by pipeline by turning it into liquefied natural gas. Even solid materials can also be transported through pipelines from the mines after converting them into the slurry.

3.6.6: Parcel mode analysis.

In Table 3-8, looking at the shipment characteristics results, the average shipment size for parcel service increases with respect to the distance by 1.8624E-01 lb. Although in average distance increases the probability of parcel, its low shipment size might indicates its flexibility for long and short distances. It is observed that the international shipment increases the average shipment size by 2.2393E+00 lb. to Canada 7.3315E+00 lb. for Mexico and 2.8904E+00 lb. for other countries.
Table 3-8: Standard least-squares regression model for selection variables in parcel mode

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.9920E+01</td>
<td>5.55E+01</td>
</tr>
<tr>
<td>Correction term</td>
<td>1.2563E-02</td>
<td>2.23E+01</td>
</tr>
<tr>
<td>Shipment distance route (mi.)</td>
<td>1.8624E+01</td>
<td>3.23E+00</td>
</tr>
<tr>
<td>Final destination Canada (Bin)</td>
<td>2.2393E+00</td>
<td>2.83E+00</td>
</tr>
<tr>
<td>Final destination Mexico (Bin)</td>
<td>7.3315E+00</td>
<td>4.28E+00</td>
</tr>
<tr>
<td>Final destination-other-country (Bin)</td>
<td>2.8904E+00</td>
<td>5.77E+00</td>
</tr>
</tbody>
</table>

| Industry cluster                              |             |        |
| Services-related manufacturing (Bin)          | 5.7259E+00  | 2.94E+01 |

Bin: binary variable.
100000 Observation
log likelihood: -4.7344E+05
R-squared: 1.4260E-02

It is expected because its practicality for direct shipment and express delivery, which make them more attractive for high-value shipments, despite its expensive shipment cost compared to other modes. This also highlights the importance of reliability for shippers, who are willing to pay more in order to avoid delay associated with some freight modes. Parcel services provide features like accelerated deliveries, tracking, signature, and specialization of express services, which are attractive for certain shipments. Thus, printed products, computer, electronic, and newspaper in average increase the shipment size by 5.7259E+00 lb. Almost all of the shipment correlated with delivery time, in the majority of the cases required parcel services which in turn correspond to the average expected. Likewise, utilizing the benefits of door-to-door
 parcel delivery service with the reasonable cost rate, make it more desirable to meet the business needs.

Table 3-9: Standard least-squares regression model for selection variables in truck-rail mode

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shipment characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>8.0344E+04</td>
<td>6.55E+00</td>
</tr>
<tr>
<td>Correction term</td>
<td>7.4007E+02</td>
<td>2.33E+00</td>
</tr>
<tr>
<td>Unitary value of shipment ($ per lb.)</td>
<td>-2.9115E+02</td>
<td>-1.17E+00</td>
</tr>
<tr>
<td>Hazmat shipment (Bin)</td>
<td>4.7706E+04</td>
<td>1.15E+00</td>
</tr>
<tr>
<td><strong>Industry cluster</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw materials manufacturing (Bin)</td>
<td>1.0838E+05</td>
<td>3.80E+00</td>
</tr>
<tr>
<td>Agriculture wholesalers (Bin)</td>
<td>4.0822E+05</td>
<td>8.85E+00</td>
</tr>
<tr>
<td>Textile/apparel manufacturing (Bin)</td>
<td>4.2940E+04</td>
<td>2.06E+00</td>
</tr>
<tr>
<td>Textile/apparel wholesalers (Bin)</td>
<td>1.0483E+05</td>
<td>1.91E+00</td>
</tr>
<tr>
<td>Wood products manufacturing (Bin)</td>
<td>5.0047E+04</td>
<td>1.28E+00</td>
</tr>
</tbody>
</table>

Bin: binary variable.
19070 Observation
log likelihood: -2.9359E+05
R-squared: 5.208E-03

3.6.7: Truck-rail mode analysis

Results from the shipment characteristics show that the unitary value of the truck-rail shipment decreases the average shipment size by -2.9115E+02 lb. Interestingly, although several attributes associated with this combination desirable for high-value shipment transportation, i.e., reliable schedule by rail, fast last mile delivery by truck, among others. As shown earlier the unattached railway is less likely to be selected for precious cargoes and also for truck-rail which might be related to the fixed railway line so only certain areas can be covered. Shipment associated with some level of hazardous materials increases the shipment size with shipment carried by
truck-rail to reached 4.7706E+04 lb. This is expected because the tank car builds with a specification to transport liquid and gaseous commodities and tanker vehicles delivering the last mile, make it more desirable for such shipments. In term of industry clusters, on average increment on shipment size for raw materials manufacturing shipment by 1.0838E+05 lb. The large capacity by railway offers both cost savings and long distance scope which becomes a real attraction for low-value shipments. On the other hand, heavier vehicles are more likely to be preferred for dense or bulk cargo for field handling or last mile delivery for their related shipments. On average, the shipment size for shipment related to agriculture wholesalers increases with selection of truck-rail by 4.0822E+05 lb. The nature of these commodities mostly require utilization of containers and, hence, the increment in shipment size might be with the same intuition mentioned earlier for unattached rail. The mechanized handling of containerization at intermodal facilities from one mode to another or vice versa without handing goods itself commensurate with the nature of these goods for loading and unloading. The parameter estimated for textile, apparel and paper manufacturing and wholesalers are positive and increases the shipment size by 4.2940E+04 lb. and 1.0483E+05 lb. respectively. This is expected because shippers are more capable of aggregating loads for rail cargo, which explains the key benefit for intermodal truck-rail lies in the combination of flexibility provided by trucks, and cost-effectiveness provided by the rail mode. Truck-rail mode is the highest between all modes in transporting wood products by average
shipment size is $5.0047E+04$ lb. This shows the high effect of rail to facilitate wood long distance travel, meanwhile trucks are highly flexible and reliable shorter distances.

**Table 3-10: Standard least-squares regression model for selection variables in truck-water mode**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shipment characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>1.6215E+07</td>
<td>2.30E+00</td>
</tr>
<tr>
<td>Correction term</td>
<td>5.7928E+05</td>
<td>3.38E+00</td>
</tr>
<tr>
<td>Shipment distance route (mi.)</td>
<td>1.2840E+05</td>
<td>1.08E+00</td>
</tr>
<tr>
<td>Unitary value of shipment ($ per lb.)</td>
<td>-2.4825E+04</td>
<td>-1.94E+00</td>
</tr>
<tr>
<td><strong>Industry cluster</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metals manufacturing</td>
<td>5.9084E+05</td>
<td>1.21E+00</td>
</tr>
</tbody>
</table>

Bin: binary variable.
2498 Observation
Log likelihood: -4.2857E+04
R-squared: 4.920E-02

3.6.8: Truck-water mode analysis.

The estimated model in Table 3-10 shows that the shipment size increases with trip distance and total freight demand. As indicated in water analysis, the trip distance can have a positive effect on shipment size when there are significant economics in mode movement cost, which in turn suggests that shipment size are bigger for longer voyages. Therefore, the average shipment size in the distance for truck-water shipment is increasing by $1.2840E+05$ lb. This results was expected since the cost of ship plays a major part in determining what mode are used during any particular leg of a multimodal journey, so, shipper are more likely to select "maritime" to consolidate shipments and ship larger quantities. The negative sign in the model
indicates that average shipment size decreases if selected truck-water. On average $1 increment in unitary value of shipment reduces the shipment size by \(-2.4825E+04\) lb. The line-haul economies of maritime cargo may be exploited for long distances, while the efficiencies of trucks provide flexible local pickups and deliveries which can more attractive for commodities with low-value. On the other hand, the average shipment size of primary metal, fabricated metal, machinery, electrical equipment and transportation equipment manufacturing increase by \(5.9084E+05\) lb. As expected the selection of truck-water increments could be attributed to many advantages, in which mostly high-capacity over long distances associated with water shipments and the flexibility is one of its unique features for the truck regarding delivering to the final destination and volume of goods to be transported. Additionally, commodities related to this group mostly transported by containers, which reveals the importance of handling requirement at intermodal facilities between differences shipments, hence, be more desirable for such commodities.

Table 3-11: Standard least-squares regression model for selection variables in other-mode

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>4.0429E+07</td>
<td>8.20E+00</td>
</tr>
<tr>
<td>Correction term</td>
<td>1.1457E+08</td>
<td>3.45E+00</td>
</tr>
<tr>
<td>Final destination Mexico (Bin)</td>
<td>1.1457E+08</td>
<td>1.87E+00</td>
</tr>
<tr>
<td>Final destination-other-country (Bin)</td>
<td>1.3203E+08</td>
<td>6.51E+00</td>
</tr>
</tbody>
</table>

Bin: binary variable.
1325 Observation
Log likelihood: -2.3959E+04
R-squared: 6.1774E-02
3.6.9: Other-mode mode analysis

The dataset indicates that several modes are categorized as other modes including animal power, belt, conveyor, car, or combinations of modes not previously specified. The international shipment plays a role in average shipment size related to other mode, where the average shipment size increase if the final destination is Mexico by $1.1457E+08$ lb. and $1.3203E+08$ lb. other countries. The shipment size increments could be attributed to the combination of rail and water or ambiguity between more than two modes which evidently can increase trip distance.

The application of the discrete-continuous choice model is illustrated with a numerical example in the next section.

3.7: Numerical Results

This section presents a numerical example to illustrate the methodological framework (discrete-continuous choice model). The numerical experiment is performed to test the selection of freight services. As explained in (Section 2.6) a new set of data required to avoid the selective biased. In this case, each freight mode is presented by 500 observation following the same sampling procedure in (Section 2.3). The utility function which represents the econometric specification of the model estimated through Equation (2-6). The probability $P_i$ of selecting freight mode $i$ is determined by logit formula as shown previously in Equation (2-7).

In this example, since the shipment size is incorporated to understand the freight selection on all regions in the U.S. Thus, the shipment weight is used as the main
input to show how the appropriate freight mode is selected. In the next scenarios, only shipments with distance less than 1000 miles, taken into accounts for understanding the freight mode selection.

![Figure 3-1: Probability of selecting freight for furniture and home finishing company](image)

In this scenario, the shipper considers all available modes to transport furniture and home furnishing form the central facility to different warehousing distributed in the U.S with the main concern which is the shipment weight. In average, the selection probabilities for multimodal, e.g., truck-rail and truck-water seems to be predominant modes for less weighted shipment by 45% and 22% respectively, and heavyweight shipments for 40% and 17% respectively. This is expected might be related to the truck in which over the flexible delivery for first and last miles, and rail and water which are more economic for bulky goods over long distances. The probability of
selecting truck-only obvious for shipments ranging from 22 to 45000 lbs. with more than 35%. The probability of selecting other mode remains constant to almost 12% despite the weight changes. Apparently, the probabilities the selecting unattached rail and water remains the same, with also the absence of air cargo for such shipments as captured in this scenario Figure 3-1.

![Figure 3-1: Selection Probability vs Shipment Weight](image)

**Figure 3-2: Probability of selecting freight for transportation equipment / motor vehicle and parts**

The second scenario related to a businessman looking to transport imported transportation equipment such as motor vehicle and parts from major ports to certain locations within 1000 miles.

Herein, in most ports in the U.S, all freight modes are available for shippers, the average probability of selecting parcel services for shipments weight ranging between 3 to 9 lbs. is about 35%. This might be related to parcel are more practical for direct shipment and express delivery, which are attractive features for high-value
shipments with limited size (vehicle parts). Additionally, the average selection probability for air cargo is almost the same under the same weight. Air cargo offers comprehensive services, i.e., regular schedule, faster handling and door-to-door delivery, which can support the logistics requirement for shipments with high value and less weight. It is obvious from Figure 3-2 that the truck-only is predominated freight mode with almost 40% probability to be selected for shipments weight ranging between 70 to 40000 lbs. In which this is expected, given the availability, reliability and flexibility that truck shipments offer to the shippers, and, in many cases, feasible for short and long distances. On the other hand, as shown in the first scenario the probability of selecting modes such as rail, water, truck-rail, truck-water, and other mode remains constant despite the weight changes.

This shows the importance of considering joint mode choice and shipment size when understanding the freight demand like those required selecting freight services.

The next section summarizes this freight mode choice investigation and its key findings.

3.8: Conclusion and summary

The joint model estimation of logistics choice is interesting in the study of freight transportation. The choice of freight mode and shipment size are among the most critical decisions that are jointly modeled. In this chapter, we have developed a discrete-continuous choice model of freight mode (the discrete choice illustrated as
a multinomial) and shipment size (the continuous model based on dependent variables, measured by pounds per freight mode). Comparable models have been used previously in freight transport, but mainly to study the decision selection at the micro level. As a macroscopic model, we used it to understand the strategic planning related to freight transportation policies and important investments, in which rely on the attempts to improve the understanding of the freight mode desirability for the holistic regions in the U.S.

The data used to estimate the model come from the 2012 CFS - one of the most comprehensive databases of intercity freight movements in the country, which contains information on individual shipment in terms of shipment weight, value, distance, industry and commodity type, etc. The industrial clusters play a significant role in promoting the regional economies in different aspects and it is also utilized to develop regional freight transportation analyses by obtaining holistic conclusion for firms that come from a set of heterogeneous and numerous industry types. Moreover, the aggregation of industry types into logistics clusters is used as additional data source to understand the selection of freight mode at the regional level.

The discrete-continuous model is estimated in two steps. The first step is estimating a multinomial logit model to predict the probabilities of discrete outcome for each observation with different freight mode. The second step is the estimation of shipment size using standard least-squares regression methods. The two step
process takes into account the biased estimation results, since both choices are derived from the same decision problem.

The findings indicated that a set of variables related to shipment characteristics, and logistic clusters are influencing the average shipment size. A continuous model OLS is estimated to determine the shipment size required to finish the mode choice process. A group of variables such as unitary value, route distance, international shipments, hazmat shipment, and temperature controlled shipments are found to be intuitive and have significant signs. Similarly, variables related to industry clusters is required to understand their influence in mode choice at regional freight activities. For example, industrial activities associated with manufacturing and wholesaler for raw materials, service, metals, agriculture, wood, textile, apparel, and papers are also implemented properly in the estimation of shipment size model for the first time.

These insights are important for freight transportation researchers and decision makers in the sense of management and improvement of freight transportation services, which can potentially affect the bottom line of business for shipper and freight transport provider.
Chapter 4: Freight mode choice selection at holistic regions in the U.S. (Approximation of the choice set)

4.1: Introduction

Mode choice is important in shipping commodities efficiently. Many studies have documented the application of mode choice models to explore the relationship between freight service and its contributing factors. Although a large amount of work has been done on different types of models, no research has been conducted to examine the effect of aggregate data with sophisticated econometric techniques for freight mode choice. This work focuses on to simultaneity between data issues and the effect of the discrete choice models competition to understand and analysis the factors influence freight demand. This paper fills that gap by estimating a mode choice model between the most available freight transportation on the holistic regions of the U.S., considering approximation of choice set for different shipments, using mixed logit model and publicly available data CFS 2012. A set of industry clusters are proposed to describe the selection of the freight mode. Different factors which are significantly influence of the mode choice can thus be found. Estimating and identifying those factors are needed to understand the general trend, the behavior of actors in the freight transport market and to forecast transportation flows, and derive elasticities for policy analysis. This is a significant contribution to the literature in transportation, logistics, and supply chain management, and is an aid in understanding this complex process.
The major growth in freight flows has been a characteristic of operational and structural alteration in economic systems at the local, regional, and global scales. Changes in structure largely involve manufacturing systems in terms of their geographic location, while operational changes largely concern the freight transportation. Therefore, the process of model building freight transport is more complex for many reasons: different quality requirements for freight service, quantity and type of data required, and the identification of the actual decision-maker, which itself is not straightforward. On the other hand, the practical solutions thus also have to be optimally compromised among the different interests concerned Dablanc (2007), and Holguín-Veras and Wang (2011). Moreover, Liedtke (2009) indicates that the existing approaches to forecast model share and policy analysis are mainly based on cost optimization, network analysis, and discrete choice model. Consequently, transport of commodities is a major force that drives economic prosperity; thus, it has attracted many interesting researchers from both methodological and empirical standpoints.

This chapter presents a macroscopic model that useful to explain the sum of many individual behavior decisions. This work to improve understanding in this area by assessing freight mode desirability for aggregated regions, commodities, and economic activities. Motivated by the gaps in the literature (Subsection 1.3, 1.4, 1.5, and 1.6). This model contributes to previous research by (1) for the first time introduced the multinomial logit model with random parameters, using aggregated
data that covers all-region in the United States. (2) Developing an aggregate model that overcomes the limitations of choice set approximation. In which a framework for the freight choices set for each shipment (choice set approximation) that contain only the possible and feasible freight alternatives.

The remaining sections of this chapter are organized as follows: Section 4.2 begins with a review of the pertinent literature by focusing of freight mode choice developed worldwide and those inside the U.S. Section 4.3 describes the dataset used in the model estimation and focuses attention on the choice set approximation, in order to investigate the available freight alternatives in each CFS zone. Section 4.4 presents the econometric approach followed in this chapter. Section 4.5 presents the model estimation to examine shipment characteristics and industry clusters and discusses the analysis that allows us to exploration of the variables’ influence on freight selection. Section 6 in the last section of the article, concludes the work and highlights the key findings.

4.2: Freight mode choice modeling.
As shown in (Section 1.5), the freight mode choice model has been studied by discrete choice models are reviewed. More details information about such models is also provided in (Section 2.2.) The few models analyze freight mode choice decisions used general mixed logit model inside or outside the U.S in this literature are reviewed next.
Freight transportation demand has been widely studied by transportation researchers to understand the decision-making related to freight patterns or carrier selection. A number of studies on the subject of the model types (e.g., Oum, 1979; Harker, 1985; Strong et al., 1996; de Jong et al., 2004; Nuzzolo et al., 2015) mainly focus on the model types that have been developed since the 1990s at the national and international level in European areas. Earlier, Gray (1982) provided a review of behavioral models, and highlighted the importance of identifying the decision makers in the freight demand modeling processes; the review examines empirical studies undertaken in Australia, Canada, the United Kingdom, and the U.S. Tavasszy (2008) describes the major lines of the freight demand model that have developed outside the U.S., and several innovations were identified, including logistics behavior, freight economy linkages, among others. Recent works that have studied these issues mainly reviewed freight forecasting models and current advances and needs with respect to model development and data combination Chow et al., (2010). Finally, De Dong et al., (2013) provide a review of the European literature on freight transport models that operate at the national or international level and that have been developed since 2004. However, limited attention has been paid to reviewing the existing freight demand modeling in the U.S. To the best of the authors’ knowledge, there is no work that reviews and identifies the freight econometrics research, in particular that uses discrete choice framework and current status of models, and that
estimates the shipper’s attributes which drives freight service selection in this context exclusively.

In an attempt to address the limitations of the MNL model, a number of researchers recognized that, in virtue of its (IIA) property, it imposes potentially unrealistic limitations on the nature of the mode choice. In an effort to address this problem, Jiang et al., (1999) proposed the use of a (NL) model, which separated all for-hire freight mode that assembled among the same nest from an own-mode. Holguín-Veras (2002) and Norojono and Young (2003) utilized the Heteroscedastic Extreme Value (HEV) model that has been used in a number of freight model applications of relaxing another restricted assumption of the MNL model. Moreover, there are a number of models in which the probability of being chosen is the result of integrating logit probability functions over parameter density factions such as Kernel Logit Walker and Ben-Akiva (2002), and Hybrid Logit Ben-Akiva and Bierlaire (1999). Consequently, a number of more flexible model structures have been introduced in the literature to relax the IID assumption, such as heteroscedastic extreme value (HEV), generalized extreme value (GEX), hierarchical logit, or mixed logit Bhat (2002). The mixed logit model solves the main limitations of the MNL and NL models. Therefore, the mixed logit model is a highly flexible model that is used to approximate any random utility model McFadden and Train (2000). There are certain published studies of the freight transport choice process utilizing the MNL model with random parameters as a tool to analyze the shipper preferences.
Kim (2002) estimated two versions of the MNL model with random parameters, with SP data for the mode choice in the freight flow across the Channel Tunnel between the UK and Europe. The models showed their superiority over traditional logit and the relevance of taste variations.

Feo-Valero et al., (2011) analyzed the viability of maritime logistics chains in the Motorway of the Sea of South-West Europe. The inland leg of Spanish containerized maritime freight shipments was analyzed using the mixed logit model. They conducted a stated preference (SP) survey showing an improved intermodal maritime transport in competition with 100% road services. The model estimation involved three variables: transport cost, reliability of delivery time, and transit time.

Hensher et al., (2013) collected data in Australia in 2010-2011 obtained from a stated choice experiment for freight mode choice. They used mixed logit models for estimations to understand the behavioral responses in the potential change in the demand for heavy vehicle demand using a particular class of vehicle on a particular route, as price and access regimes changed.

Arencibia et al., (2015) used advanced choice modeling techniques (mixed logit model) to analyze demand for freight transport in a context of model choice in Pyrenean corridors of Madrid (Spain). The SP survey was conducted in order to estimate freight shipper preference for main attributes to determine the service offered by the various transport modes. The model provides interesting results which
can be utilized to analyze the potential diversion of the traffic from the road, to alternatives such as rail and maritime.

Bergantino et al., (2013) have analyzed the factors determining the choice behavior of Sicilian road truck carriers using the mixed logit model. To achieve the objective, the mixed RP/SP survey was conducted. The authors created guidelines to develop intermodal freight in hypothetical scenarios when shipments face transshipment-related models with respect to three alternatives: road transport, road with transshipment at logistic terminal, and RO/RO road-sea transport. The model provides useful information for policy-makers to improve the regional freight mobility system in Italy.

Arunotayanun and Polak (2011) dealt with shippers’ mode choice behavior by investigating the prevalence of observed and unobserved variables influencing the selection. The study is based on SP data collected in Java, Indonesia. The discrete choice (mixed logit) models were used to analyze the data which was capable of accommodating random variables among three alternatives, e.g., small truck, large truck and rail way, characterized by different attributes, e.g., flexibility, time, cost and service attributes (defined in terms of various levels).

Larranaga et al., (2017) used the discrete choice model (mixed logit model) to identify the preference of freight attributes for the case of Rio Garnde do Sul in Brazil. A stated preference survey technique was conducted to collecting the data on respondent’s choice among hypothetical options. Three alternatives of freight
transport were considered: road, intermodal considering rail, and intermodal considering waterway, and four attributes described each alternative: transport time, total cost, on-time delivery percentage and deliveries delayed percentage. The results discussed some possible sustainable policies that could increase the competitiveness in the region, with Brazil freight movement mainly based on road transport.

Brooks et al., (2012) examined the Australian domestic freight transport market, focusing on the competitiveness of short sea services. The mixed logit model is used to make mode choice allocation decisions between land-based transport and coastal shipping. The report results of a stated choice experiment identifies and quantifies freight shippers' preferences for components of services offered by freight transport, such as transit time, frequency of departure, reliability, freight distance, freight distance, direction (head haul/backhaul), and delivery window.

All of these works have emphasized the importance of the discrete choice model, e.g., mixed logit model, to fully explain freight agents’ mode choice behavior. They have demonstrated that the mixed logit model can be systematically related to attributes of the shipments and characteristics of the operators (freight mode). Based on those findings, we conclude that the previous models share the role of disaggregate data in understanding the mode choice in the freight industry focusing directly on surveys collected, based on SP/NP and their underlying factors. However, many of these studies did not consider all available freight modes as alternatives in the mode choice selection, but usually specified the comparison between certain
modes, and none of them studied the choice of freight service using aggregate data and analysis by the most sophisticated model, such as mixed logit model exclusively.

In relation to freight transport, notwithstanding the availability of modeling tools, research taking into account mixed logit model to analyze the choice behavior in the U.S. among shippers is, with a few exceptions, still limited.

A pioneering study on the application of mixed logit models to the freight industry are those works related to willingness-to-pay for service. The work of Puckett et al., (2011) used data from survey questionnaire 2008 administered via internet, focused on frequency data in the Atlantic Canada-US Eastern Seaboard market, and developed mode choice models integrated factors related to frequency of departure of freight transport services to link the attribute of the market in terms of price and travel time. The study offers an empirical advancement in the analysis of the competitiveness between truck and short sea shipping. In addition, Mesa-Arango and Ukkusuri (2014) investigate the selection of trucking services by shipper and the shipper willingness-to-pay. A state choice experiment (SCE) survey collected a set of pragmatic attributes to describe features of the trucking service offered by carriers. A discrete choice mixed logit model is estimated to test the attributes and random parameters that allow the consideration of the various tests among respondents and unobserved factors affecting the utilities of the various alternatives.
This chapter adds to the existing research by exploring the mode choice selection by incorporating logistics clusters in the U.S regions. It explores in the previous research the core of the model developed for mode choice in the U.S., using surveys for collecting disaggregated data. It is important to note that a discrete choice mixed logit model was incorporated as a tool to analyze the choice behaviors, which allows considering mixed tests between alternatives and correlation in unobserved factors to be used. Generally, industry clusters are considered to aggregate heterogeneously, and numerous industry types follow well-structured approaches that are economically consistent for cost-effective transportation services, and facilitate access to various freight modes and efficient logistics that enhanced the comparative advantages of the regions. However, there was no discussion about the effect aggregated attributes have on the mode choice process. The corresponding dataset for all regions of the United State also was not considered. The present work exclusively studies freight mode selection by employing the industry clusters relevant to all the available freight modes covering the holistic regions of the U.S.

The choice set approximation method advanced discrete choice model (MNL model with random parameters) are also incorporated, which dramatically facilitates the analysis and understanding of freight mode choice for aggregated data.

More details on the data and context of the limitations are provided next.
4.3: Data description and experimental design

4.3.1: Commodity Flow Survey datasets

The aim of this research is to obtain empirical evidence on the determination of mode choice among several alternatives. The mode choices are 100% road transport (truck and rail), maritime (inland, great lakes and deep sea), air, pipeline, parcel (USPS or courier), combination of truck-rail, truck-water and rail-water and other-mode by decision-makers that require freight service in the holistic regions in the U.S.

As shown in (Section 1.6) that commodity flow survey is one of the most comprehensive and public databases on regional freight movements in the US. Moreover, as shown before, in (Section 2.3) in which describe the challenging and limitation associated with the data as any freight related study. Thus, these potential problems associated with freight data most be understood when constructing and using freight models (Giuliano et al., 2006; Holguín-Veras et al., 2002; Southworth, 2003). The research fills a void in the existing literature by focusing on national freight movement modeling and data issues, and explicitly investigates problems associated with data in freight-based mode choice models. Thus, aggregate data are usually available but generally not sufficient for behavioral freight modeling efforts. Miller (1999) reported that due to data limitations and to facilitating computational tractability, national and regional freight demand models frequently employ diverse aggregated geographic representations.
The CFS suffers from certain series of limitations described previously but, additionally, the data neither provides sufficient information related to available freight mode in the CFSs, nor the alternative freight modes for each shipment. Thus, analyzing this data based on the hypothesis that all freight modes are available, will lead to inaccuracies in freight patterns selection.

4.3.2: Empirical choice set approximation

In the limitations described previously, each shipper is asked to consider a set of hypothetical freight modes and all shipments share the same set of hypothetical carriers. The CFS data shares only information about the selected mode and does not mention the details about the set available freight modes for each shipper. Therefore, understanding the choice set for each shipment is required, and the choice set should be contained within the feasible freight alternatives. Thus analyzing this data based on the hypothesis that all freight modes are available, and without proper understanding of the shipping patterns available in each CFS Area of shipment, will lead to inaccuracies in freight patterns selection; for example, the trucks mode for shipments to countries outside of North America and Central America is included in the choice set, though using this freight mode is impossible. On the other hand, the water mode for shipment which originates in land-locked locations will be allowed. If impossible modes are included in the choice set, it will lead to biased parameter estimates. When limitations are explicitly considered, a selective approach is needed to approximate the choice set for each CFS area of shipment of origin and destination.
This chapter presents a unique method for preference information intended to create the formation of the choice set, and a subjective choice set for each individual shipment, from which the final alternative is selected. Since a certain number of freight transport alternatives is available for any individual shipment, the choice set has to be formulated on the basis of some principles to form a feasible and relevant set of routes between the origin and destination. The efficiency and relevance of these procedures require precise data on observed modes to compare the consistency between the actual shipment moved and the generated choice set.

The approximation of choice set for the freight mode choice model includes truck, water, rail, air, pipeline, parcel, truck-rail, tuck-water, rail-water and other-mode. The attributes taken into account are origin and destination of shipment, industry classification NAICS, commodity code SCTG, geographic distance between origin and destination, shipment size, and unitary value of commodity. In the study described in this chapter, the attributes are divided into two groups. For origin and destination, NAICS and SCTG are used as the existing networks to generate the choice set for an individual shipment. In the process, only those variables are considered as fixed, so the choice set was bound to change for every individual. Therefore, variables related to shipment size, geographic distance and unitary value of each commodity was given 0.05% tolerance to accommodate all possible freight modes in the surrounding CFS area. Moreover, explicit tolerance is especially needed in an approximation of the choice sets for many reasons. For
example, the size of the shipment decides the potential mode, so the closest sizes will possibly share the same available carriers. Also, the related difference of geographic distance between observations gives an indication about the available modes in the CFS area. This strongly rules out the hypothesis of using the route distance because each mode follows a certain route, like a fixed route for trains.

After several steps, the choice set procedures that present the best specification for freight mode alternatives available for shippers. The software used for the approximation of the choice set is MATLAB R2014b. The complete dataset of 4,534,071 million observations were processed. Thus the approximated choice sets are meaningful and have a reasonable number of available freight modes. The number of freight modes in each individual choice set varies between two modes, three modes, and four modes. The in comparison with hypothetical choice set that is commonly used in freight mode choice model, in which all alternatives are available for each shipment, the approximation of choice set is not easily definable. The ultimate goal of the estimation purposes is that the choice sets contain a reasonable number of alternative freight patterns in order to obtain a reliable estimated model.

4.3.3: Industry clusters

As shown in (Section 2.3), the group of industry types described in the 2012 CFS is segmented by industry clusters depending on the taxonomy developed by Mesa-Arango and Kumar (2017). Consequently, in new industry clusters are (1) allowed to facilitate the analysis and to clearly understand freight mode-choice, (2) useful for
accessibility to different freight modes, cost-effectiveness, and logistics efficiency. This work incorporated the same industry clusters with an approximation choice set to understand the selection of freight services in the holistic regions in the U.S.

The following summary statistics are based on the commodity flow characteristic and industry clusters presented on Table 4-1.

Table 4-2 presents the summary statistics for the selected variables related to shipment characteristics and industry clusters covered by the datasets including all available freight modes. Notice that the statistics provide general insights, but the specified conclusion can only be drawn from the model developed in (Section 4.5). On the other hand, the obtained general statistics should be analyzed accurately based on the experiment itself. Moreover, the analysis will not affect the results of the subsequent model.

It is observed that the average route distance between the origin and destination of the shipment by truck is roughly 560 miles; meanwhile, for the modes which mostly carry light shipments, i.e., air cargo and parcel, the average distances are 1142 miles and 681 miles, respectively. The average route distance for modes which are mostly a combination of two modes that are used to travel long distances, such as truck-rail, truck-water, and rail-water, are 626 miles, 841 miles, 390 miles, respectively. These results show that in many long distance destinations, the selected mode might be the only option, in terms of commodity type, shipment size and final destination, so these shipments are excluded from the choice set approximation.
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</table>

Std.D.: Standard deviation
*: Binary variable
*: Manufacturing activities
$: Wholesalers activities
Considering the unitary value of the shipments, as expected in the majority of the cases, the average value of the air shipments is $1731.48 per lb., followed by parcel at $808.78 per lb. This indicated that shippers select services that correspond to the average time expected. Although some shippers prefer fast service, average times are more desirable because they are related to the nature of those services operations. On the other hand, the average value of the shipment for rail, water, and rail-water modes have almost similar values of rail $0.696, water $0.531 and rail-water $0.142. In general, this suggests that shipments with low-value and high-weight are more attracted to those modes. On the other hand, the value of shipments carried by truck-rail and truck-water ($7 on average each), might be related to truck handling the last mile for any high-value shipments.

About 4.30% of the total observations are hazardous materials; 41% of such records are transported by truck, which might be because truck offers large fleets that are more available for reliable service, and 25% are relocated by pipeline, which might be safer than other modes, with truck-rail and parcel at 10% average for each.

The general statistic shows that 3.8% of the record are regular temperature controlled shipments. As expected, shippers tend to select modes they have had the most satisfactory experiences with. Remarkably, truck and truck-rail are the most selected modes, with 46% and 25%, respectively. This results tell shippers that quality of service offered by truck is a very important aspect in the current business,
and customer satisfaction for various services offered by traditional truck make it more desirable for both short and long distances combined with rail.

About 1.3% of the total shipments have Canada as the final destination. Almost 31% of those are shipped via truck, 25% via parcel, 18% via air cargo, 16% via rail and 10% via truck-rail, and the remaining freight modes neither have small margins, nor are not an option for this destination.

Likewise, almost 0.90 % of the total observations have Mexico as their final destination. It is observed that truck and rail are the dominant modes with Mexico as the final destination. They are carrying almost 72% of the cases, which might be related to the long land border between the U.S and Mexico, hence, make the ground shipment more desirable. The remaining observations distributed evenly throughout other modes.

Nearly 12% of all cases are shipments heading to other-country, which is relatively high compared to other destinations. It is observed that air cargo and parcel service have priority with 26% and 24% respectively, over other modes, which is associated with the geographical locations of obstacles of the U.S. It is also noticed that truck carried considerable portions with nearly 20% that might be related to the shipment going to Central America via Mexico.

In general, 9% of the total observations are raw materials for manufacturing-related activities, 43% of which is transported by truck, followed by 20% by rail, and 20% by other-mode. In many cases, trucks offer a large fleet and certain attributes of
the service in combination with the characteristics of the shipments. The remaining observations distribute evenly throughout the other desirable freight patterns.

Only 0.84% of the total cases is shipment related to raw materials wholesalers. Remarkably, pipeline mode carries almost 90% of these shipments. Some other modes are also used to convey them, but the average does not exceed 10% total.

The service-related manufacturing constitutes almost 20% of the entire observations. In shipments related to printing, computers, electronics, and newspapers, the average delivery time is critical due to the nature of the commodities. It is expected that parcel transported 45% of those followed by truck 36%, and air cargo at 15%. The complete door-to-door service associated with parcel and truck might prioritize them over the rest of the desired modes.

The general statistics shows that about 4% of the total cases are service-related wholesalers, with 46% transported by air cargo, 36% by truck, and 17% selected parcel services.

Metals manufacturing groups constitute nearly 12% of the entire observations. There is a trend to select modes with high-capacity over long distances, i.e., truck 37%, truck-water 28%, water 14%, other-mode 13%, and rail 10%.

About 21% of the total cases are metals wholesaler’s activities. Interestingly, truck and water carried most of the shipments, which constitutes nearly 83% of the entire shipments.
Activities related to agriculture manufacturing form nearly 7% of the total observation. There is a trend to select truck at 44%, truck-rail at 35% and unattached rail at 16%. It is expected because their heavily used containers might make them more desirable.

Agriculture wholesalers groups constitute roughly 4% of the observation. Although different modes are utilized to convey them, the truck and rail are still the predominant mode with 87%.

About 18% of the total cases of shipments are related to textile, apparel, and paper manufacturing.

Shipments related to textile, apparel, and paper wholesalers make up nearly 0.34% of the total observations, with truck selected for 46%, parcel for 35%, and the rest of the mode remain relatively constant.

Wood products manufactures represent almost 2% of the observations. Truck-water is the highest among all modes in transporting wood at 32%, followed by truck at 31%, rail at 20%, then by truck-rail at 16%. It is expected, because water and rail are more economical and best suited for bulky commodities over long distances.

Wood products wholesalers hardly represent 0.31% of the entire observation, which remains the smallest group in the entire dataset. It is observed that specific modes are utilized to transport them such as truck at 50%, parcel at 31%, truck-rail at 18.6% rail at 0.4%, and in many cases the rest of the modes are not even an option to carry these shipments.
The proposed method to analyze those data is presented next.

4.4: Econometric approach

As shown in the (Section 2.4) the mixed logit model is considered to be the most promising state of the art discrete choice model currently available. Increasingly researchers and practitioners are estimating mixed logit models of various degrees of sophistication, in which it allows for random taste variation, unrestricted substitution patterns and even correlation in unobserved factors over time, which is particularly useful when dealing with SP or panel data. It is a very flexible model that can approximate any random utility model with total precision. In which motivates the development of a model to understand the freight mode choice. The model structure is described in (Section 2.4).

4.5: Estimated Results

This section presents the results for estimated discrete choice model, i.e., MNL model with random parameters for the selection of freight mode in entire regions in the U.S., considering industry clusters retrieved from the publicly available data 2012 CFS. Then, the marginal effects associated with this decision are computed and discussed.

The estimation for the entire process involved different stages: First is the estimation of classic MNL. After several iterations the estimated model showed the best specifications for mode choice selection presented in Table 4-2. The available variables present satisfactory overall fit and are significant with intuitive signs.
Table 4-2: MNL with Random Parameters for Fright mode choice: Truck only (base utility)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Truck</th>
<th>Rail</th>
<th>Water</th>
<th>Air</th>
<th>Pipeline</th>
<th>Parcel</th>
<th>Truck-Rail</th>
<th>Truck-Water</th>
<th>Rail-Water</th>
<th>Other-Mode</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Coeff t-stat</td>
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<td>Shipment characteristics</td>
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<tr>
<td>Constant</td>
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<td>-8.8E+00</td>
<td>-1.5E+00</td>
<td>-4.2E+00</td>
<td>-4.3E-01</td>
<td>-1.2E+00</td>
<td>-1.2E+00</td>
<td>-2.1E+00</td>
<td>-1.1E+00</td>
<td>-4.1E+00</td>
</tr>
<tr>
<td>Shipment distance route (mi.)</td>
<td>-1.7E-04</td>
<td>-5.4E-01</td>
<td>6.2E-04</td>
<td>1.9E+00</td>
<td>2.3E-04</td>
<td>5.0E-01</td>
<td>3.7E-03</td>
<td>1.5E+00</td>
<td>1.9E-04</td>
<td>6.3E-01</td>
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<tr>
<td>Unitary value of shipment ($ per lb.)</td>
<td>3.7E-03</td>
<td>4.4E+00</td>
<td>6.7E-03</td>
<td>4.2E+00</td>
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<td>1.2E+00</td>
<td>1.2E+00</td>
<td>2.1E+00</td>
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<tr>
<td>Hazmat (flammable liquids) (Bin)</td>
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<td>-1.2E+00</td>
<td>1.5E+00</td>
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<td>-1.2E+00</td>
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<td>2.0E+00</td>
<td>3.8E-05</td>
<td>6.1E-01</td>
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<tr>
<td>Temperature Controlled (Bin)</td>
<td>-3.5E+00</td>
<td>-1.2E+00</td>
<td>1.5E+00</td>
<td>2.2E+00</td>
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<td>2.2E+00</td>
<td>1.1E+00</td>
<td>2.2E+00</td>
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<tr>
<td>Final destination Canada (Bin)</td>
<td>-1.3E+00</td>
<td>-1.2E+00</td>
<td>1.5E+00</td>
<td>2.2E+00</td>
<td>-1.1E+00</td>
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<td>1.5E+00</td>
<td>2.2E+00</td>
<td>1.1E+00</td>
<td>2.2E+00</td>
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<tr>
<td>Final destination Mexico (Bin)</td>
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<td>1.5E+00</td>
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<td>-1.2E+00</td>
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<tr>
<td>Raw Materials manufacturing(Bin)</td>
<td>3.6E-01</td>
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<td>1.0E+00</td>
<td>1.8E+00</td>
<td>1.2E+00</td>
<td>1.6E+00</td>
<td>1.2E+00</td>
<td>2.4E+00</td>
<td>2.4E+00</td>
<td>2.2E+00</td>
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<td>1.4E+00</td>
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<tr>
<td>Services-related manufacturing(Bin)</td>
<td>1.1E+00</td>
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<td>5.5E-01</td>
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<tr>
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<tr>
<td>Metals Wholesalers(Bin)</td>
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<tr>
<td>Textile, apparel, and paper(Bin)</td>
<td>5.6E-01</td>
<td>4.0E+00</td>
<td>7.5E-01</td>
<td>1.3E+00</td>
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<td>Wood products Wholesalers(Bin)</td>
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</table>
| Bin: Binary variable. (NAICS) North America Industry Classification. Notation: $a \pm b = a \times 10^{b}$ Log likelihood at convergence = -13696.20 Log likelihood at zero = -9887.51 Adjusted $r^2 = .6993894$ Random parameters normally distributed and estimated with 200 Halton draws.
Table 4-3: Marginal Effects for Attributes in the (MNL) Model for Freight Mode-Choice.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Truck</th>
<th>Rail</th>
<th>Water</th>
<th>Air</th>
<th>Pipeline</th>
<th>Parcel</th>
<th>Truck-Rail</th>
<th>Truck-Water</th>
<th>Rail-Water</th>
<th>Other-Mode</th>
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<tbody>
<tr>
<td>Shipment characteristics</td>
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<tr>
<td>Shipment distance route (mi.)</td>
<td>-6.94E-02</td>
<td>6.75E-01</td>
<td>1.22E-02</td>
<td>1.91E-02</td>
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<td>1.06E-02</td>
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<tr>
<td>Unitary value of shipment ($ per lb.)</td>
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<td>1.31E-02</td>
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<td>6.17E-01</td>
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<td>1.06E-02</td>
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<td>Hazmat shipments (Bin)</td>
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<td>-2.17E-02</td>
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<td>-1.16E-02</td>
<td>-1.74E-01</td>
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<td>2.24E-02</td>
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<td>Destination-Mexico (Bin)</td>
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<tr>
<td>Destination-Other-Country (Bin)</td>
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<td>1.28E-01</td>
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<tr>
<td>Raw Materials manufacturing (Bin)</td>
<td>3.1E-01</td>
<td>4.08E-02</td>
<td>1.14E-02</td>
<td>5.34E-02</td>
<td>2.98E-02</td>
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<tr>
<td>Raw materials Wholesalers (Bin)</td>
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<td>6.50E-03</td>
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<tr>
<td>Services manufacturing (Bin)</td>
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<td>1.02E-01</td>
<td>5.21E-02</td>
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<tr>
<td>Metals manufacturing (Bin)</td>
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<td>Metals wholesalers (Bin)</td>
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<tr>
<td>Textile/apparel manufacturing (Bin)</td>
<td>5.77E-01</td>
<td>2.42E-02</td>
<td>1.37E-01</td>
<td>2.95E-01</td>
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<tr>
<td>Textile/apparel wholesalers (Bin)</td>
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<td>Wood products wholesalers (Bin)</td>
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</table>

Bin: Binary variable.
The estimated variables are divided into shipment-characteristics (i.e., shipment value, route distance, international shipments, temperature controlled and hazardous material transported) and industry clustering (shipments-related to manufacturing and wholesalers activates presented in Table 4-2. Notice that shipment size was excluded from the set of variables in order to avoid the selectivity-bias problem affecting mode-choice and shipment size. The second stage is testing random parameters. Again, after several testing’s the MNL model with random parameter that represent the best specification for freight selection is presented in Table 4-2. The variables in the final model are significant and have intuitive signs. Notice, that random parameters follow normal distribution. The software used for this model estimation is LIMDEP 10 (NLOGIT 5).

Table 4-3 presents the marginal effects, used to quantify the effect that a unitary change in each variable has on the mode choice probability. The MEs are computed to provide a better understanding on how each variable impacts freight mode choice.

\[ \chi^2 = -2[LL(\beta_R) - LL(\beta_U)] \]  \hspace{1cm} (4-1)

The likelihood ratio test statistic is presented in Equation (4-1) used to test the overall significance of the MNL model with random parameters \(LL(\beta_R)\) over the corresponding classic MNL model \(LL(\beta_R)\). From the model estimation, the corresponding log-likelihood functions at convergences are\(LL(\beta_R) = -6733.165\) and \(LL(\beta_U) = -6897.109\). Therefore, \(X^2 = 327.888\)
The chi-squared = 327.888 is distributed with two degrees of freedom (two more parameters estimated in MNL with random parameters, i.e., standard deviation of random parameters). Therefore, with at least a 99.9% level of confidence, the MNL can be rejected, and the MNL with random parameters is preferred.

The intuition and findings related to the variables in the model are presented next.

**4.5.1: Shipments characteristic**

This first group of variables related to the commodities characteristics is indispensable for any freight transportation analysis.

Distance is one of the main attributes driving the choice of freight mode and has either a negative or positive effect on the mode selection probability. So as the distance increases the probability of selecting certain modes increases or decreases. From the marginal effects computed in Table 4-3, it is observed that the 1 mile increment in route distance, on average, increases the probability of selecting combination of rail-water by almost 1.96%, followed by truck-rail by 0.42%. The key benefit for rail and water in this is combination is the flexibility provided for international trade, due to cost-effectiveness for long-distance compared with other freight patterns.

The parameter for unconnected rail is random. Random effects indicate that 53.69% of the observation have rail probability increments, and 46.31% of the rail selection reductions, but at different scales (normal distributed). The rail selection
increment could be attributed to many advantages, including high speed over long distances, larger capacity, and less cost in respect to the distance.

Similarly, the parameter for air cargo is random. Random effects indicate 51.80% of the observations have air cargo selection probability increments, and 48.20% of selection probability decrements, both at different scales (normal distributed). Although, in average, distance increases the probability of air cargo, and its marginal difference in the scales might indicate its flexibility for long and short distances alike.

Also, the parameter associated with the truck mode is random. On average, selection probability of the truck with respect to distance decreases by 0.070%. Random effects indicate 48.17% of observations have truck selection probability increments, and 51.83% of truck selection decrements, both at different scales (normal distributed). Although the small reduction in truck selection for long distance seems counterintuitive, companies might be aware of the hazards associated with long driving under different conditions which increases their level of accidents, which might allow them to take precautionary action in avoiding the unfortunate cases of accidents. Likewise, the shipping cost associated with trucks can increase significantly with respect to distance and make it less desirable. This is supported by a report from the U.S Department of Transportation USDOT BTS (2017) indicating that trucks carry 60.0 percent of the weight of all goods shipped in the United states and is the predominate mode for shipments under 750 miles.
The unitary value of the shipments is the other attribute which contributes significantly in determining the freight pattern. The unitary value of the shipments is captured by the ratio of shipment value to shipment weight. This variable has a negative effect for maritime cargo selection probability. On average, a $1 per lb. increment in unitary value decreases the selection probability by 0.028%. The high capacity and long transit time of maritime cargo generates low unitary shipment costs that might attract commodities with low unitary value. Notice that the weight incorporates characteristics of the shipments that are useful when analyzing different types of logistics activities.

On the other hand, unitary increments in unitary values on average increase the probability of selecting air cargo 0.013% and parcel services 0.012%, respectively. The parameter for selecting air cargo is random. Random effects indicate 51.89% of the observation have air cargo selection probability increments, and 48.11% of selection probability reduction, both at different scales (normally distributed). Several attributes might make these modes more desirable for high value shipments. Air cargo and parcel services are more practical for direct shipment and express delivery, which are attractive features for high-value shipments. Additionally, these freight patterns provide comfortable, efficient, and fast transport service by avoiding delays in obtaining clearance. It is regarded as the best mode of freight for transporting mail and light and costly cargo.
Shipments contain hazardous materials required freight mode compliance with safety regulations in their operation system. On average, hazardous shipments decrease the probability of selecting air cargo by 0.023%. Several reasons might make air cargo undesirable to carry such shipments. For example, the high manipulation associated with this mode might be unsafe for hazmat deliveries, and flammable liquids cases are expected to be high risk for both passengers and airlines alike, and might also be prohibited to transport by air cargo.

It is observed that temperature-controlled shipments on average decrease the probability of selecting rail 0.180%, truck-rail 0.175%, and air cargo 0.016%. Rail might not have the equipment to maintain these products with a pre-defined operating temperature range during the transporting process, and hence, be more undesirable. Certain measuring procedures might reduce the probability of selecting truck-rail and air cargo to transport such shipments, in which the condition of load, unloading, and handling equipment are the key characteristics of the transport operations process; thus the high manipulation and surrounding environment during service exchanges between freight modes and individuals might be a greatest risk or hazard to an acceptable level of temperature control. Additionally, fixed storage systems, such as cold rooms and refrigerators required for those modes during exchange and unloading, might be another restriction. Generally speaking, the shipper is responsible for ensuring product temperature compliance during transport. Refrigerated and temperature-controlled transport services are often supplied by a
third party service provider specializing in such transport. Moreover, the service may be monitored directly by the national public health system.

The presence of an international shipment, if the final destination is Canada, tends to decrease the probability of selecting rail by 0.046% under this condition. The United States and Canada share a long land border, which might greatly reduce dependence on using the railway system which is related to inflexibility because its routes and timings cannot be adjusted to individual shipments. In contrast, the desirability of selecting air cargo increases by 0.023%. The higher ME for air cargo might be related to its widespread availability and scope, as compared to railway transportation. It is, therefore, accessible to all areas regardless of the obstruction of land. However, if the final destination is other-country, air cargo still desirable 1.30% in which might be similar with intuition indicated earlier. The presence of freight patterns have high-capacity over long-distance, on average increasing the probability of selecting truck-rail 1.35% and maritime cargo 0.069%. Despite the restricted geographic location of the U.S, the combination of truck-rail still is an option to facilitate long-distance shipping. It might be related to shipments to Central America through Mexico. Maritime tends to be more attractive for international segments and water transport plays an important role in foreign trade, since the cost of operation is very low over long distances.
4.5.2: Industry clusters

The second set of variables are related to industry clusters, in which commodities-related to industry type is aggregated into logistics clusters that help in understanding and analyzing the selection of freight mode.

Shipments related to raw materials manufacturing tend to select freight modes with high-capacity, due to the nature of these commodities. On average, the probability of selecting railway increases 0.31%. Railway transport is economical, faster and best suited for carrying heavy and bulky goods over long distances. On the other hand, the probability of selecting water and water-truck on average increases 0.041% and 0.054% respectively. Some advantages might make these freight patterns more desirable. For example, water can carry much larger quantities of heavy and bulky goods, it provides much more flexible service than railways, and it can be adjusted to individual requirements; moreover, trucks are highly flexible and reliable for shorter distances. Interestingly, other-mode tends to be preferred for carrying raw materials. On average, the probability of selecting it increases by 0.030%. Despite other-mode consisting of a mixture of transport patterns, it is still ambiguous which mode is most suitable for these shipments, which might be due to a combination of more than two mode, i.e., truck-rail-water, truck-water-truck, etc.

Raw materials wholesale group increase the probability of selecting pipeline by 0.007%. Intuitively, pipeline is a predominant mode in transporting petroleum
products. It is clear that pipelines are the most convenient, efficient and economical mode to transport selected liquid commodities, which are safer than other modes.

Perhaps the most important issue that businesses concern about time delivery. A company’s adherence to delivery dates is an essential factor that decides the success of the company in an industry. This attribute has a positive effect in freight mode selection probability. On average, the probability of selecting air cargo to carry printing, computer, electronic, and newspaper increases by 1.20%. Air cargo offering faster deliveries services are preferred due to the nature of these commodities. On the other hand, the probability of selecting railway and rail combined with truck to transport these shipments increase by 0.086% and 0.052%, respectively. Fixed delivery, might reduce negative conditions associated with delay to make truck-rail and rail more desirable for such shipments. High speed and fixed schedules associated with railway are expected to enhance the service performance and increases reliability, which may reduce the delay frequency. Additionally, truck provides features like shipment tracking and door-to-door delivery that are desirable attributes for these shipments.

The parameter for service-related wholesale is random. On average, it increases the probability of selecting air cargo by 0.015%. Random effects indicate 54.37% of the observations have air cargo selection increments, and 45.63% decrements, both at different scales (normally distributed). Air cargo increments could be attributed to both the exporting and the importing of pharmaceutical products. Air cargo provides
clear instructions to the handling, and transport requirements, which is required by law for drugs and druggists wholesale. Any pharmaceutical products storage and transport should comply with time and temperature-sensitivity, within predefined environmental conditions and/or within pre-defined time limits, or it is degraded to the extent that it no longer performs as originally intended TCTO WHO (2015).

Metals manufacturing commodities favor selecting freight mode with larger-capacity and serving routes that are regular for shippers. On average, the probability of selecting unattached rail is 0.32%, followed by truck-rail and truck-water (0.001% on average each). Rail transportation improves travel time with consistent schedules. Its large capacity offers both cost savings and long distance scope for their related shipments. Similarly, the increments of selecting truck-rail and truck-water might be due to the line-haul economies of those freight patterns and may be exploited for long distances, while the efficiencies of trucks provide flexible local pickups and deliveries.

Interestingly, metals wholesalers tend to select single mode, such as rail and water, to transport its commodities. On average, the probability of selecting railway system increases by 0.23%, and maritime cargo by 0.065%. Both modes are suitable for transporting heavy and bulky goods, and they mostly utilize containers which vary in size, and, hence, reduce negative conditions, in term of damages and transport cost.
It is observed that rail and truck-rail are the predominant freight modes for agriculture manufacturing and wholesalers. On average, increases the probability of selecting rail 0.09%, and truck-rail 0.12%. On the other hand, modes like water, air, truck-water or other-mode are not even feasible to transport those commodities. Rail offers consistent and reliable schedules for production and distribution, and is the main mode for large quantities of low value-per-ton goods, in which food cost is maintained low. The high ME for truck-rail might be due to quality of shipping containers, in which the shipping systems (container) consists of a combination of insulated material for temperature stabilizing. These containers can keep the internal contents of the package within a specified temperature range for a pre-defined period of transport, without reliance on mechanical assistance. On the other hand, in average the probability of selecting truck-rail for carrying agriculture products related to wholesaler increases by 0.055%. The same intuition for selecting rail and truck provides features like shipment tracking and door-to-door delivery that are desirable attributes for these shipments.

Commodities related to textiles, apparel, and paper manufacturing and wholesalers tend to select freight mode offering flexible capacity and faster deliveries. On average, the probability of selecting freight mode increases proportionally to the amount of the time associated with a shipments’ delivery. The probability of selecting rail cargo for manufacturing increases by 0.58%, and for wholesalers by 0.22%, which might be related to its fast and more regular form of
transport, and thus, its dependence and less influenced by weather conditions, in which the most preferred among freight pattern for industrialization process. The probability of selecting truck-rail is in the second position by 0.30%, since the intermodal process might affect the delivery time and capacity alike. Maritime cargo is in the third position with increments of 0.024%. It is a slow means of transport, which is considered suitable for products with long lead times. On the other hand, the high probability of selecting pipeline by 0.14%, might be related to the chemical manufacturing. This is sufficient representation that shows pipeline is a predominant mode in transporting hazmat products, and might be associated with the satisfactory safety levels related to this mode (accidents are rare in pipeline transportation).

The truck-rail system is more desirable for on carrying wood products compared to other freight patterns. The probability of selecting the truck-rail to transport wood products during manufacturing and wholesaler increases by 0.028% during manufacturing, and 0.013% during distribution. The increments could be attributed to the many advantages this intermodal has over the rest of freight modes. Despite the large capacity of the railway its, capacity is elastic and can easily be increased by adding more wagons. Flexibility is one of unique features of the truck in terms of first carrier from field to intermodal terminal or final destination and volume of goods to be transported after manufacturing.
4.6: Numerical Results

This section presents numerical results for the model formulated defined above. This hypothetical example used to illustrate the application of MNL model with random parameters that presented in (Section 2.6). (Section 1.3) discussed the importance of incorporate non-monetary variables in freight mode choice and (Section 2.3) illustrated the limitation associated with the data such as absence or unrevealed of some mode-specific characteristics, e.g., transport time, cost, and total demand per year, among others. Therefore, the numerical example in (Section 2.6) utilized shipment distance to understand the mode choice selection, and (Section 3.7) used shipment weight for the same purpose. In this section, the shipment value will be employed for the same reason to show the importance of non-monetary attributes that constitute strong support to understand the choice of freight modes.

![Figure 4-1: Probability of selecting freight for textile / apparel / leather manufacturing company](image-url)
In this scenario, the shipper of textile, apparel, and leather manufacturing company asks for transportation service from different resources (nation and international) to certain factories and considered that all freight modes are available Figure 4-1. In this case, the average selection probabilities for parcel services are almost 40% for shipments their value per pound between: 1 to 17 ($ per lb.) and reduces dramatically to reach less than 10% with higher value shipments. Parcel services provide features like accelerated deliveries, tracking, and specialization of express services, which are attractive for certain shipments. Moreover, the selection of air cargo remains relatively constant, which might refer to the effects of other attributes like distance, shipping cost, package weight, among others. It is observed that the desirability to choose the unattached rail and truck-rail increases with increasing the value per pound to reach 40% and 20% respectively for specific shipments. Rail transportation offers consistent schedules and its large capacity offers both cost savings and long distance scope for their related shipments in which can keep the manufacturing cost as low possible. The selection probability reached 20% for truck-only for shipments their between: 1 to 40 ($ per lb.) and disappeared for higher value shipment. The effect of travel cost and weight associated with the truck can be obvious. On the other hand, despite the high capacity and international shipment associated with water and truck-water their selection probability still constant with these shipments.
The final scenario is for a company manufacturing paper products, which requires understanding the suitable freight modes which align with the nature of its shipment. The major concerns of the company are the distance of shipments in which includes sources form out of the State. The company tried to comprehend and interpret the selection based on the unitary value of commodities to make its product competable on the markets. It is observed in Figure 4-2 that the average selection probabilities for unattached rail mostly remains constant between: 30% to 40% despite the changing of the unitary value of the shipments. This is might be related to nature of the shipments in which usually shipped in large quantity with low value that compatible with advantages of rail transportation. In this scenario, track-only is desirable for shipments their unitary value between: 0.6 to 2.0 ($ per lb.), and hence,
be more undesirable for higher value shipments. On the other hand, the average selection probabilities with respect to unitary value remain constant with 4% for the water, 3% for air cargo, 9% for the parcel services, 4% for truck-water and 3% for other mode. Additionally, the selection probability fluctuated for both pipeline and truck-water, in which might be related to the effect of other factors such as shipment weight, and direct distance.

The following section focus on the key findings from the proposed method.

4.7: Conclusion

This chapter investigates the selection of freight services to transport commodities in holistic regions in the U.S. The publicly available data, 2012 CFS (as relates to all geographic regions), is used for this analysis to understand the complexity of the selection process. The proposed choice set approximation method has been used to aggregate the available freight mode in each CFS TAZ’s, to avoid estimating modes which are not feasible freight alternatives. A set of variables related to shipment characteristics and industry clusters which encompass the firms’ related activities and freight transportation into logistics clusters are utilized to understand the mode choice selection are proposed. A discrete choice framework offers a powerful means of analyzing trade-offs made by shippers in their choices of preferred freight transport strategies, enabling researchers to quantify behavioral measures of strategic and policy interest. The estimation of random parameters in this model allows the consideration of mixed tests among alternative freight modes and unobserved
variables influencing the selection. Several variables of the shipment characteristics are found to be significant in the choice. Furthermore, there are new findings associated with the effect of industry clusters on mode choice which add novel insights on the freight mode-choice process. Marginal effects are used to rank the importance of shipment attributes and industry clusters with respect to the freight mode selection probability.

Thus, this chapter makes a significant contribution to the literature by addressing a line of research that has largely been neglected in the U.S: (1) studying the effect of industry clusters with more advanced discrete choice to clearly understand freight mode choice with aggregate data, (2) test the approximate choice set to eliminate unavailable freight alternatives, which might drive the estimation toward certain freight patterns, and (3) provide a discussion on how these attributes affect mode choice.

The findings are of significant importance for freight transportation, logistics, and supply chain management. The findings of this study provide a timely contribution to the management and improvement of services in freight transportation. Characteristics like route distance, unitary value of shipment, international shipments, temperature control, among others discussed in the chapter, have differential impacts on mode choice. Likewise, the desirability of multiple industry clusters for specific transportation alternatives are clearly supported by statistical and econometric methods. The chapter also enriches freight literature by
indicating the role played approximating choice set related to mode choice at the regional level, which aims to reduce the challenges faced by aggregate data.

Decision makers can use the results from this model to better understand freight mode selection and the key components driving this decision. For public agencies at the local and national level, such models are necessary for certain critical policy issues, such as highway construction or intermodal facility planning, while regional and/or metropolitan areas need the model to solve problems such as warehouse distribution, among others. Private sectors also can benefit from these findings by understanding the significance of freight modes to certain commodities and industrial activities which can be the center of their interest for determining industry location or transport for new materials.
Chapter 5: Conclusion

5.1: Summary, finding, and contributions

This dissertation develops freight aggregate models to understand how shippers select freight transportation modes in the U.S. This is a challenging task driven by three distinctive elements: (i) shipper preferences, (ii) actors and attributes involved into the choice process, and (iii) analytical methods based on nature of dataset. The main motivations for this dissertation are presented below.

This study is motivated by real-world implementation of freight mode choice in the U.S., in which government agencies and private sectors can improve transportation services and tackle the certain critical policies problem. It has also provided significant savings for both shippers and carriers. More benefits for both public and private sectors is explained in (Section 2.1). Likewise, freight mode choice improves inefficiencies in asset utilization, e.g., reduced empty trips and unused capacity with using logistic clusters. Furthermore, new paradigms are proposed to improve modeling gaps found in previous literature. The important findings obtained from this research are presented next.

5.2: Findings

Mode choice is a very interesting problem that deserves more attention form the research community. Improvements in this direction can significantly benefit
shippers, carriers, and society. However, this is not an easy task because the freight mode choice problem involves addressing hard transportation planning problems.

Furthermore, modeling this complex interaction demands a good detailed and a better understanding of the relationship between carriers and shippers, behavior, and operation. Despite the fact that in many cases is easy to find a problem that is complex and interesting for the academic perspective, meanwhile, it does not mean that such a problem is relevant in practice. This dissertation narrows the gap in the literature by paying special attention to these details and combining tools that provide a better quality solution given the demanding complexity of the problem.

Understanding behavior is very crucial to study the interaction among agents in transportation systems. Thus, "economic rationality" in many cases is commonly assumed in models where agents always take the most economic decisions, e.g., the cheapest options. This assumption has gradually relaxed in passenger paradigms and it is erroneously believed that firms involved in freight interactions are exclusively driven by monetary incentives. This dissertation finds that although missing some important attributes, e.g., travel time and shipment cost among others to determinant the attractiveness and selection of freight services, there are other behavioral attributes influencing this decision. This research reports a rigorous econometric exercise that supports this behavior and corroborated statistically.

Likewise, literature has a great number of models that postulate complete and idealistic information for operational decisions. However, transportation entities
mostly operate in different environments usually surrounded by uncertainty, which is commonly relaxed in transportation models. This dissertation recognizes the importance of such issues, effects for decision making, and develops models that properly handle them. Those advance models are important to take decisions when information is ambiguous or incomplete.

In addition to these general findings, several specific research contributions result from this dissertation.

5.3: Contributions

This work expands and improves the current knowledge in transportation research with higher impact in the area of freight and logistics modeling. There are a number of contributions related to each objective met in the dissertation.

- **Objective 1.** Utilize the 2012 Commodity Flow Survey data which covers all regions in the U.S to overcome the data-availability issue in any freight-related study.

  Chapter 2 meets the objective and contributes to the literature by developing an aggregate model for freight mode choice that covers all regions in the U.S at the same time overcome the data limitation to understand the shipper choices.

- **Objective 2.** Aggregate the industries into economic clusters by employing a well-structured and economically consistent approach to aggregate multiple heterogeneous industry types into industry clusters.
Chapter 2 meets this objective. It combines the set of industry types available in the 2012 CFS to derive the logistic clusters following the taxonomy developed by Mesa-Arango and Kumar (2017). This pragmatic structure for logistics clusters not only plays an important role in promoting regional economies, but also incorporated to understand the selection of freight patterns for the first time.

- **Objective 3.** Develop a framework for the freight choices set for each shipment (choice set approximation) to contain only the possible and feasible freight alternatives.

  This objective is met in Chapter 4, where a choice set approximation for each shipment is proposed and is a contribution to the literature itself. This framework drives the feasible alternatives among available freight modes to overcome the limitations described that each shipper is asked to consider a set of hypothetical freight modes and all shipments share the same set of hypothetical carriers.

- **Objective 4.** Understand shipper preferences toward freight-modes selection using econometric analysis.

  This objective is met in Chapter 2. As contributions, this chapter provides a comprehensive understanding of shipper preferences, postulates a set of pragmatic attributes to explain freight mode selection, and provides meaningful discussion and guidance for shippers and carriers based on
behavioral inferences. The developed model is a macroscopic model to understand the effect of shipment and characteristics, logistics clusters on mode choice for regional level using advanced econometric approaches.

- **Objective 6.** Develop a model for freight mode choice in an aggregate model that considers shipments-characteristics including shipment size, logistics clusters, and set of freight transportation modes.

  The latter contribution are expanded in Chapter 3, where the objective is met by incorporating shipment size into the freight mode choice process using discrete-continuous choice model.

- **Objective 7.** Develop a model for freight mode choice in aggregate model that considers shipments-characteristics, logistics clusters, set of freight transportation modes, and choice set approximation.

  Chapter 4 meets the objective and contributes to literature developing an aggregate model to understand the influence of the shipments characteristics and logistics clusters on selection of transportation services, with considering the approximation of choice set related to the data.

- **Objective 8.** Demonstrate the economic benefits of the aggregate model required for strategic planning in the development of certain regions in relation to freight transportation investments and policies.

  This objective is met in Chapters 2, 3, and 4, demonstrating these benefits as research contribution.
These contributions are elaborated on top of relevant and meaningful works developed by many researchers in the past. Likewise, there are several opportunities to expand and improve the work proposed in this dissertation. These extensions are summarized and presented next.

5.4: Future research directions

The following future research directions are identified and proposed as extensions and improvements of the current work.

- Although there is sufficient variability and a large number of observations for all available freight transport modes, future research can significantly benefit from a larger sample. This would allow the incorporation of additional variables from the public and private datasets, to refine and support the results.

- Similarly, the amount of the current dataset is extremely helpful, the large amount of observations related to the CFS motivates the development of future efficient algorithms and methodologies that can handle big freight data for mode-choice analysis.

- The numerical results show that the multinomial logit model with a random parameter has performance-well in describing the effected attributes. So improvements can estimate of other sophisticated econometric approaches, e.g., Nested logit model.
• Exploring additional variables not captured in the models. Practically, this work constitutes an initial step to integrate variables related to socioeconomics at the regional level. Incorporating socioeconomic variables and other socioeconomic variables, e.g. income, regional GDP, annual payroll, revenues, land-use occupancy, etc. would improve the understanding of the relationship between freight demand and socioeconomic activities.
Reference


Train, K., 1986. Qualitative choice analysis: Theory, econometrics, and an
application to automobile demand. The MIT Press, Cambridge, MA.


### Appendices

A-1: Summary of input, output, and outcome associated with each model

Table A-1: The specific applications of the estimated models

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Model</th>
<th>Input</th>
<th>Output</th>
<th>Outcomes</th>
<th>Methodological Improvements</th>
</tr>
</thead>
</table>
| Chapter 2 | Multinomial logit model with random parameters | -Shipment characteristics  
Industry cluster | -Probability of selecting freight transport mode. | Public sectors: to assess the existing services, and evaluate infrastructure.  
Private sectors: to forecast demand for transport services. | Based model: understanding mode selection and effect of logistics cluster. |
| Chapter 3 | Discrete-Continuous choice model               | -Shipment characteristics  
Industry cluster | -Shipment size  
-Probability of selecting freight transport mode | Shipper: to understand the suitable freight mode and quantity to be shipped.  
Carriers: jointly determined the magnitude of commodities to be transported.  
Government agencies: predict future transport requirements for both people and goods in order to allow such a movement.  
Companies: understanding the significance of freight modes to certain commodities and industrial activities. | -Understanding the joint decision.  
-To overcome bias estimation which resulted from the disturbance correlation of discrete and continuous equations. |
| Chapter 4 | Multinomial logit model with random parameters | -Shipment characteristics  
Industry cluster  
Choice set approximation | -Choice set for each shipment  
-Probability of selecting freight transport mode | Public agencies: to plan successfully for investment in infrastructures such as highway maintenance and construction, and intermodal facility, among others.  
Public agencies: at the local and national level, such models are necessary for certain critical policy issues.  
Private sectors: to anticipating factories locations, and commodities mobilization, or transport for new materials. | -Using choice set to overcome the data limitations when available modes not mention.  
-To avoid inaccuracies of selecting freight patterns due to the hypothesis that all freight modes are available. |
A-2: Specific examples of application of each model

A-2-a: An applied example of the model in chapter 2

An example shows the application of the MNL with random parameters in selecting freight mode based on the model developed in chapter 2.

This example about farm product raw material merchant wholesalers (Cereal Grains) required freight service from Minneapolis-St. Paul, CFS Area Minnesota (MN) to New Orleans-Metairie, CFS Area Louisiana (LA). Table A-2 provides more details about the shipment used.

Table A-2: Numerical example: attributes of cereal grains shipment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Unit</th>
<th>Value</th>
<th>Variable</th>
<th>Definition</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>Shipment distance</td>
<td>Miles</td>
<td>1598</td>
<td>X11</td>
<td>Services-related wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X2</td>
<td>Unitary value</td>
<td>$ per lb.</td>
<td>0.12</td>
<td>X12</td>
<td>Metals manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X3</td>
<td>Final destination Canada</td>
<td>binary</td>
<td>0.00</td>
<td>X13</td>
<td>Metals wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X4</td>
<td>Final destination Mexico</td>
<td>binary</td>
<td>0.00</td>
<td>X14</td>
<td>Agriculture manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X5</td>
<td>Final destination other-country</td>
<td>binary</td>
<td>0.00</td>
<td>X15</td>
<td>Agriculture wholesalers</td>
<td>binary</td>
<td>1.00</td>
</tr>
<tr>
<td>X6</td>
<td>Temperature control shipment</td>
<td>binary</td>
<td>0.00</td>
<td>X16</td>
<td>Textile/apparel manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X7</td>
<td>Flammable materials shipment</td>
<td>binary</td>
<td>0.00</td>
<td>X17</td>
<td>Textile/apparel wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X8</td>
<td>Raw materials manufacturing</td>
<td>binary</td>
<td>0.00</td>
<td>X18</td>
<td>Wood products manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X9</td>
<td>Raw materials wholesalers</td>
<td>binary</td>
<td>0.00</td>
<td>X19</td>
<td>Wood products wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X10</td>
<td>Services-related manufacturers</td>
<td>binary</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Equation (2-6) defines the average utility function $U_i$ associated with freight modes $i \in \{\text{Truck (T), rail (R), water (W), Air (A), pipeline (P), parcel (PA), truck-rail (TR), truck-water (TW), and other-mode (OM)}\}$. In this case, the constant for each mode $i$ and the estimated parameters $\beta_i$ associated with each attribute in which presents the econometric specification of the model are obtained from Table 2-4.

Equation (A-1) is used to understand the computing of utility function for rail mode.
In this equation placing the parameters from Table 2-4 into it to get the utility function for rail mode.

\[ 1.316_{rail} = (-1.52) + (1.78 \times 10^{-3} \times 1598) - (1.82 \times 10^{-2} \times 0.12) \]
\[ + (2.05 \times 0) + (4.36 \times 0) + (8.42 \times 10^{-1} \times 0) \]
\[ - (2.86 \times 10^{-1} \times 0) + (1.12 \times 0) + (1.69 \times 0) + (1.85 \times 0) \]
\[ + (9.13 \times 10^{-1} \times 0) \] (A-1)

The probability \( P_i \) of selecting freight mode \( i \) is determined by logit formula presented in Equation (2-7).

Equation A-2 shows how to compute the selection probability of rail mode based on the utilities related to rest of the freight modes.

\[ (0.1028_R) = \frac{e^{1.315_R}}{e^{0.07_T} + e^{1.315_R} + e^{-1.275_W} + e^{-11.770_A} + e^{0.191_P} + e^{1.474_PA} + e^{2.355_T} + e^{2.355_TW} + e^{0.888_OM}} \] (A-2)

After computing the probability of selecting rail mode the same steps will be followed to computing the probability of selecting: truck, water, air, parcel services, pipeline, truck-rail, truck-water, and other mode. The constants and parameters will be getting from Table 2-4 to compute the utility function for each mode. Then place those utilities to get the probability for each mode as shown in equation (A-2).

After finished computing all probabilities associated with all freight modes the results indicated that on average the selection probabilities are 2.76% for truck, 10.28% for rail, 34.97% for water, 0.77% for air cargo, 0.01% for pipeline, 3.34% for the parcel, 12.05% for truck-rail, 29.11% for truck-water and 6.71% for other mode. High preference for water and truck-water might be attributed to the
combination of the large capacity offer by water in which provide low prices and long distance scope for this shipment, and last mile delivery by truck. On the other hand, the location of these cities on the banks of Mississippi River makes these modes more practical option.

**A-2.b: An applied example of the model in chapter 3**

A numerical example is presented to illustrate the application of discrete-continuous choice model and its importance for both shippers and carriers.

A shipment is selected randomly from the dataset and used to understand the application of this model. The shipment related to chemical manufacturing (fertilizers) in which required transport from New Orleans-Metairie, CFS Area Louisiana (IN) to St. Louis-St. Charles, CFS Area Missouri (MO). More details information about this shipment is shown in Table A-3.

**Table A-3: Numerical example: attributes of machinery shipment**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Unit</th>
<th>Value</th>
<th>Variable</th>
<th>Definition</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>Shipment distance</td>
<td>Miles</td>
<td>1097</td>
<td>X11</td>
<td>Services-related wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X2</td>
<td>Unitary value</td>
<td>$ per lb.</td>
<td>0.27</td>
<td>X12</td>
<td>Metals manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X3</td>
<td>Final destination Canada</td>
<td>binary</td>
<td>0.00</td>
<td>X13</td>
<td>Metals wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X4</td>
<td>Final destination Mexico</td>
<td>binary</td>
<td>0.00</td>
<td>X14</td>
<td>Agriculture manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X5</td>
<td>Final destination other-country</td>
<td>binary</td>
<td>0.00</td>
<td>X15</td>
<td>Agriculture wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X6</td>
<td>Temperature control shipment</td>
<td>binary</td>
<td>0.00</td>
<td>X16</td>
<td>Textile/apparel manufacturing</td>
<td>binary</td>
<td>1.00</td>
</tr>
<tr>
<td>X7</td>
<td>Flammable materials shipment</td>
<td>binary</td>
<td>0.00</td>
<td>X17</td>
<td>Textile/apparel wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X8</td>
<td>Raw materials manufacturing</td>
<td>binary</td>
<td>0.00</td>
<td>X18</td>
<td>Wood products manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X9</td>
<td>Raw materials wholesalers</td>
<td>binary</td>
<td>0.00</td>
<td>X19</td>
<td>Wood products wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X10</td>
<td>Services-related manufacturers</td>
<td>binary</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Since this model is a joint decision between mode-choice and shipment-size. In developing discrete/continuous equation systems, a construct to link the discrete and continuous components is required. If this interrelationship between mode (discrete) and size (continuous) is ignored, selectivity bias will result in the statistical model estimated to predict shipment size. One of the most popular approaches to resolving selectivity-bias problems is to develop a selectivity-bias correction term. Thus, the selectivity bias in discrete/continuous models is corrected by undertaking the following three steps:

1- Estimate a multinomial logit model (MNL) to predict the probabilities of discrete outcomes mode \( i \) for the each observation.

In this case, the constant for each freight mode \( i \) and the estimated parameters \( \beta_i \) associated with each attribute are obtained from Table 2-4.

2- Use the logit-predicted outcome probabilities to compute the portion of Equation (3-5) in large brackets (\( \{ \cdot \} \)) for each observation.

In order to compute the probabilities, the utility function is required. Equation (2-6) defines the average utility function \( U_i \) associated with freight modes \( i \in \{\text{Truck (T), rail (R), water (W), Air (A), pipeline (P), parcel (PA), truck-rail (TR), truck-water (TW), and other-mode (OM)}\} \). The constants for each mode \( i \) and the estimated parameters \( \beta_i \) associated with each attribute are obtained from Table 2-4. Equation (A-3) is used to comprehend the computation of utility function for water mode.
\[-0.209_{\text{water}} = (-1.69) + (1.35 \times 10^{-3} \times 1097) - (1.68 \times 10^{-2} \times 0.27) \\
+ (1.48 \times 0.0) + (2.40 \times 0.0) - (2.76 \times 0.0) + (2.39 \times 0.0) \\
+ (2.63 \times 0.0) + (2.56 \times 10^{-1} \times 0.0) + (7.51 \times 10^{-2} \times 0.0) \\
+ (2.54 \times 10^{-1} \times 0.0) + (2.07 \times 0.0) \]  

(A-3)

The same process will be used to obtain the utility functions for all freight modes. After that the probability $P_i$ of selecting freight mode $i$ is determined by logit formula presented in Equation (2-7).

\[
(0.033_w) = \frac{e^{-0.209_w}}{e^{-0.209_w} + e^{0.074} + e^{-0.209_w} + e^{0.024} + e^{1.759} + e^{1.702} + e^{0.527} + e^{0.240}} \]  

(A-4)

Equation (A-4) is used to illustrate the computation of the probability for selecting water mode. Therefore, the same process will be used to compute the probabilities for all freight modes. Thus, the computed probabilities will be used to complete a portion of Equation (3-5) in which defines in Equation (3-6) as $\lambda_n$. Moreover, the first part of the equation in which defined in Equation (3-6) as $\alpha_i$ in common practice to not included in the summation over discrete outcomes $j$, and more information about this restriction is provided in Washington et al., (2010). This restriction is relaxed by estimate selectivity-bias parameters $\alpha_i$ for each continuous equation corresponding to each discrete outcome $i$, Washington et al., (2010). In this case the correction term will be used to estimate continuous equation related to water mode.

3- Use the values computed in step 2 to estimate Equation (3-3) using standard least-squares regression method.
\[
\left\{ \frac{1}{(i)} \sum_{j \neq i} \left[ \frac{0.041_T \times LN}{1 - 0.041_T} + \frac{0.400_R \times LN}{1 - 0.400_R} \\
+ \frac{0.042_A \times LN}{1 - 0.042_A} + \frac{0.001_p \times LN}{1 - 0.001_p} \\
+ \frac{0.133_{PA} \times LN}{1 - 0.133_{PA}} + \frac{0.226_{TR} \times LN}{1 - 0.226_{TR}} \\
+ \frac{0.069_{TW} \times LN}{1 - 0.069_{TW}} + \frac{0.400_{OM} \times LN}{1 - 0.052_{OM}} \right] \right\} 
\]

Thus Equation (3-3) is estimated for each freight mode as (3-6).

The final step is to compute the continuous part using standard least-squares regression methods (OLS) simultaneously with the selectivity-bias correction term.

The NLOGIT 5 software used for model estimation. The estimates parameter for fertilizers manufacturing is statistically significant and on average increase the shipment size by 1.6381E+07 lb. This is expected because of several reasons related to the distance in which the water is the more economical mode for long distances. Moreover, the high capacity and low transit time for water generate low unitary shipment costs that might attract commodities with low unitary value such fertilizers.

**A-2-c: An applied example of the model in chapter 4.**

This example shows the flexibility of the model utilizing the MNL with random parameters for selecting freight transport mode. Additionally, employing the choice set approximation in which determine available freight mode that weight decisions towards labeled choices.
Table (A-4) provides detailed information about the shipment selected randomly from the whole dataset for commodity related to transportation equipment manufacturing (motorized and other vehicles (includes parts)) requires freight service from origin Detroit-Warren-Ann Arbor, CFS Area Michigan (MI) to Baton Rouge, CFS Area Louisiana (LA).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
<th>Unit</th>
<th>Value</th>
<th>Variable</th>
<th>Definition</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>Shipment distance</td>
<td>Miles</td>
<td>1144</td>
<td>X11</td>
<td>Services-related wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X2</td>
<td>Unitary value</td>
<td>$ per lb</td>
<td>4.45</td>
<td>X12</td>
<td>Metals manufacturing</td>
<td>binary</td>
<td>1.00</td>
</tr>
<tr>
<td>X3</td>
<td>Final destination Canada</td>
<td>binary</td>
<td>0.00</td>
<td>X13</td>
<td>Metals wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X4</td>
<td>Final destination Mexico</td>
<td>binary</td>
<td>0.00</td>
<td>X14</td>
<td>Agriculture manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X5</td>
<td>Final destination other-country</td>
<td>binary</td>
<td>0.00</td>
<td>X15</td>
<td>Agriculture wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X6</td>
<td>Temperature control shipment</td>
<td>binary</td>
<td>0.00</td>
<td>X16</td>
<td>Textile/apparel manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X7</td>
<td>Flammable materials shipment</td>
<td>binary</td>
<td>0.00</td>
<td>X17</td>
<td>Textile/apparel wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X8</td>
<td>Raw materials manufacturing</td>
<td>binary</td>
<td>0.00</td>
<td>X18</td>
<td>Wood products manufacturing</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X9</td>
<td>Raw materials wholesalers</td>
<td>binary</td>
<td>0.00</td>
<td>X19</td>
<td>Wood products wholesalers</td>
<td>binary</td>
<td>0.00</td>
</tr>
<tr>
<td>X10</td>
<td>Services-related manufacturers</td>
<td>binary</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this example, the same process for case A-2-a will be followed. Equation (2-6) will be used for average utility function $U_i$ associated with each mode as an outcome of the choice set approximation for available freight modes to any shipment, in which $i \in \{\text{Truck (T), rail (R), Air (A), parcel (PA), and truck-rail (TR)}\}$. The constant for each mode $i$ and the estimated parameters $\beta_i$ associated with each attribute will be obtained from Table 2-6. The probability $P_i$ of selecting freight mode $i$ is computed by Equation (2-7).
\[ 1.323_{\text{truck-rail}} = (-4.0 \times 10^{-1}) + (2.3 \times 10^{-4} \times 1144) + (2.8 \times 10^{-1} \times 0.0) \\
- (8.5 \times 10^{-1} \times 0.0) + (7.5 \times 10^{-1} \times 0.0) \\
+ (3.7 \times 10^{-1} \times 1.0) + (2.3 \times 10^{-1} \times 0.0) \\
+ (7.7 \times 10^{-1} \times 0.0) + (3.8 \times 10^{-1} \times 0.0) + (1.4 \times 0.0) \\
+ (2.3 \times 0.0) \] (A-6)

Equation (A-6) is used to illustrate the calculation of the utility function of truck-rail mode by obtained constant and all parameters from Table 4-2. The same procedure will be used to calculate of all utility function of the modes available for this shipment, e.g., truck, rail, air cargo, and parcel services.

For each utility furcation associated with each freight mode the probability \( P_i \) of selecting freight mode \( i \) is determined by Equation (2-7). Equation (A-7) illustrates the computation of the probability for selecting truck-rail. The identical process will be used to obtain the probability for selecting the freight modes available of this shipment e.g., truck, rail, air cargo, and parcel services without considering all freight modes.

\[
(0.3436_{TR}) = \frac{e^{1.323_{TR}}}{e^{0.0791_{PA}} + e^{0.410_{A}} + e^{0.410_{A}} + e^{1.323_{TR}}} \] (A-7)

From the probabilities computed for this example it is observed that on average, the selection probabilities are 8.38% for the truck, 12.64% for air cargo, 19.09% for parcel services, 25.52% for unattached rail, and 34.36% for truck and rail. The results herein indicate the significant importance with respect to rail transportation. Rail transportation improves travel time with consistent schedules. Its large capacity
offers both cost savings and long distance for such shipment. On the other hand, the absence of water transportation due to the landlocked location which mostly offers the same advantages make this mode the most desirable for this shipment.