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# Freight Mode Choice with Public Data from the United States

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## ABSTRACT

This paper investigates the selection of freight modes by shippers that require transportation for their shipments. A discrete choice multinomial logit model is used to understand the connectivity and integration between mode-choice and the regional socioeconomic environment. The 2012 Commodity Flow Survey and United States Census Bureau data are public sources used to estimate the corresponding model. Analytical results indicate that shipment characteristics, commodity and industry types, and regional socioeconomic attributes provide an enhanced representation of the economic linkages that determine mode choice at the regional level. Meaningful discussion and guidance is provided to understand this complex process.

**Keywords:** Mode choice; commodity flow survey; socioeconomic data; freight transportation.

## INTRODUCTION

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 (Eissa, 2019). Thus, it is challenging to account for all of the different variables involved in these decisions. Likewise, limitations on freight data availability impose additional obstacles to transportation planning efforts. 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. This paper studies freight mode choice for strategic macroscopic models. Earlier freight mode choice models are exclusively based on direct comparison of shipment costs (Cunningham, 1982; Hashemian, 1982; 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. Several works conclude that service attributes are more important than the cost in determining mode choice (Gray, 1982; Wilson et al., 1986). Recently, discrete choice models are increasingly used to analyze freight mode choice decisions. This approach can incorporate the multiple attributes and influences related to behavioral, logistic, and shipper-related variables. The most widely used modeling form is the Multinomial Logit (MNL) model (Golias and Yannis, 1998; Jiang et al., 1999; McGinnis et al., 1981; Nam, 1997).

There is no unique agreement about the role of shippers and carriers on mode choice in previous literature. A group of works (Danielis and Marcucci, 2007; Golias and Yannis, 1998; Hensher and Figliozzi, 2007; Kim, 2002; McGinnis et al., 1981; Murphy et al., 1997; Train and Wilson, 2006) indicate that shipment size does not affect the mode choice process, which depends exclusively on the attributes of the mode, i.e., cost, travel time, safety, reliability, flexibility, frequency of service, length of haul security, among others. In contrast, a large group of researchers consider that shipment size affects mode choice. This approach is divided in two group. One considers that shipment size determines mode choice, not the opposite, i.e., mode-choice does not affect shipment size (Arunotayanun and Polak, 2007; Cullinane and Toy, 2000; Evers et al., 1996; Grue and Ludvigsen, 2006; Hummels, 2007; Jeffs and Hills, 1990; Mesa-Arango and Ukkusuri, 2014; Rodrigue, 2006). On the other hand, the two-way interaction between shippers and carriers is studied through joint mode-choice and shipment size models (Abate and De Jong, 2014; Abdelwahab and Sargious, 1992; Abdelwahab and Sayes, 1999; Chiang et al., 1981; Combes, 2012; De Jong, 2007; Inaba and Wallace, 1989; McFadden et al., 1985; and as in Pourabdollahi et al., 2013; Windisch et al., 2010), i.e., mode choice is the result of the cooperation between shippers and carriers. Therefore, using shipment size without the proper discrete-continuous selectivity bias correction can add undesired bias to model estimation, i.e., might be more relevant to use other variables for pure mode choice.

Macroscopic models are useful to explain the sum of many individual behavior decisions. Aggregate models are mainly used for strategic planning decisions associated with freight transportation investments and policies. The present paper attempts to improve understanding in this area by assessing freight mode desirability for aggregated regions, commodities, and economic activities. Such model is a significant contribution to freight transportation forecasts, complement freight performance measures, and improves the understanding of the general freight market.

In order to understand how shippers, select freight transportation modes, a set of shipment characteristics, commodity/industry types, economic sectors, and socioeconomic regional activities are proposed and statistically tested through the discrete choice econometric approach. The source data is obtained from public sources like the 2012 Commodity Flow Survey (CFS) and regional economic data from the U.S. Census Bureau. Furthermore, a MNL model tests the statistical significance of the presented variables, and marginal effects are used to provide a better explanation of the variables behind freight mode choice.

This paper is organized as follows: Section 1 introduces and motivates the problem. Section 2 reviews freight mode choice literature and supports the use of the proposed method. Section 3 describes the data and sample characteristics. Section 4 explains the econometric framework used for discrete choice. Section 5 presents model estimation results and the corresponding analysis. Finally, the paper is concluded in Section 6.

## Literature review

This section presents a literature review of previous studies related to the selection of freight transportation services. Additionally, the interaction between shipper and carriers is summarized. The review demonstrates the gap associated with use of socioeconomic attributes for macroscopic freight mode-choice models for regional analysis.

Several studies have contributed to the understanding of the interactions between shippers and carriers in the context of joint mode choice and shipment size. There is a fraction number of papers that discuss the influence of shipment size on mode choice. This assumption is based on optimal shipment size, in which shippers build on the experience with various shipment sizes and receive feedback form carriers. In this concept, 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, where freight mode or vehicle are discrete and shipment size is continuous. Although the aforementioned studies in which joint models with discrete mode and continuous shipment size were developed, small branches of this formulation consider shipment size as the other discrete component (Chiang et al., 1981; De Jong, 2007; Pourabdollahi et al., 2013; Windisch et al., 2010). Other groups of work do not consider the impact of shipment size at all on mode choice. The assumption implies that the interaction between shipper-carrier has no role in the selection of the mode, or it is equivalent to the independent decision-making processes assumption. The choice assumed to depend completely on the mode attributes, i.e., reliability, flexibility, frequency of service, service level, length of haul, transit time, price, monitoring, shipper's market, considerations, security, travel time, and more (Danielis and Marcucci, 2007; Golias and Yannis, 1998; Hensher and Figliozzi, 2007; Kim, 2002; McGinnis et al., 1981; Murphy et al., 1997; Train and Wilson, 2006). It seems obvious that the interactions between shippers and carriers must affect freight demand, thus, there are certain connections between these works and the selection of transport mode services. However, these works study mode choice, which highly depend on different assumptions about the interaction between shippers-carriers and on operational characteristics of the transportation system. On the other hand, the selection of mode is a more strategic decision. Likewise, understanding this fundamental interaction can improve freight demand studies by providing specific details about the pragmatic variables considered in the selection of a transportation mode. In this case, the two-way interactions consider shipment size as the most complex assumption.

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. (Arencibia et al., 2015; Arunotayanun and Polak, 2011; Boerkamps et al., 2000; Hunt and Stefan, 2007; Liedtke, 2009; Ravibabu, 2013; Samimi et al., 2011a; Wang and Veras, 2008; Wisetjindawat et al., 2007) and national/regional areas (De Jong and Ben-Akiva, 2007; Dhulipala and Patil, 2021; Samimi et al., 2014; Wisetjindawat and Sano, 2003; Zhong et al., 2007). 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 firm to firm (sender - receiver) related to choice of shipment size and transportation chain. Samimi et al., (2014) developed 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 disaggregate firm-to-firm level, and is named the Freight Activity Microsimulation Estimator (FAME). The estimator model is largely based on public freight data.

On the other hand, 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. The advantage is to capture general trends based on the general characteristics observed. Nam, (1997) applied the mode choice analysis with an aggregated binary logit model to understand the effect of heterogeneous commodity types and test different variables. The desirability of the aggregated model is also emphasized. 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 to understand freight mode choice (track 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. Recently, discrete choice models have been used to determine the international freight transport mode using available macroscopic commodity trade information (Sou and Ong, 2015). Aggregated trade data (from the U.S. Census Bureau) between the U.S. and China, and the U.S. and the European Union are used to understand strategic planning level decisions. 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.

Mode choice models are sensitive to the attributes of the shipper (decision maker), i.e., basic information about each establishment. These attributes do not change across transportation alternatives, unlike the mode attributes that vary significantly from one alternative to another. Samimi et al., (2011) utilize some essential information about establishments, i.e., square footage, industry type, establishment location, and number of employees in their model of the microsimulation mode selection decision for truck-rail and intermodal truck-rail. Pourabdollahi et al., (2013) consider exogenous variables related to decision-maker characteristics (such as employee size and industry type) to estimate joint mode-choice and shipment size models simultaneously. Disaggregated survey data is used to analyze the decision selection at the micro level (Roorda et al., 2010). Kumar et al., (2017) propose a comprehensive freight microsimulation formwork. Although no modeling output is reported, new aspects of freight mode choice are emphasized. They indicate that business establishment, i.e. geographic location, industry classification, and number of employees, play various roles in supply chains and the economy as a whole. Holguı´n-Veras, (2002) emphasizes in his model for commercial vehicle choice at the firm level the need for future research exploring the integration of economic activity taking place at the trip origin and destination for commodity based modeling. However, many of these studies did not consider detailed information about establishments and none of them studied the choice of freight mode considering socioeconomic activities exclusively.

In summary, there is no discrete choice mode in literature that is used to understand the connection between freight mode choice and socioeconomic activities at the regional level. Therefore, this paper will narrow the gap in literature by proposing MNL to investigate how variations in shipments-characteristics, commodity type, and regional socioeconomic environment affect the freight mode choice. Previous studies have focused on mode choice at the firms level (microsimulation model). Thus, this study addresses important issues in the economics of freight demand analysis by identifying the main determinants of the choice of mode at the strategic macroscopic level.

**Datasets**

This research studies the mode choice selection by decision makers that require freight transportation services. As in any data-based study, data-collection and data-reliability are extremely challenging. Therefore, depending on public databases is adopted methodology in different engineering fields, (Alsalhin, 2020; Hmouda, 2010; Kyamo, 2022; Valencia A et al., 2017; Wtaife et al., 2019). Mainly in freight-related study, the most comprehensive and public databases on freight movements is the Commodity Flows Survey (CFS) (Eissa et al., 2023).

The 2012 CFS is the primary data source for this research (Commodity Flow Survey, 2012). The CFS is conducted as a partnership between the U.S. Census Bureau and the Bureau of Transportation Statistics. 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. These data are also used as the main inputs of the Freight Analysis Framework (FAF).

An additional data source is used to enrich the CFS dataset and derive meaningful socioeconomic attributes associated with the transportation analysis zones (TAZs), where the CFS is conducted, i.e., socioeconomic data from the U.S Census Bureau, 2012 (U.S Census Bureau, 2012). Since freight demand is driven by economic and population growth, it is important to understand the connectivity and integration of the transportation system, across and between modes, for freight and the regional socioeconomic environment. Together, these datasets provide detailed freight planning information for modeling the mode choice at the regional level.

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 North America Industry Classification System (NAICS). The dataset targets all the U.S. and contains more than 4.5 million records, from approximately 60,000 responding establishments.

Detailed information on individual shipments is obtained from the survey, including origin, destination (either the destination is in the U.S., Mexico, Canada or other countries), shipment value, weight of the shipment, and commodity and industry types. All transportation modes are represented. The survey provides information on the exact shipping chain, including the distance shipped, and ton-miles of commodities shipped. Shipments are classified according to two major classifications systems, i.e., (i) the NAICS, and (ii) the Standard Classification of Transported Goods (SCTG).

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), and 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. A diverse range of industry types are covered by the CFS. Likewise, the survey covers various commodity types. However, detailed operational information of the firms is not available. Therefore, 2012 data from the census bureau is used to approximate the impact of firm-related and other socioeconomic variables at the TAZ level, e.g., number of establishments, number of employees per establishment, overall population, employment rate, number of transportation establishments, among others.

**Table 1.** Summary statistics for main freight transportation modes.

| Mode | Observations | Percentage |
|---|---|---|
| Truck | 3,231,969 | 71.28 |
| Rail | 38,458 | 0.85 |
| Water | 2,972 | 0.07 |
| Air | 68,809 | 1.52 |
| Pipeline | 3,673 | 0.08 |
| Parcel, USPS, or courier | 1,165,297 | 25.70 |
| Truck and rail | 19,070 | 0.42 |
| Truck and water | 2,498 | 0.06 |
| Other mode | 1,124 | 0.03 |

Nine transportation modes were selected for model estimation, including single-mode and multimodal alternatives. The single-mode alternatives include: truck, air, water, pipeline, and rail. The multimodal alternatives include parcel (including U.S. Postal Service (USPS) and other couriers), truck-water, truck-rail, and other combinations. Table 1 presents the summary of 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 small packages moved via express carriers, i.e., (USPS, FedEx, DHL and UPS). In the third position, air freight accounts for 1.52% of the total observations. 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 and a high level of security. Then, rail transportation represents 0.85% of the total cases. Rail transportation improves travel time with consistent schedules. Its large capacity offers both cost savings and long distance scope for their related shipments. 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 modes (single and combinations), are used in 0.08%, 0.07%, 0.03% of the cases respectively.

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 the subset, 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. For example, 263 observations in McGinnis et al. (1981), 600 observations by Shen and Wang (2012), 881 observations by Samimi et al. (2014), 1,302 observations by Pourabdollahi et al., (2013), 1,674 observations in Arencibia et al., (2015), 1,785 observations in Nam, (1997), 1,487 observations in Arunotayanun and Polak, (2007), 4,544 observations in Samimi et al., (2011b), 5,276 observations in Holgu ı´ n-Veras, (2002), and 5,545 observations in Sou and Ong, (2015).

Table 2 presents summary statistics for selected variables of the shipments covered by the dataset and socioeconomic characteristics related to the regional activities. The average route distance between shipment origin and destination by truck is roughly 56 miles, meanwhile the average of traveling distance by truck-water is about 399 miles. The average unity value for air shipments ($401.8 per lb.) is the highest among all modes, followed by parcel ($253.4 per lb.). Then, truck related modes have similar values (truck $10.53, truck-Rail $8.83, and truck-water $4.40 per lb.). In general, this suggests that shipments with high value and low weight are more attracted to these modes. About 0.092% of the observations are hazardous materials transported in pipelines, which might be safer than other modes. 0.006% of the shipments are transported by rail if the final destination is Canada.

Similarly, 0.004% of the total observations involve rail shipments with Mexico as the final destination. This general statistic shows how important rail is for border shipping. Likewise, 0.012% of the observations are carried by maritime cargo and have their destinations in other countries. Similarly, 0.018% of the observations are carried by the truck-water combination and have international destinations (other than Canada and Mexico). 0.022% of the observations are associated with some level of temperature-controlled shipment transported by truck-water.

From the industry type and commodity perspective, 0.003% of the observations are agricultural products transported by water. Similarly, 0.004% of the observations for animal feed, eggs, honey, and other products of animals are transported with the truck-water combination. 0.003% of the observations are grain and related products shipped by rail mode. Railways are economical and best suited for bulky goods over long distances, in which food cost is maintained low. Only 0.005% of total cases are alcoholic beverage transported by truck–water. Non-metallic minerals mostly select high-capacity modes to reduce their transportation costs. This happens in 0.003% of the cases for rail transportation. Although 0.019% of the observations are fuel oils (includes diesel, bunker and biodiesel) transported by pipeline, this is a sufficient representation that shows pipeline is a predominant mode in transporting petroleum products. About 0.036% of the observations are basic chemical products shipped with the same previous mode. It is clear that pipelines are the most convenient, efficient and economical mode to transport selected liquid commodities. Also, 0.007% of the observations are pharmaceutical products shipped by air cargo. Air shipping offers reliable arrival times and reduced risk damage. 0.002% of the observations are fertilizer products transported by rail. Truck-rail mode is the highest between all modes in transporting wood products by 0.010%, followed by truck 0.008%, then by rail 0.005%.

**Table 2.** Summary statistics for selected variables for mode-choice.

| Variable | Truck | | Rail | | Water | | Air | | Pipeline | | Parcel | | Truck-Rail | | Truck-Water | | Other-Modes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| **Shipment characteristics** | | | | | | | | | | | | | | | | | | |
| Shipment distance route (mi.) | 0.056 | 0.230 | 0.058 | 0.234 | 0.012 | 0.109 | 0.052 | 0.222 | 0.040 | 0.196 | 0.010 | 0.100 | 0.052 | 0.222 | 0.198 | 0.399 | 0.208 | 0.406 |
| Unitary value of shipments ($ per lb.) | 10.53 | 44.70 | 0.572 | 1.638 | 0.533 | 3.144 | 401.8 | 1281 | 1.168 | 6.200 | 253.4 | 3069 | 8.828 | 118.7 | 4.398 | 10.35 | 8.358 | 64.71 |
| Hazmat (flammable liquids ) (Bin) | 0.010 | 0.097 | 0.018 | 0.132 | 0.032 | 0.177 | 0.003 | 0.054 | 0.092 | 0.289 | 0.000 | 0.015 | 0.004 | 0.067 | 0.003 | 0.056 | 0.006 | 0.074 |
| Final destination - Canada (Bin) | 0.001 | 0.030 | 0.006 | 0.076 | 0.000 | 0.000 | 0.003 | 0.058 | 0.000 | 0.000 | 0.001 | 0.026 | 0.003 | 0.052 | 0.003 | 0.058 | 0.009 | 0.096 |
| Final destination - Mexico (Bin) | 0.001 | 0.026 | 0.004 | 0.065 | 0.001 | 0.026 | 0.000 | 0.021 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.047 | 0.000 | 0.000 | 0.001 | 0.030 |
| Final destination- other-country (Bin) | 0.001 | 0.033 | 0.003 | 0.054 | 0.012 | 0.105 | 0.045 | 0.207 | 0.000 | 0.000 | 0.002 | 0.045 | 0.024 | 0.154 | 0.018 | 0.135 | 0.008 | 0.088 |
| Temperature controlled (Bin) | 0.006 | 0.079 | 0.006 | 0.080 | 0.001 | 0.036 | 0.006 | 0.076 | 0.004 | 0.067 | 0.001 | 0.033 | 0.006 | 0.076 | 0.022 | 0.147 | 0.023 | 0.150 |
| **Commodity type** [a] | | | | | | | | | | | | | | | | | | |
| Agricultural Products (Bin) | 0.001 | 0.026 | 0.002 | 0.047 | 0.010 | 0.100 | 0.000 | 0.021 | 0.000 | 0.000 | 0.000 | 0.021 | 0.003 | 0.056 | 0.009 | 0.094 | 0.001 | 0.030 |
| Animal Feed/ Eggs/ Honey/ Other Products of Animal (Bin) | 0.002 | 0.039 | 0.002 | 0.039 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 | 0.021 | 0.004 | 0.065 | 0.002 | 0.047 | 0.001 | 0.026 |
| Meat/ Poultry/ Fish/ Seafood (Bin) | 0.002 | 0.042 | 0.000 | 0.015 | 0.000 | 0.000 | 0.001 | 0.026 | 0.000 | 0.000 | 0.000 | 0.015 | 0.001 | 0.033 | 0.003 | 0.054 | 0.008 | 0.087 |
| Milled Grain/ Bakery Products (Bin) | 0.001 | 0.030 | 0.003 | 0.058 | 0.001 | 0.030 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.015 | 0.003 | 0.054 | 0.000 | 0.015 | 0.000 | 0.000 |
| Prepared Foodstuffs/ Fats/ Oils (Bin) | 0.004 | 0.061 | 0.007 | 0.084 | 0.001 | 0.036 | 0.001 | 0.030 | 0.000 | 0.000 | 0.001 | 0.030 | 0.008 | 0.092 | 0.009 | 0.096 | 0.014 | 0.117 |
| Alcoholic Beverages (Bin) | 0.003 | 0.056 | 0.001 | 0.033 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.015 | 0.003 | 0.056 | 0.005 | 0.071 | 0.003 | 0.056 |
| Gravel/Crushed Stone (Bin) | 0.003 | 0.058 | 0.003 | 0.054 | 0.014 | 0.119 | 0.000 | 0.000 | 0.004 | 0.067 | 0.000 | 0.000 | 0.002 | 0.045 | 0.002 | 0.039 | 0.004 | 0.063 |
| Non-Metallic Minerals (Bin) | 0.000 | 0.021 | 0.003 | 0.054 | 0.004 | 0.060 | 0.000 | 0.000 | 0.001 | 0.036 | 0.000 | 0.015 | 0.002 | 0.039 | 0.000 | 0.000 | 0.000 | 0.021 |
| Coal (Bin) | 0.000 | 0.000 | 0.004 | 0.067 | 0.014 | 0.116 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.030 | 0.002 | 0.049 | 0.026 | 0.158 |
| Fuel Oils/ Diesel/ Bunker C (Bin) | 0.002 | 0.042 | 0.001 | 0.033 | 0.020 | 0.138 | 0.000 | 0.000 | 0.019 | 0.137 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 | 0.000 |
| Coal and Petroleum Products (Bin) | 0.002 | 0.042 | 0.001 | 0.033 | 0.020 | 0.138 | 0.000 | 0.000 | 0.019 | 0.137 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 | 0.000 |
| Basic Chemicals (Bin) | 0.002 | 0.049 | 0.015 | 0.121 | 0.008 | 0.087 | 0.004 | 0.061 | 0.036 | 0.187 | 0.001 | 0.033 | 0.003 | 0.052 | 0.000 | 0.000 | 0.002 | 0.049 |
| Pharmaceutical Products (Bin) | 0.001 | 0.033 | 0.000 | 0.000 | 0.000 | 0.000 | 0.007 | 0.084 | 0.000 | 0.000 | 0.004 | 0.061 | 0.000 | 0.015 | 0.002 | 0.049 | 0.002 | 0.042 |
| Fertilizers Products (Bin) | 0.001 | 0.033 | 0.005 | 0.071 | 0.001 | 0.036 | 0.000 | 0.000 | 0.004 | 0.067 | 0.000 | 0.000 | 0.001 | 0.036 | 0.000 | 0.000 | 0.000 | 0.000 |
| Chemical Products/Preparation (Bin) | 0.004 | 0.065 | 0.001 | 0.036 | 0.000 | 0.000 | 0.004 | 0.061 | 0.001 | 0.030 | 0.003 | 0.056 | 0.002 | 0.047 | 0.005 | 0.068 | 0.002 | 0.045 |
| Plastics and Rubber (Bin) | 0.007 | 0.083 | 0.012 | 0.108 | 0.001 | 0.030 | 0.003 | 0.054 | 0.000 | 0.000 | 0.005 | 0.068 | 0.007 | 0.084 | 0.004 | 0.060 | 0.003 | 0.054 |
| Wood Products (Bin) | 0.008 | 0.087 | 0.005 | 0.073 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 | 0.021 | 0.010 | 0.098 | 0.004 | 0.061 | 0.003 | 0.058 |
| Newsprint/Paper/ Paperboard (Bin) | 0.001 | 0.026 | 0.005 | 0.070 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.068 | 0.000 | 0.000 | 0.000 | 0.000 |
| Printed Products (Bin) | 0.004 | 0.060 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.056 | 0.000 | 0.000 | 0.009 | 0.095 | 0.001 | 0.026 | 0.000 | 0.021 | 0.000 | 0.000 |
| Textiles and Leather (Bin) | 0.004 | 0.065 | 0.000 | 0.021 | 0.001 | 0.026 | 0.003 | 0.056 | 0.000 | 0.000 | 0.014 | 0.117 | 0.004 | 0.067 | 0.004 | 0.060 | 0.003 | 0.058 |
| Non-Metallic Mineral Products (Bin) | 0.004 | 0.067 | 0.006 | 0.074 | 0.001 | 0.033 | 0.001 | 0.033 | 0.000 | 0.000 | 0.001 | 0.036 | 0.008 | 0.087 | 0.006 | 0.074 | 0.004 | 0.061 |
| Articles of Base Metal (Bin) | 0.008 | 0.088 | 0.002 | 0.047 | 0.000 | 0.000 | 0.004 | 0.063 | 0.000 | 0.000 | 0.006 | 0.079 | 0.003 | 0.058 | 0.003 | 0.054 | 0.004 | 0.061 |
| Machinery (Bin) | 0.007 | 0.084 | 0.001 | 0.026 | 0.000 | 0.000 | 0.016 | 0.124 | 0.000 | 0.000 | 0.010 | 0.098 | 0.003 | 0.054 | 0.003 | 0.054 | 0.001 | 0.030 |
| Electronic/Components/ Office (Bin) | 0.005 | 0.071 | 0.000 | 0.000 | 0.000 | 0.000 | 0.022 | 0.146 | 0.000 | 0.000 | 0.013 | 0.114 | 0.003 | 0.058 | 0.003 | 0.052 | 0.002 | 0.039 |
| Motorized/ Vehicles (parts) (Bin) | 0.004 | 0.060 | 0.001 | 0.036 | 0.000 | 0.000 | 0.004 | 0.067 | 0.000 | 0.000 | 0.003 | 0.058 | 0.007 | 0.085 | 0.004 | 0.065 | 0.001 | 0.030 |
| Transportation Equipment (Bin) | 0.000 | 0.021 | 0.001 | 0.026 | 0.003 | 0.056 | 0.008 | 0.089 | 0.000 | 0.000 | 0.002 | 0.049 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 | 0.000 |
| Precision Instrument/Apparatus (Bin) | 0.001 | 0.030 | 0.000 | 0.000 | 0.000 | 0.000 | 0.017 | 0.131 | 0.000 | 0.000 | 0.010 | 0.098 | 0.000 | 0.021 | 0.000 | 0.000 | 0.000 | 0.000 |
| Miscellaneous Products (Bin) | 0.005 | 0.071 | 0.000 | 0.000 | 0.000 | 0.000 | 0.008 | 0.090 | 0.000 | 0.000 | 0.014 | 0.118 | 0.001 | 0.033 | 0.005 | 0.071 | 0.001 | 0.033 |
| Waste and Scrap (Bin) | 0.001 | 0.033 | 0.008 | 0.092 | 0.006 | 0.076 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.009 | 0.095 | 0.003 | 0.058 | 0.001 | 0.033 |
| Mixed Freight (Bin) | 0.007 | 0.084 | 0.001 | 0.026 | 0.003 | 0.054 | 0.001 | 0.033 | 0.000 | 0.000 | 0.006 | 0.080 | 0.003 | 0.058 | 0.020 | 0.141 | 0.014 | 0.119 |

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| Variable | Truck | | Rail | | Water | | Air | | Pipeline | | Parcel | | Truck-Rail | | Truck-Water | | Other-Modes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| **Industry type** [b] | | | | | | | | | | | | | | | | | | |
| Mining except oil/gas (Bin) | 0.004 | 0.065 | 0.015 | 0.121 | 0.031 | 0.173 | 0.000 | 0.000 | 0.001 | 0.036 | 0.000 | 0.000 | 0.007 | 0.084 | 0.010 | 0.100 | 0.030 | 0.169 |
| Wood Product Manufacturing (Bin) | 0.005 | 0.071 | 0.005 | 0.071 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 0.000 | 0.000 | 0.015 | 0.006 | 0.074 | 0.001 | 0.030 | 0.001 | 0.036 |
| Computer/ Electronic Products (Bin) | 0.003 | 0.052 | 0.000 | 0.021 | 0.000 | 0.000 | 0.010 | 0.098 | 0.000 | 0.000 | 0.006 | 0.077 | 0.001 | 0.036 | 0.002 | 0.047 | 0.000 | 0.021 |
| Transportation Equipment (Bin) | 0.002 | 0.045 | 0.001 | 0.033 | 0.003 | 0.056 | 0.007 | 0.085 | 0.000 | 0.000 | 0.002 | 0.042 | 0.007 | 0.085 | 0.000 | 0.000 | 0.000 | 0.000 |
| Miscellaneous Manufacturing (Bin) | 0.001 | 0.033 | 0.000 | 0.000 | 0.000 | 0.000 | 0.009 | 0.093 | 0.000 | 0.000 | 0.005 | 0.073 | 0.000 | 0.021 | 0.001 | 0.036 | 0.000 | 0.000 |
| Motor and parts Wholesalers (Bin) | 0.002 | 0.039 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.058 | 0.000 | 0.000 | 0.004 | 0.060 | 0.000 | 0.021 | 0.003 | 0.054 | 0.003 | 0.052 |
| Grocery Merchant Wholesalers (Bin) | 0.003 | 0.058 | 0.000 | 0.015 | 0.000 | 0.021 | 0.002 | 0.039 | 0.000 | 0.000 | 0.000 | 0.015 | 0.000 | 0.015 | 0.013 | 0.114 | 0.018 | 0.135 |
| **Socioeconomic Activities** | | | | | | | | | | | | | | | | | | |
| Water Transportation at O (Est) | 14.59 | 24.24 | 14.02 | 25.65 | 27.53 | 37.54 | 18.37 | 26.64 | 35.62 | 36.89 | 18.52 | 29.26 | 13.69 | 22.76 | 19.60 | 24.76 | 21.98 | 26.19 |
| Pipeline Transportation at O (Est) | 30.49 | 41.77 | 54.25 | 68.36 | 52.17 | 51.92 | 25.72 | 40.63 | 73.26 | 85.12 | 28.35 | 42.82 | 37.48 | 49.24 | 21.92 | 26.38 | 19.88 | 26.12 |
| Rail Transportation at O (Est) | 13.88 | 14.91 | 18.38 | 18.03 | 16.29 | 14.92 | 14.19 | 16.45 | 23.56 | 23.04 | 14.74 | 16.42 | 17.01 | 17.00 | 9.85 | 12.90 | 8.46 | 10.60 |
| Air Transportation at D (Est) | 58.63 | 70.84 | 56.04 | 57.37 | 32.74 | 38.22 | 118.2 | 96.28 | 63.04 | 66.63 | 70.09 | 70.99 | 80.40 | 84.41 | 70.23 | 80.44 | 63.35 | 68.63 |
| Water Transportation at D (Est) | 17.04 | 27.65 | 16.99 | 25.89 | 41.04 | 40.61 | 35.47 | 39.44 | 31.54 | 34.75 | 19.84 | 28.72 | 27.08 | 34.18 | 28.02 | 35.41 | 22.79 | 31.41 |
| Population at D (Million) | 2.884 | 2.880 | 2.830 | 2.399 | 1.864 | 1.546 | 4.749 | 3.856 | 2.909 | 3.037 | 3.350 | 2.823 | 3.768 | 3.632 | 1.612 | 2.897 | 1.107 | 1.670 |

Bin: Binary variable. Est: Number of transportation establishments. O: Origin. D: Destination. [a] Based on the Standard Classification of Transported Goods (SCTG). [b] Based on the North America Industry Classification System (NAICS).

This shows the high effect of rail to facilitate wood long distance travel, meanwhile trucks are highly flexible and reliable shorter distances. It is observed that rail and truck-rail are the predominant modes for newsprint, paper, and paperboard. Each combination happens in 0.005% of the cases. On the other hand, modes like water, air, truck-water or other-mode are not even feasible to transport that commodity. About 0.022% of the observations are electronic and office equipment shipments carried by air cargo. The parcel still maintained the second position among all modes with 0.0012% followed by truck (0.005%), truck-rail (0.003%), and truck-water (0.003%). Electronic and office equipment are time sensitive and air transportation provide reliability, security, and good handling. Similarly, precision instruments and apparatus select the same mode by 0.017% of the cases and parcel in 0.010% of the observations, with the similar intuition indicated for electronic and office equipment. In the cases of motorized and other vehicles (includes parts), 0.007% of the total observations are transported by truck–rail. Noticeably, the selection of truck is equal to the selection of truck-water, i.e., 0.005% of the total observations. This shows that truck-rail combines hybrid features to facilitate their distribution channels. 0.014% of the observations are miscellaneous products transported by parcel. In the same way, about 0.009% of the observations are printed products shipped with the same mode mentioned earlier. Parcel provides features like shipment tracking and door-to-door delivery that might be desirable attributes for these shipments. In the group of grocery and related products merchant wholesalers, about 0.018% of the total cases are transported by other-mode, followed by truck-water 0.015%. By contrast, modes such as, rail, water, parcel truck-rail in many cases, are not even an option to transport these commodities.

The general statistics of socio-economic activities show how important transportation facilities are for the mode selection. The average number of water transportation establishments for maritime-related shipments is 27.52 at the origin and 41.04 at the destination respectively. It is expected that the availability of facilities such as ports and other logistics companies, will help to link shipments with intermodal freight, i.e., trucks, rail, or other modes. In many cases, shippers prefer to ship using water cargo if this is an option among the mode choice, for large quantities of heavy and bulky goods for long distances. The average number of pipeline facilities and related establishments for pipeline-associated shipments is 73.26 at the origin of the shipments. In the case of rail shipments, the average number of rail-related establishments at the origin is 18.38, for truck-rail shipments this number is 17.01. For air shipments, the average number of air establishments is 119 at the destination. Centralizing air cargo operation close to air transport offers comprehensive services, i.e., regular schedule, faster handling and door-to-door delivery, which can support the logistics requirement for their customers. Looking to the importance of population for mode choice. The TAZs that receive shipments by air are associated with an average population of 4.749 million people. This shows the high effect that variety of businesses has in the supply chains and how the highly populated areas are playing an important role in the freight mode choice. This draws the line between populated areas, business diversity, and customer satisfaction. Notice that they provide general insights, but particular conclusions can only be obtained from the final model estimated in Section 5 following the econometric approach described in the next section.

**Econometric approach**

As described in the previous literature review, freight mode choice is studied through discrete choice model estimation. Usually, advanced econometric and computational methods are used in several engineering studies to analyze data and model complex phenomena (Kyamo et al., 2019; Mesa-Arango et al., 2018; Omar et al., 2023; Wtaife et al., 2018). Various methods have been employed for the analysis of transportation data, but the Multinomial Logit (MNL) method continues to be the dominant approach (Mesa-Arango et al., 2017). For freight mode choice, an econometric approach widely used to understand discrete choices is the MNL model, which will be employed in this paper to analyze the dataset described in the previous section. The subsequent formulation follows the work presented in (Washington et al., 2010). A freight mode choice model estimates the expected discrete transportation mode choice $y_i$ as a function of a vector of covariates $\boldsymbol{X_i}$ related to the shipment $i \in \boldsymbol{I}$, where $\boldsymbol{I}$ is the set of observed shipments. Specifically for this paper, the choice set $\boldsymbol{F}$ is composed by nine alternatives, i.e., $\boldsymbol{F} =$ {truck, rail, water, air, pipeline, parcel, truck-rail, truck-water, other-mode}. The MNL model indicates that the probability $P(y_i = f)$ of an observation $i \in \boldsymbol{I}$ having a discrete freight mode choice outcome $y_i = f \in \boldsymbol{F}$ can be computed using Equation (1).

$$P(y_i = f) = \frac{e^{T_f}}{\sum_{\varphi \in \boldsymbol{F}} e^{T_\varphi}}, \forall i \in \boldsymbol{I} \tag{1}$$

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In Equation (1), $T_f$ is the deterministic component of the utility function associated with alternative $f \in \boldsymbol{F}$ that can be estimated as a function of a vector of covariates $\boldsymbol{X_{if}}$ for each observation $i \in \boldsymbol{I}$ and mode $f \in \boldsymbol{F}$ as presented in Equation (2).

$$T_f = \boldsymbol{\beta_f X_{if}}, \forall f \in \{0,1,2 \dots, F\} \tag{2}$$

For the current research, such covariates are related to shipment characteristics, industry and commodity types for the shipments, and socioeconomic variables for the corresponding origins and destinations. Furthermore, the vector of estimable parameters $\boldsymbol{\beta_f}$ can be approximated using maximum likelihood estimation. The corresponding log-likelihood function $LL(\boldsymbol{\beta_f})$ is presented in Equation (3), where $\delta_{if}$ is a binary variable indicating whether observation $i$ is associated with an alternative choice $f$ ($\delta_{if} = 1$) or not ($\delta_{if} = 0$).

$$LL(\boldsymbol{\beta_f}) = \sum_{i \in \boldsymbol{I}} \sum_{f \in \boldsymbol{F}} \delta_{if} \left[ \boldsymbol{\beta_f X_{if}} - LN \sum_{f \in \boldsymbol{F}} e^{\boldsymbol{\beta_f X_{if}}} \right] \tag{3}$$

Marginal effects $\boldsymbol{ME_{X_{if}}^{P_i}}$ can be computed after model estimation to assess how unitary changes in the variables $\boldsymbol{X_{if}}$ affect the outcome probability $P_i$ (Equation 4).

$$\boldsymbol{ME_{X_{if}}^{P_i}} = \frac{\delta P_i}{\delta \boldsymbol{X_{if}}} \tag{4}$$

The next section presents and discusses the results associated with the MNL model estimated with the dataset described in Section 3.

## RESULTS AND DISCUSSION

This section presents the results of the estimated MNL model for freight mode choice. Then, the marginal effects for attributes associated with this decision are computed and discussed.

After several iterations, the MNL that presents the best specification for transport mode selection is presented in Table 3. The software used for this model estimation is LIMDEP 10 (NLOGIT 5) (NLOGIT 5.0, 2012). Variables in the model have intuitive signs and are significant. The truck mode is the based case in this model. Therefore, the estimated coefficients show the difference compared to the trucks.

During the model fitting process, various combinations of variables were tested. The results indicate that a broad range of variables influence the mode choices process. These variables are divided into three groups, (i) shipment-characteristics (i.e., value, distance, international shipments, temperature controlled, and hazardous material transported), (ii) commodity/industry types (categorized based on NAICS or SCTG classification codes) and socioeconomic characteristics for the origin/destination TAZs (i.e., population and transportation facilities at origin/destination).

Table 4 presents the marginal effects (MEs), 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.

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

### *5.1. Shipment characteristics*

The first group of the variables is related to shipment characteristics. It is found that a unitary mile increase on geodesic distance between shipment origin and destination largely decreases the probability of pipeline (-0.231%), followed by truck (-0.058%), and other-mode (-0.0219%). Pipelines might have a reduced scope and, hence, be more undesirable for longer distances.

Likewise, the shipping cost associated with trucks can increase significantly with respect to distance, and make it more undesirable. Furthermore, unitary changes in distance in average increase the probability of selecting parcel (0.003%), air (0.031%), water (0.058%), and truck-water (0.066%). Although in average distance increases the probability of parcel, its low ME might indicates its flexibility for long and short distances. On the other hand, modes like air, water, rail, and truck-water are more economic for longer distances, and, in many cases, infeasible for shorter distances.

The shipment unitary value is the ratio of shipment value to shipment weight. In average, a $1 per lb. increment in shipment unitary value decreases the probability of selecting rail (-0.032%) and water (-0.013%). The high capacity and low transit time of rail and water generates low unitary shipment costs that might attract commodities with low unitary value. On the other hand, unitary increments in unitary values in average increase the probability of selecting air (0.002%), parcel (0.003%), pipeline (0.004%), and truck-rail (0.011%). Air and parcel are more practical for direct shipment and express delivery, which are attractive features for high-value shipments. Additionally, truck-rail combines the main advantages of the two of the main freight modes making it attractive for high-value shipments. Shipments associated to some level of hazardous materials prefer modes that maintain a certain level of safety in their operation and/or equipment. In average, hazardous shipments decrease the probability of selecting parcel (-0.236%), other-modes (-0.051%), and truck-water (-0.042%).

The high manipulation associated with these modes might be unsafe for hazmat deliveries. On the other hand, hazmat shipments in average have increased probability of selecting air (0.095%), followed by truck (0.066%) and rail (0.040%). The security measures and special cargo handlers at airports increase the probability of air cargo. The rules, regulations, and licenses required by truck/rail hazmat shipments combined with regular inspections to tank motor vehicles containing chemicals or supplying fuel, make truck and rail more desirable for such shipments.

From the international shipment perspective, if the final destination is Canada in average shipments are preferred by rail (0.107%), truck-water (0.098%) and air (0.066%). However, if the final destination is Mexico, in average rail is more desirable (0.119%) and then truck-rail (0.050). It is obvious that the U.S. has borders with few countries, so, few alternatives are available to export products to countries different than Mexico and Canada. In average, shipments aimed to other countries prefer air (0.106%) and truck-water (0.086%). The higher ME for air might be related to its widespread availability and scope as compared to truck-water transportation.

It is observed that temperature-controlled shipments in average decrease the probability of selecting parcel (-0.123%), water (-0.069%) and truck-rail (-0.015%). Parcel might not have particular types of temperature-controlled equipment available during their distribution process and, hence, be more undesirable. On the other hand, temperature-controlled shipments in average increase the probability of selecting air (0.045%), truck (0.038%), and truck-water (0.035%). Air and truck might be more suitable for temperature-controlled shipments for regional and national shipments. Truck-water might be more attractive for international segments.

### *5.2. Commodity and industry type*

The second group of variables describes the commodities and industries associated with the shipments in the dataset. Observations are classified using two classification systems, i.e., SCTG, and NAICS. The next paragraphs use MEs to describe each mode and its relationship with commodities and industries.

Truck transport is the most popular freight mode used by businesses and suppliers to deliver orders. It provides reasonable prices for a wide range of distances, a level of accessibility incomparable with other modes, and low requirements for shipment loading/unloading. Shipments like those related to non-metallic mineral products have higher probability of selecting truck (0.010%). On the other hand, products like coal and fertilizer products have lower probability of being shipped by truck (-0.105% and -0.006%, respectively). Truck services might be too expensive for many cheap and bulk commodities in intercity services. Similarly, waste and scrap (excludes agriculture or food) decreases the probability of selecting trucks (-0.104%).

The high manipulation associated with these modes might be unsafe for hazmat deliveries. On the other hand, hazmat shipments in average have increased probability of selecting air (0.095%), followed by truck (0.066%) and rail (0.040%). The security measures and special cargo handlers at airports increase the probability of air cargo. The rules, regulations, and licenses required by truck/rail hazmat shipments combined with regular inspections to tank motor vehicles containing chemicals or supplying fuel, make truck and rail more desirable for such shipments.

From the international shipment perspective, if the final destination is Canada in average shipments are preferred by rail (0.107%), truck-water (0.098%) and air (0.066%). However, if the final destination is Mexico, in average rail is more desirable (0.119%) and then truck-rail (0.050). It is obvious that the U.S. has borders with few countries, so, few alternatives are available to export products to countries different than Mexico and Canada. In average, shipments aimed to other countries prefer air (0.106%) and truck-water (0.086%). The higher ME for air might be related to its widespread availability and scope as compared to truck-water transportation.

It is observed that temperature-controlled shipments in average decrease the probability of selecting parcel (-0.123%), water (-0.069%) and truck-rail (-0.015%). Parcel might not have particular types of temperature-controlled equipment available during their distribution process and, hence, be more undesirable. On the other hand, temperature-controlled shipments in average increase the probability of selecting air (0.045%), truck (0.038%), and truck-water (0.035%). Air and truck might be more suitable for temperature-controlled shipments for regional and national shipments. Truck-water might be more attractive for international segments.

**Table 3.** Multinomial logit (MNL) model for mode-choice.

| Variable | Rail | | Water | | Air | | Pipeline | | Parcel | | Truck- Rail | | Truck-Water | | Other-Mode | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** |
| **Shipment characteristics** | | | | | | | | | | | | | | | | |
| Constant | -1.365 | -9.45 | -1.674 | -10.4 | -3.940 | -21.1 | -0.830 | -6.14 | -2.361 | -13.8 | -2.316 | -16.7 | -2.009 | -13.6 | -1.732 | -14.70 |
| Shipment distance route (mi.) | -0.001 | 10.90 | 0.001 | 6.76 | 0.002 | 13.03 | -0.003 | -7.92 | 0.001 | 9.11 | 0.002 | 13.3 | 0.002 | 15.10 | 0.001 | 9.91 |
| Unitary value of shipment ($ per lb.) | -0.471 | -7.65 | -0.278 | -5.58 | 0.008 | 6.98 | -0.095 | -7.06 | 0.008 | 6.85 | | | -0.025 | -4.55 | | |
| Hazmat (flammable liquids) (Bin) | | | | | | | | | -3.567 | -3.52 | -0.840 | -3.33 | -1.072 | -3.55 | | |
| Final destination Canada (Bin) | 2.556 | 5.42 | | | 2.234 | 4.24 | | | | | 1.925 | 3.87 | 2.674 | 5.46 | 2.358 | 5.26 |
| Final destination Mexico (Bin) | 1.739 | 3.94 | | | | | | | | | 0.978 | 2.01 | | | | |
| Final destination-other-country(Bin) | | | | | 2.249 | 13.27 | | | | | | | 1.481 | 8.68 | 0.796 | 3.64 |
| Temperature Controlled (Bin) | | | -1.655 | -3.73 | | | | | -1.758 | -3.64 | -0.260 | -2.09 | | | | |
| **Commodity type** [a] | | | | | | | | | | | | | | | | |
| Agricultural Products (Bin) | | | 2.190 | 7.18 | | | | | | | 1.263 | 3.51 | 2..408 | 8.04 | | |
| Animal Feed/Eggs/ Honey/ Other Products of Animal (Bin) | | | | | | | | | | | 1.715 | 5.20 | | | | |
| Meat/ Poultry/ Fish/ Seafood (Bin) | | | | | | | | | | | | | | | 1.540 | 5.25 |
| Milled Grain/ Bakery Products (Bin) | 1.962 | 4.36 | | | | | | | | | 1.841 | 3.89 | | | | |
| Prepared Foodstuffs/ Fats/ Oil (Bin) | 1.325 | 4.74 | | | | | | | | | 1.641 | 5.96 | 1.509 | 5.43 | 1.870 | 7.19 |
| Alcoholic Beverages (Bin) | | | | | | | | | | | 1.285 | 3.30 | 1.574 | 4.48 | 1.405 | 3.82 |
| Gravel/ Crushed Stone (Bin) | | | 2.622 | 10.7 | | | | | | | | | | | 1.815 | 6.04 |
| Non-Metallic Minerals (Bin) | | | 2.105 | 5.49 | | | | | | | | | | | | |
| Coal (Bin) | 0.908 | 2.28 | 4.196 | 12.1 | | | | | | | | | | | 4.756 | 14.91 |
| Fuel Oils/ Diesel/ Bunker C (Bin) | | | 3.490 | 10.9 | | | 2.680 | 8.65 | | | | | | | | |
| Coal and Petroleum Products (Bin) | | | 0.641 | 2.16 | | | 1.820 | 8.20 | | | | | | | | |
| Basic Chemicals (Bin) | 2.233 | 8.96 | 1.688 | 5.87 | 1.098 | 3.04 | 3.353 | 13.66 | | | | | | | | |
| Pharmaceutical Products (Bin) | | | | | 3.847 | 7.57 | | | 2.885 | 5.60 | | | 2.941 | 5.55 | 2.015 | 3.66 |
| Fertilizers Products (Bin) | 0.532 | 1.80 | | | | | | | | | | | | | | |
| Chemical Product/Preparation (Bin) | | | | | 1.197 | 3.25 | | | 1.328 | 3.73 | | | 1.435 | 4.68 | | |
| Plastics and Rubber (Bin) | 1.332 | 6.17 | -1.084 | -2.03 | | | | | 0.615 | 2.14 | | | | | | |
| Wood Products (Bin) | | | | | | | | | | | 1.409 | 6.16 | | | 0.710 | 2.32 |
| Newsprint/ Paper/ Paperboard (Bin) | 3.255 | 5.50 | | | | | | | | | 3.363 | 5.72 | | | | |
| Printed Products (Bin) | | | | | 2.570 | 6.56 | | | 2.889 | 9.36 | | | | | | |
| Textiles and Leather (Bin) | | | | | | | | | 1.798 | 8.04 | | | | | | |
| Non-Metallic Mineral Product (Bin) | | | -1.064 | -2.18 | | | | | | | | | | | | |

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| **Variable** | **Rail** | | **Water** | | **Air** | | **Pipeline** | | **Parcel** | | **Truck- Rail** | | **Truck-Water** | | **Other-Mode** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** | **Coeff** | **t-stat** |
| Articles of Base Metal (Bin) | | | | | | | | | 0.826 | 3.08 | | | | | | |
| Machinery (Bin) | | | | | 1.843 | 7.43 | | | 1.367 | 5.36 | | | | | | |
| Electronic/Components/Office (Bin) | | | | | 1.944 | 7.70 | | | 1.568 | 6.28 | | | | | | |
| Motorized / Vehicles (parts) (Bin) | 1.914 | 3.69 | | | 2.411 | 6.19 | | | 1.859 | 4.72 | 2.060 | 6.26 | 1.965 | 5.31 | | |
| Transportation Equipment (Bin) | | | | | 2.153 | 5.82 | | | | | | | | | | |
| Precision instrument/Apparatus(Bin) | | | | | 3.824 | 7.96 | | | 3.316 | 6.98 | | | | | | |
| Miscellaneous Products (Bin) | | | | | 2.203 | 7.12 | | | 2.400 | 9.00 | | | 1.636 | 5.34 | | |
| Waste and Scrap (Bin) | 2.627 | 7.01 | 2.810 | 7.08 | | | | | | | 2.965 | 8.00 | 2.098 | 4.80 | | |
| Mixed Freight (Bin) | | | 1.255 | 3.51 | | | | | 1.696 | 6.01 | | | 2.059 | 9.33 | 1.573 | 7.05 |
| **Industry type** [b] | | | | | | | | | | | | | | | | |
| Mining, except oil/gas (Bin) | 1.243 | 5.41 | | | | | | | | | 1.333 | 5.44 | 1.730 | 7.20 | | |
| Wood Product Manufacturing (Bin) | 1.184 | 4.10 | | | | | | | | | | | | | | |
| Computer/ Electronic Products (Bin) | | | | | 1.186 | 4.33 | | | | | | | | | | |
| Transportation Equipment (Bin) | | | 2.644 | 6.87 | | | | | | | | | | | | |
| Miscellaneous Manufacturing (Bin) | | | | | 0.700 | 2.24 | | | | | | | | | | |
| Motor (parts) Wholesalers (Bin) | | | | | | | | | | | | | | | 1.482 | 4.01 |
| Grocery Merchant Wholesalers(Bin) | | | | | | | | | | | | | 1.822 | 6.46 | 2.101 | 7.90 |
| **Socioeconomic Activities** | | | | | | | | | | | | | | | | |
| Water Transportation at O (Est) | | | 0.011 | 5.60 | | | | | | | | | | | | |
| Pipeline Transportation at O (Est) | | | | | | | 0.007 | 7.73 | | | | | | | | |
| Rail Transportation at O (Est) | 0.014 | 4.08 | | | | | | | | | 0.016 | 4.97 | | | | |
| Air Transportation at D (Est) | | | | | 0.004 | 3.19 | | | | | | | | | | |
| Water Transportation at D (Est) | | | 0.018 | 11.02 | | | | | | | | | | | | |
| Population at D (Est) | $0.126^{-06}$ | 5.44 | | | $0.128^{-06}$ | 3.61 | $0.169^{-06}$ | 6.75 | $0.196^{-06}$ | 8.41 | $0.195^{-06}$ | 9.35 | 0.000 | -2.6 | | |

4500 Observations. / Log likelihood at convergence = - 6205.001 / Log likelihood at zero = - 9887.510 / $\rho^2$= 0.7324 / Adjusted $\rho^2$ = 0.3701

Bin: Binary variable. Est: Number of transportation establishments. O: Origin. D: Destination. [a] Based on the Standard Classification of Transported Goods (SCTG). [b] Based on the North America Industry Classification System (NAICS).

**Table 4.** Marginal effects for attributes in the (MNL) model for mode-choice.

| Variable | Truck | Rail | Water | Air | Pipeline | Parcel | Truck- Rail | Truck-Water | Other-Mode |
|---|---|---|---|---|---|---|---|---|---|
| | ME | ME | ME | ME | ME | ME | ME | ME | ME |
| **Shipment characteristics** | | | | | | | | | |
| Shipment distance route (mi.) | -0.058 | 0.058 | 0.057 | 0.031 | -0.230 | 0.003 | 0.051 | 0.066 | -0.022 |
| Unitary Value of shipment ($/lb.) | 0.009 | -0.032 | -0.013 | 0.002 | 0.004 | 0.003 | 0.011 | 0.006 | -0.009 |
| Hazmat (flammable liquids) (Bin) | 0.066 | 0.040 | 0.026 | 0.095 | 0.015 | -0.236 | -0.015 | -0.042 | -0.051 |
| Final destination Canada (Bin) | -0.112 | 0.107 | -0.104 | 0.066 | -0.051 | -0.120 | 0.034 | 0.098 | 0.080 |
| Final destination Mexico (Bin) | -0.029 | 0.119 | -0.029 | -0.013 | -0.021 | -0.017 | 0.050 | -0.032 | -0.027 |
| Final destination-other-country (Bin) | -0.035 | -0.030 | -0.027 | 0.106 | -0.009 | -0.068 | -0.047 | 0.086 | -0.025 |
| Temperature Controlled (Bin) | 0.038 | 0.030 | -0.069 | 0.045 | 0.027 | -0.123 | -0.015 | 0.035 | 0.032 |
| **Commodity type** [a] | | | | | | | | | |
| Agricultural Products | -0.055 | -0.074 | 0.125 | -0.032 | -0.048 | -0.040 | 0.052 | 0.149 | -0.078 |
| Animal Feed/Eggs/ Honey/Other Products of Animal (Bin) | -0.017 | -0.031 | -0.014 | -0.014 | -0.006 | -0.019 | 0.142 | -0.024 | 0.016 |
| Meat/ Poultry/ Seafood (Bin) | -0.019 | -0.016 | -0.018 | -0.007 | -0.006 | -0.011 | -0.015 | -0.026 | -0.118 |
| Milled Grain/ Bakery Products (Bin) | -0.040 | 0.121 | -0.039 | -0.021 | -0.026 | -0.028 | 0.117 | -0.047 | 0.038 |
| Prepared Foodstuffs/ Fats/Oils (Bin) | -0.067 | 0.039 | -0.066 | -0.037 | -0.030 | -0.049 | 0.073 | 0.049 | -0.088 |
| Alcoholic Beverages (Bin) | -0.044 | -0.054 | -0.042 | -0.029 | -0.014 | -0.037 | 0.070 | 0.081 | -0.069 |
| Gravel/ Crushed Stone (Bin) | -0.046 | -0.050 | 0.167 | -0.014 | -0.052 | -0.020 | -0.038 | -0.055 | -0.107 |
| Non-Metallic Minerals (Bin) | -0.019 | -0.026 | 0.152 | -0.004 | -0.036 | -0.006 | -0.017 | -0.020 | -0.025 |
| Coal (Bin) | -0.105 | -0.029 | 0.234 | -0.033 | -0.100 | -0.048 | -0.095 | -0.128 | 0.303 |
| Fuel Oils/ Diesel/ Bunker C (Bin) | -0.067 | -0.069 | 0.206 | -0.010 | 0.085 | -0.016 | -0.038 | -0.039 | -0.052 |
| Coal and Petroleum Products (Bin) | -0.030 | -0.026 | 0.015 | -0.003 | 0.087 | -0.006 | -0.012 | -0.010 | 0.015 |
| Basic Chemicals (Bin) | -0.089 | 0.118 | 0.035 | 0.045 | 0.129 | -0.046 | -0.075 | -0.055 | -0.062 |
| Pharmaceutical Products (Bin) | -0.110 | -0.074 | -0.066 | 0.112 | -0.027 | 0.080 | -0.124 | 0.144 | -0.066 |
| Fertilizers Products (Bin) | -0.006 | 0.042 | -0.006 | -0.002 | -0.005 | -0.002 | -0.010 | -0.006 | 0.006 |
| Chemical Products /Preparation (Bin) | -0.037 | -0.024 | -0.019 | 0.024 | -0.008 | 0.056 | -0.045 | 0.092 | 0.039 |
| Plastics and Rubber (Bin) | -0.013 | 0.115 | -0.096 | -0.016 | 0.004 | 0.042 | -0.022 | -0.009 | -0.005 |
| Wood Products (Bin) | -0.023 | -0.032 | -0.020 | -0.015 | -0.008 | -0.020 | 0.110 | -0.032 | -0.041 |
| Newsprint/Paper/ Paperboard (Bin) | -0.069 | 0.195 | -0.066 | -0.037 | -0.044 | -0.049 | 0.219 | -0.082 | 0.065 |
| Printed Products (Bin) | -0.052 | -0.019 | -0.012 | 0.074 | -0.011 | 0.148 | -0.053 | -0.042 | 0.033 |
| Textiles and Leather (Bin) | -0.024 | -0.007 | -0.005 | -0.040 | -0.005 | 0.128 | -0.020 | -0.015 | 0.013 |
| Non-Metallic Mineral Products (Bin) | 0.010 | 0.013 | -0.077 | 0.002 | 0.018 | 0.003 | 0.009 | 0.010 | -0.013 |
| Articles of Base Metal (Bin) | -0.018 | -0.005 | -0.004 | -0.031 | -0.004 | 0.097 | -0.015 | -0.011 | -0.010 |
| Machinery (Bin) | -0.018 | -0.005 | -0.004 | -0.031 | -0.004 | 0.097 | -0.015 | -0.011 | -0.010 |
| Electronic/ Components/ Office (Bin) | -0.031 | -0.012 | -0.008 | 0.069 | -0.006 | 0.068 | -0.033 | -0.027 | 0.020 |
| Motorized /Vehicles (parts) (Bin) | -0.097 | 0.078 | -0.067 | 0.051 | -0.039 | 0.032 | 0.068 | 0.071 | 0.097 |
| Transportation Equipment (Bin) | -0.011 | -0.006 | -0.004 | 0.116 | -0.003 | -0.048 | -0.018 | -0.015 | 0.010 |
| Precision Instrument/Apparatus (Bin) | -0.064 | -0.024 | -0.016 | 0.131 | -0.013 | 0.150 | -0.068 | -0.055 | 0.042 |
| Miscellaneous Products (Bin) | -0.059 | -0.033 | -0.026 | 0.053 | -0.013 | 0.108 | -0.068 | 0.092 | -0.055 |
| Waste and Scrap (Bin) | -0.104 | 0.097 | 0.127 | -0.052 | -0.090 | -0.067 | 0.145 | 0.067 | 0.124 |
| Mixed Freight (Bin) | -0.072 | -0.060 | 0.048 | -0.062 | -0.037 | 0.089 | -0.073 | 0.108 | -0.059 |
| **Industry type** [b] | | | | | | | | | |

| Variable | Truck | Rail | Water | Air | Pipeline | Parcel | Truck- Rail | Truck-Water | Other-Mode |
|---|---|---|---|---|---|---|---|---|---|
| | **ME** | **ME** | **ME** | **ME** | **ME** | **ME** | **ME** | **ME** | **ME** |
| Mining, except oil/gas (Bin) | -0.043 | 0.055 | -0.042 | -0.027 | -0.021 | -0.034 | 0.063 | 0.102 | 0.054 |
| Wood Product Manufacturing (Bin) | -0.013 | 0.093 | -0.014 | -0.003 | -0.012 | -0.005 | -0.021 | -0.012 | 0.012 |
| Computer/ Electronic Products (Bin) | -0.006 | -0.003 | -0.002 | 0.064 | -0.001 | -0.027 | -0.010 | -0.009 | 0.006 |
| Transportation Equipment (Bin) | -0.024 | -0.032 | 0.190 | -0.005 | -0.045 | -0.007 | -0.021 | -0.025 | -0.032 |
| Miscellaneous Manufacturing (Bin) | -0.004 | -0.002 | -0.001 | 0.038 | -0.001 | -0.016 | -0.006 | -0.005 | 0.003 |
| Motor (parts) Wholesalers (Bin) | -0.018 | -0.015 | -0.018 | -0.007 | -0.006 | -0.011 | -0.014 | -0.025 | -0.113 |
| Grocery Merchant Wholesalers (Bin) | -0.042 | -0.041 | -0.042 | -0.023 | -0.013 | -0.030 | -0.046 | 0.107 | -0.130 |
| | | | | | | | | | |
| **Socioeconomic** | | | | | | | | | |
| Water Transportation at O (Est) | -0.0001 | -0.0001 | 0.0008 | 0.0000 | -0.0002 | 0.0000 | -0.0001 | 0.0001 | 0.0002 |
| Pipeline Transportation at O (Est) | -0.0001 | -0.0001 | -0.0001 | 0.0000 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |
| Rail Transportation at O (Est) | -0.0004 | 0.0008 | -0.0003 | -0.0001 | -0.0002 | -0.0003 | 0.0011 | -0.0003 | 0.0003 |
| Air Transportation at D (Est) | 0.0002 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0001 |
| Water Transportation at D (Est) | -0.0002 | -0.0002 | 0.0013 | 0.0000 | -0.0003 | 0.0000 | -0.0001 | -0.0002 | 0.0003 |
| Population at D (Est) | -0.0082 | 0.0042 | -0.0060 | 0.0009 | 0.0067 | 0.0087 | 0.0112 | -0.0131 | 0.0044 |

Bin: Binary variable. Est: Number of transportation establishments. O: Origin. D: Destination. [a] Based on the Standard Classification of Transported Goods (SCTG). [b] Based on the North America Industry Classification System (NAICS).

### *5.2. Commodity and industry type*

The second group of variables describes the commodities and industries associated with the shipments in the dataset. Observations are classified using two classification systems, i.e., SCTG, and NAICS. The next paragraphs use MEs to describe each mode and its relationship with commodities and industries.

Truck transport is the most popular freight mode used by businesses and suppliers to deliver orders. It provides reasonable prices for a wide range of distances, a level of accessibility incomparable with other modes, and low requirements for shipment loading/unloading. Shipments like those related to non-metallic mineral products have higher probability of selecting truck (0.010%). On the other hand, products like coal and fertilizer products have lower probability of being shipped by truck (-0.105% and -0.006% respectively). Truck services might be too expensive for many cheap and bulk commodities in intercity services. Similarly, waste and scrap (excludes agriculture or food) decreases the probability of selecting trucks (-0.104%).

Risk of damage can decrease the probability selecting trucks, especially for high-value shipments. In average precision instruments and computer and electronic product shipments decrease the probability of selecting trucks by 0.064% and 0.006% respectively.

Waterborne freight covers domestic commerce and international trade including deep sea, great lakes, and inland waterway routes. Water transportation is a cost-effective mode to move large quantities of goods for long distances. Products like gravel and crushed stone in average increase the probability of water by 0.167%. Similarly, coal and petroleum products in average increases the probability of selecting it by 0.015%. Other prepared food products, such as fats and oils, in average decrease the probability of water (-0.065%), which might be related to the perishable nature of these products. Newsprint, paper, paperboard in average decreases the probability of selecting water transportation (-0.0066%), possibly due to slower transit time that do not align with the requirements of these products.

Rail offers consistent and reliable schedules for production and distribution, and is the main mode for large quantities of low value-per-ton goods. By looking at rail transportation, it is observed that several products tend to select this mode, e.g., plastics and rubber (0.115%), mining products (0.055%), and fertilizer products (0.033%). On the other hand, mixed freight decreases the probability of selecting rail by 0.006%, which is probably related to the inflexibility of railway transport, i.e., its routes and timings cannot be adjusted to individual mixed-freight shipments.

The operational characteristics of the air mode makes it more attractive for light and high-value commodities. For example, the following shipments in average tend to increase the probability of selecting air, i.e., precision instruments and apparatus (0.131%), pharmaceutical products (0.112%), printed products (0.074%), as well as computer and electronic products (0.064%). In contrast, machinery products in average decrease the probability of selecting air cargo by 0.031%, which might be associated to the carrying capacity of the air mode.

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, several products and economic activities tend to select pipelines, e.g., crude oil (0.087%), and fuel oil (0.085%). Oil refineries work as intermediaries that receive crude oil via pipelines, and produce various intermediate petroleum products, i.e., diesel fuel, gasoline, naphtha, kerosene, and others mostly transported by pipelines. Pipelines also carry flammables and explosive chemical materials, which in average prefer pipelines by 0.129% and might be associated with the satisfactory safety levels related to this mode (accidents are rare in pipeline transportation).

Parcel services provide features like accelerated deliveries, tracking, signature, and specialization of express services, which are attractive for certain shipments. Thus, printed products in average increase the probability of selecting parcel by 0.148%. Electronic, other electrical equipment, components and office equipment in average increase the parcel selection probability by 0.068%. Finally, textiles and leathers increase the probability of selecting parcel service by 0.128%. Transportation equipment decreases the probability of parcel by 0.048%, likely due to the limitation in size and weight associated with parcel services.

The key benefit for intermodal truck-rail lies in the combination of flexibility provided by trucks, and cost-effectiveness provided by the rail mode. Eggs, honey and other animal products increase the probability of truck-rail by 0.142%. Similarly, agricultural products in average increase the probability of truck-rail by 0.052%. Newsprint, paper, and paperboard in average increases the probability of truck-rail by 0.219%. Additionally, mixed freight and Waste and Scrap (excludes agriculture or food) in average increase the probability of truck-rail by 0.293% and 0.023% respectively.

Truck-water also combines the main benefits of road and water modes. The line-haul economies of maritime cargo may be exploited for long distances, while the efficiencies of trucks provide flexible local pickups and deliveries. Non-metallic mineral products, in average, increases the probability of truck-water by 0.010%, which might be related to containerization that allows the mechanized handling of cargoes. Correspondingly, alcoholic beverages in average increase the probability of truck-water by 0.081%, which may be associated with specialized containers (refrigerated-container) for food transportation. On average, motorized and other vehicles (includes parts) increase the probability of selecting truck-water by 0.071%, in which they might take full advantage of roll on/off vessels designed to allow cars and trucks to be loaded directly on board. Mixed freight increases the probability of truck-water by 0.108%, which might be because intermodality enhances the economic performance of transportation chains.

The "other-mode" category encapsulates shipments sent by any other mode of transportation or an unknown mode. The CFS reports other single modes, such as belt, conveyor, and animal power. Other multiple modes, such as rail-water and other combinations not previously specified are also available in this category. In average coal products increase the probability of selecting other-mode by 0.030%. This might be associated with rail-water shipments which are cost-effective and highly available for coal. Similarly, wood products in average increase the probability of "other-mode" by 0.012%, which may be related to rail-water too. Shipments in need of time critical delivery require capable modes providing delivery within certain times. High value shipments, i.e., precision instruments, apparatus, electronics, office equipment and computer products increases the probability of other-modes by 0.19%, 0.002% and 0.12% respectively, which might be related to intermodal combinations between truck, air, parcel, among other not previously specified.

### *5.3. Socioeconomic characteristics*

The third group of variables captures the effect of socioeconomic activities on mode choice. TAZ population is found to impact the probability of freight mode choice. From the marginal effects in Table 3, it is observed that 1 million increment in population at a shipment's destination in average increases the probability of selecting truck-rail by 0.011%. Intuitively, freight demand is driven by population and economic growth in a region. Rail stations are usually built in densely populated areas for goods and passengers. Likewise, the population at shipment's destination on average increases the probability of rail by 0.004%. In contrast, a million increment in population at shipment's destination in average decreases the probability of choosing water transportation by 0.006%, which may indicate that not all densely populated areas are accessible through waterways. This highlights the overall importance of surface transportation for crowded areas and regions. In highly populated areas, coordinating surface transportation to reduce highway congestion and making quick movements for truck is critically important. Rail may help to divert truck traffic from the roads and mitigate congestion.

Additionally, the number of transportation establishment at origin and destination are found to influence mode choice. When water transportation facilities are available at the origin or destination of a shipment, the water mode is more likely to be selected. An additional water transportation establishment at the origin of a shipment in average increases the probability of water by 0.008% and 0.0013% if such establishment is at the destination. Moreover, it is observed that an additional establishment associated with pipeline services at the origin of a shipment in average increases the probability of selecting pipeline by 0.0004%. 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. Subsequently, rail transportation facilities at shipment origins influence rail mode choice. In average and additional railroad facility at the origin increases the probability of selectin rail mode by 0.0008%. These facilities are important for shippers because they can easily systematize and synchronize their supply chains. On the other hand, availability of these facilities is also necessary for intermode procedures, which require to finish processes at certain places with special equipment and advanced technologies. Finally, in average an additional air cargo facility at destination increases the selection of air by 0.0002%. The holistic findings obtained from the econometric analysis of the 2012 CFS data are significantly important to understand and characterize the complex freight mode choice process taking place in the U.S. These findings 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. The next section summarizes the work conducted in the paper and provides research directions for future developments.

## CONCLUSIONS

Freight mode choice models are important for decision making by public and private agencies. This paper 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 for the current research effort. Likewise, U.S. Census Bureau's data related to socioeconomic attributes for CFS TAZs are used to understand the relationship between freight movements and socioeconomics at the regional level. A set of variables related to shipments, commodities, industry types, and socioeconomics are found to affect freight mode choice. A discrete choice MNL model is estimated to determine the variables that are relevant in this process. Variables like route distance, unitary value, hazardous shipment transported, international shipments, are found to be significant. Commodities categorized based on SCTG, and industries based on NAICS, are also found to be intuitive and significant. These findings align with the previous results in literature. Furthermore, new findings related to the effect of socioeconomic attributes on mode choice add novel insights on the freight mode-choice process, i.e., variables like population and transportation establishments at origin/destination are satisfactorily incorporated in 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.

The results herein are of significant importance with respect to freight transportation, logistics and supply chain management. The contributions of the paper are: (1) studying the effect of socioeconomic characteristic, among other variables used in previous research, to clearly understand freight mode-choice, and (2) 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. The findings of this study provide a timely contribution to the management and improvement of services in freight transportation. Characteristics like geodesic distance, shipment value, international shipments, temperature control, among other discussed in the paper have differential impacts on mode choice. Likewise, the desirability of multiple commodity and industry types for specific transportation alternatives are clearly supported by statistical and econometric methods. The paper also enriches freight literature by indicating exogenous variables affecting mode choice at the regional level. The strong role played by the socioeconomic variables, like population and number of transportation establishments at origins and destinations, provides new ideas on the role of these variables for freight mode choice.

Several future research directions can be explored to enhance the value of this work. The key challenge in the current study is the lack of additional freight data that is necessary to understand the behavior of different actors involved in the decision process. Future developments can take advantage of new datasets (public or private) to refine and support the results reported in the paper. Although 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. Adapt new feature selection techniques to identify the most relevant and informative variables or attributes from the CFS data that contribute to understanding and predicting commodity flows. By selecting the most important features, the goal is to reduce the dimensionality of the data, improve model performance, and enhance interpretability (Hmouda, 2022). Such as, using the Bayesian statistics for estimation in which is useful with limited data available that identifies significant factors and explicate unobserved heterogeneity across observations (Jaber, 2022).

Future developments should also address the estimation of more sophisticated econometric approaches, e.g., MNL models with random parameters, which allow random taste variation for selected variables. Likewise, discrete-continuous choice models are required to properly incorporate the effect of shipment size in this decision process and are currently under development by the research team.

## DECLARATIONS

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### Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

### Authors' contribution

Taleb Eissa, Rodrigo Mesa-Arango, Hussin A.M Yahia, and Saeed Alghamdi contributed to the research, data analysis, and manuscript writing.

**Competing interests**

The authors declare no competing interests in this research and publication.

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