Development of Structural Equations Models of Statewide Freight Flows

by

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Dedication

I dedicate this thesis to my father, Mr. J. V. S. R. K. Prasad, who sacrificed all his happiness for me. I was really fortunate to have him as my father, and I take this opportunity to express my deep respect for him. I am also indebted to my mother, sister and brother for their constant encouragement and co-operation.
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Development of Structural Equations Models of Statewide Freight Flows

Siva S. Jonnavithula

ABSTRACT

The modeling of freight travel demand has gained increasing attention in the recent past due to the importance of efficient and safe freight transportation to regional economic growth. Despite the attention paid to the modeling of freight travel demand, advances in modeling methods and the development of practical tools for forecasting freight flows have been limited. The development of freight demand models that incorporate the behavioral aspects of freight demand face significant hurdles, partially due to the data requirements, which are a consequence of the inherent complexity of the mechanisms driving freight demand. This research attempts to make a contribution in this context by proposing a relatively data simple, but behaviorally robust statewide modeling framework for the state of Florida, in the spirit of an aggregate level four-step planning process.

The modeling framework that is developed in this research can be applied to the modeling of freight travel demand using data contained in readily available commercial databases such as the Reebie TRANSEARCH database and the InfoUSA employer database. The modeling methodology consists of a structural equations modeling framework that can accommodate multiple dependent variables simultaneously. This
framework predicts freight flows on various modes between two zipcodes based on the socio-economic characteristics and the modal level of service characteristics. Separate models have been developed for various commodity groups.

The estimated models for various commodity groups are found to offer statistically valid indications and plausible interpretations suggesting that these models may be suitable for application in freight transportation demand forecasting applications. The sensitivity analysis conducted on these models clearly added evidence to the fact that employment is the key factor influencing freight flows between two regions.
Chapter 1

Introduction

1.1 Background

Profound and revolutionary transformations in the areas of computer technology, communication networks, and information and production systems have characterized the latter part of the 20th century and the beginning of the 21st century. The development and growth of the internet combined with the convergence of these trends has made possible ever deeper changes in the ways both businesses and consumers do their economic transactions. Business-to-business and business-to-consumers internet systems enable businesses to effectively integrate their operations in a seamless way, and enable both businesses and consumers to have access to vendors way beyond the traditional geographic boundaries. Such internet systems are intensely changing the nature and characteristics of production systems, commerce in general, and the supporting freight transportation system (Holguin-Veras et al., 2003). Of 50 leading shipping companies polled in 1996 at the World Express & Mail Conference in Brussels, more than half cited e-commerce as the single most important factor driving their growth (Holguin-Veras et al., 2003). In that year DHL Worldwide Express, for example, projected 40% annual growth for its online business. Also, Fingerhut Business Services Inc. in Minneapolis credited 70% of its fulfillment business to internet companies including new customers such as the Wal-Mart Stores Inc. Web site and eToys Inc. (Holguin-Veras et al., 2003).
In spite of the burst of the “dotcom bubble”, US census data indicated that ecommerce sales in the first quarter of 2001 increased 33.5% with respect to the first quarter of 2000 (Hu, 2001; Holguin-Veras et. al., 2003). There is agreement among business analysts that: (a) e-commerce will keep growing in the foreseeable future; and (b) the totals for business-to-consumers will be dwarfed by business-to-business transactions, once businesses fully integrate their operations with e-commerce (Lahsene, 2001; Holguin-Veras et. al., 2003). All of this points toward an increasing role of the freight transportation system as the conveyor of goods for the e-commerce systems.

1.2 Importance of Freight Transportation

In addition to e-commerce, economic globalization, high-tech warehousing, and Just-In-Time production systems are also increasing the already important role of the freight transportation system. More and more, businesses and consumers alike are relying on the freight transportation industry for the delivery of goods on demand, thus reducing the need for inventory stocks (Holguin-Veras et. al., 2003). Thus, freight transportation is one of today's most important activities, not only as measured by the yardstick of its own share of a nation's gross national product (GNP), but also by the increasing influence that the transportation and distribution of goods have on the performance of virtually all other economic sectors (Crainic et. al., 1997). A few figures illustrate these assertions. In 1978, Taff estimated that transportation accounts for approximately 10% of the United States GNP and current figures could very well be significantly larger (Crainic et. al., 1997). In the United Kingdom, for example, it has been estimated that transportation represents 15% of national expenditures (Crainic et. al., 1997). These figures are similar to those
observed for Canada (some 16%) (Zalatan, 1993) and France (around 9%) (Crainic et. al., 1997). Furthermore, transportation represents a significant part of the cost of a product. In Canada, for example, this part may reach 13% for the primary industrial sector and 11% for the transformation and production industry (Owoc et. al., 1992; Crainic et. al., 1997).

At the same time, there is increasing pressure from both community and environmental groups to ameliorate the negative impacts of freight activity. More and more, local communities, environmentalists, and researchers are demanding actions to reduce the negative externalities of freight traffic. In this context, a number of studies are looking at the environmental impacts of freight activity upon local communities (Holguin-Veras et. al., 2003). However, in spite of the negative externalities that freight activity produces, there is no doubt that freight transportation makes significant contributions to the vitality of the nation’s economy. In 1997, the value of the cargoes transported amounted to 6.9 trillion dollars, with a total tonnage equal to 11 billion tons, totaling 2.66 trillion ton-miles across the continental United States. Trucking, the dominant mode, accounts for 70% of the total tonnage (Bureau of Transportation Statistics, 1999).

Moreover, in a context of increasing economic globalization and in the interest of minimizing the total costs of producing and delivering goods, production systems are reaching out to global markets of supply and demand. The net effect of economic globalization is to extend the geographic realm of freight transportation systems. Once often confined by national boundaries, the transportation systems of today and tomorrow
will have to operate across multiple nations at a global scale, and at some point in time they will operate as if political boundaries did not exist.

All of the above imply that the freight transportation systems of the 21st century will be expected to cover a larger geographic area, be more responsive to user needs and expectations, and reduce the environmental, safety & health externalities associated with truck traffic. Moreover, the freight transportation systems have to achieve all of this in a context in which the provision of additional freight infrastructure capacity will become more difficult and expensive.

1.3 Problem Definition

Freight transportation lies at the heart of our economic life. In industrialized countries, it accounts for significant share of the gross national product. In developing countries, it is the essential ingredient of sustainable development. With free trade zones emerging in several parts of the world and with the globalization of the economic system, freight transportation will in all likelihood play an even more major role in years to come.

The trend towards larger, more integrated and more efficient transportation systems is likely to remain and should create the need for better planning at the strategic, tactical and operational levels (discussed in Chapter 2). Thus, various freight demand modeling methodologies have emerged over time to assist in freight transportation planning efforts. Some of the models are simple growth factor models while others are more complex and accurate autoregressive integrated moving average models (ARIMA), elasticity models,
network models of logistics, direct demand and aggregate demand models, disaggregate demand models, and economic input-output models. Major research efforts have been devoted to the design of models for dynamic and stochastic problems. Key developments are also taking place in the artificial intelligence-related area of metaheuristics such as tabu search, genetic algorithms, neural networks, etc (Crainic et. al., 1997). These have already given a new impetus to the whole area of global optimization and have lead to a rethinking of the entire field of heuristics. These developments, coupled with the growth of parallel methods, mean that in the near future larger and more complex problems should be amenable to analysis and optimization. In particular, significant advances should be expected in the areas of dynamic, stochastic and real-time programming, central to so many transportation systems. Chapter 3 furnishes a comprehensive literature review on the various freight demand models that have been developed till date.

Despite the attention paid to the modeling of freight travel demand and advances in modeling methods, the development of practical and reliable tools for forecasting freight flows have been limited. This limitation has been due to complexity of freight demand modeling arising from the multiple dimensions of freight demand (volume, weight and trips) under the control of a number of decision-makers (drivers, dispatchers, freight forwarders) who interact in a rather dynamic environment. Moreover, freight transportation data has been traditionally difficult to collect due to the proprietary nature of the data and due to the difficulty with identifying the proper entity to which a freight transportation survey needs to be administered. These factors contributing to the complexity of freight demand modeling are discussed in detail in Chapter 2.
It is against the backdrop of such limitations that the Florida Department of Transportation, as part of its ongoing research into the development of statewide freight transportation models, desired to develop a robust and practical statewide modeling framework that can be used to estimate freight travel demand in Florida at a microscopic level using data contained in readily available commercial databases. Thus, the objective of this study is to propose a relatively data simple, but behaviorally robust statewide freight travel demand modeling framework at a microscopic level in the spirit of an aggregate level four-step planning process.

1.4 Objectives

The primary objective of this dissertation is to develop a behaviorally robust and practical modeling framework that can quantify and predict freight flows by various modes between origin-destination pairs in the state of Florida. The other distinguishable objectives would be as follows:

- To understand the factors that contribute to the complexity of freight demand modeling;
- To perform a comprehensive literature review on freight demand modeling techniques and study their advantages and limitations;
- To develop a model concept that is data simple, but largely in line with paradigms and freight transportation demand-supply relationships identified in the literature;
- To identify a suitable freight data source and prepare a comprehensive freight flow database merging freight data with other data, as required by the developed model concept;
To perform a descriptive analysis of the developed freight flow database, in order to understand the freight flow patterns in Florida;

To estimate the statewide freight travel demand at a microscopic level using an appropriate modeling methodology, and

To analyze the potential influence of various factors on freight travel demand using sensitivity analysis.

1.5 Outline of Thesis

The remainder of this thesis is organized as follows. The next chapter provides a good understanding of the factors that contribute to the complexity of freight demand modeling. This chapter is followed by a comprehensive literature review that discusses the advantages and limitations of various freight demand modeling methodologies developed earlier. The fourth chapter identifies the paradigms and freight transportation demand-supply relationships identified in the literature and leads to the model concept that will be used in this study. In the fifth chapter, various data sources available at disposal are reviewed and the database preparation is discussed. This chapter is followed by a description of the database used in the study. The seventh chapter discusses the identification of an appropriate modeling technique and its methodology. The model estimation results are provided in the eighth chapter. The sensitivity analysis performed to analyze the potential influence of various factors on freight travel demand, using the developed model systems is discussed in chapter nine. Finally, conclusions and implications of the research findings are discussed in the tenth chapter together with future directions in freight demand modeling.
Chapter 2

Complexity of Freight Demand Modeling

2.1 Factors Affecting Freight Transportation

The freight transportation industry, as all other economic sectors, has to achieve high performance levels both in terms of economic efficiency and service quality. Economic efficiency because a transportation firm has to make profits while at the same time competing in an increasingly open and competitive market where cost is still the major decision factor in selecting a carrier or distribution firm. Yet, one also observes an increasing emphasis on the quality of the service offered. Indeed, the new paradigms of production and management, such as small or no inventories associated to just-in-time procurement, production and distribution, quality control of the entire logistics chain driven by customer demand and requirements, etc., impose high service standards on the transportation industry. This applies, in particular, to total delivery time and service reliability (Crainic et. al., 1997).

The political evolution of the world also has an impact on the transportation sector. The emergence of free trade zones, in Europe and on the American continent in particular, has tremendous consequences for the evolution of freight transportation systems, not all of which are yet apparent or well understood. For example, open borders generally mean that firms are no longer under the obligation to maintain a major distribution center in
each country. Then, distribution systems are reorganized and this often results in fewer warehouses and transportation over longer distances (which still have to perform according to low cost-high service standards). A significant increase in road traffic is a normal consequence of this process, as may be observed in Europe. A study conducted for the European Parliament forecasts a 34% increase in land-based transport for the countries of the European Economic Community between 1988 and the year 2000 (Crainic et. al., 1997).

Additional factors which impact on the organization, operation policies and competitiveness conditions in the transportation industry are the internationalization of the economy and the opening of new markets due to political changes, mainly in central Europe and Asia, and the evolution of the regulatory environment. The first two imply larger economic spaces and transportation networks. Thus, from 1971 to 1988, the total volume of goods moved by ship has doubled, while the total number of kilometers covered by air cargo quadrupled (Crainic et. al., 1997). Changes to the regulatory environment of transportation, particularly significant in North America and starting to gather momentum in Europe and elsewhere also has a powerful impact on the operation and competitive environment of transportation firms. The deregulation drive of the 80's has seen governments remove numerous rules and restrictions, especially with regard to the entry of new firms in the market and the fixing of tariffs and routes, resulting in a more competitive industry and in changes in the number and characteristics of transportation firms. At the same time, more stringent safety regulations have been
imposed, resulting in more complex planning and operating procedures (Crainic et. al., 1997).

Moreover, there are several different types of players in the transportation field, each with its own set of objectives and means. However, the most important players are the shippers, carriers and governments (Crainic et. al., 1997). Producers of goods require transportation services to move raw materials and intermediate products and to distribute final goods in order to meet demands. Hence, they determine the demand for transportation and are often called shippers (Other players, such as brokers, may also fall in this category). Transportation is usually performed by carriers, such as railways, shipping lines, motor carriers, etc. Thus, one may describe an intermodal container service or a port facility as a carrier. Governments constitute another important group of players. First, they regulate several aspects of freight transportation. Then, they also provide a large part of the transportation infrastructure: roads and highways, and often a significant portion of the port, internal navigation, and rail facilities.

2.2 Freight Transportation Planning

As described in the previous section, transportation systems are rather complex organizations which involve a great deal of human and material resources and which display intricate relationships and trade-offs among the various decisions and management policies affecting their different components. Crainic and Laporte (1997) classify these policies according to the following three planning levels.
2.2.1 Strategic Planning

Strategic (long term) planning at the firm level typically involves the highest level of management and requires large capital investments over long time horizons. Strategic decisions determine general development policies and broadly shape the operating strategies of the system. Prime examples of decisions at this planning level are the design of the physical network and its evolution (upgrading or resizing), the location of main facilities (rail yards, multimodal platforms, etc.), resource acquisition (motive power units, rolling-stock, etc.), the definition of broad service and tariff policies, etc. Strategic planning also takes place at the international, national and regional levels, where the transportation networks or services of several carriers are simultaneously considered. State transportation departments, consultants, international shippers, etc. engage in this type of activity.

2.2.2 Tactical Planning

Tactical (medium term) planning aims to ensure, over a medium term horizon, an efficient and rational allocation of existing resources in order to improve the performance of the whole system. At this level, data is aggregated, policies are somewhat abstracted and decisions are sensitive only to broad variations in data and system parameters (such as the seasonal changes in traffic demand) without incorporating the day-to-day information. Tactical decisions need to be made mainly concerning the design of the service network, i.e., route choice and type of service to operate general operating rules for each terminal and work allocation among terminals, traffic routing using the available
services and terminals, repositioning of resources (e.g., empty vehicles) for use in the next planning period.

2.2.3 Operational Planning

Operational (short term) planning is performed by local management (yardmasters and dispatchers, for example) in a highly dynamic environment where the time factor plays an important role and detailed representations of vehicles, facilities and activities are essential. Scheduling of services, maintenance activities, crews, etc., routing and dispatching of vehicles and crews, resource allocation are important operational decisions.

This classification highlights how the data flows among the decision-making levels and how policy guidelines are set. The strategic level sets the general policies and guidelines for the decisions taken at the tactical level, which determines goals, rules and limits for the operational decision level regulating the transportation system. The data flow follows the reverse route, each level of planning supplying information essential for the decision making process at a higher level. This hierarchical relationship prevents the formulation of a unique model for the planning of freight transportation systems and calls for different model formulations addressing specific problems at specific levels of decision making.

2.3 Complexity of Freight Demand Modeling

The hierarchical relationship discussed in the above section puts a significant amount of pressure on metropolitan planning organizations (MPOs) in enhancing their freight
transportation planning processes. Further, federal legislations such as the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Transportation Equity Act for the 21st Century (TEA-21), and a host of state-level initiatives necessitate the undertaking of comprehensive freight transportation planning and mobility strategies. However, this objective is confounded by the lack of freight-transportation-specific demand modeling methodologies. For the most part, the bulk of freight transportation modeling applications are nothing more than adaptations of transportation modeling methodologies originally designed for passenger transportation, that tend to overlook the fundamental differences between freight movements and passenger transportation. This is because passenger issues traditionally have been assigned the highest priorities, effectively reducing the amount of resources and attention allocated to freight transportation research and education (Holguin-Veras et. al., 2000).

Thus, the most significant hurdle to including freight transportation in the transportation modeling process is that most of the demand forecast methodologies have been developed for passenger trips, not freight trips. This methodological void usually is filled by simplistic approaches such as assuming that freight trips follow the same behavioral mechanisms as passenger trips, which is an implicit assumption when truck traffic is estimated as a function of passenger traffic (Holguin-Veras et. al., 2000). Although the error induced by this assumption may not be important for small urban areas where the number of freight trips is relatively small, it cannot be used in large metropolitan areas such as New York City where freight-related trips are a major contributor to urban congestion, and freight-specific transportation policies are warranted.
The complexity of modeling freight demand arises from a combination of factors (Holguin-Veras et. al., 2000). First and foremost, multiple dimensions are to be considered (Ogden, 1992; Holguin-Veras et. al., 2000). Whereas in passenger transportation there is only one unit of demand – that is, the passenger, who for the most part happens to be the decision-maker – in freight transportation there are multiple dimensions (volume, weight and trips) under the control of a number of decision-makers (drivers, dispatchers, freight forwarders) who interact in a rather dynamic environment. Also, a significant portion of freight demand is discretionary in nature. In this context, a relatively small number of companies have control over a significant number of freight movements. Integrating their behavior into planning models is rather challenging because the dynamics of their decision-making process, marked by their commercially sensitive nature, are not part of the public domain.

The second major factor contributing to the complexity in modeling freight demand is significant difference in time value, or opportunity costs, exhibited by cargoes (Cambridge Systematics, 1997). Cargo time value – determined by opportunity costs – exhibits a much wider range compared to the passenger’s time value ranges within the same order of magnitude. Cargoes’ opportunity costs are determined by a combination of the intrinsic cargo value (determined by market value and replacement costs) and the logistic cargo value (a function of the importance of the cargo for the production system at a given moment in time and inventory levels) (Holguin-Veras et. al., 2000). At one end, low-priority cargoes may have intrinsic cargo values as low as $9/ton (gypsum); and at the other, high priority cargoes have intrinsic cargo values that frequently exceed
$500,000/ton (e.g., computer chips) (Holguin-Veras et. al., 1999). These figures would increase significantly once the logistic cargo value is factored in.

The third and the most important factor that makes the freight demand modeling complicated is its data collection. Major advances have been made in the development of freight transportation modeling methods and frameworks (Este, 2002; Regan et. al., 2002). However, many of these methods have not seen application in practice partially due to the lack of adequate data to support their estimation and application to forecasting. Freight transportation data has been traditionally difficult to collect due to the proprietary nature of the data and due to the difficulty with identifying the proper entity to which a freight transportation survey needs to be administered. The absence of freight transportation data is particularly critical at the disaggregate (spatial and temporal) level, making the estimation of disaggregate models of freight transportation demand a challenge that needs to be addressed. While there are aggregate level freight transportation data sets such as the commodity flow survey (CFS) data, these data sets are generally insufficient to develop models that can estimate origin-destination freight flows by mode and commodity.

The multitude of factors discussed in this chapter result in the complexity of freight demand modeling. In this context, there is a need for developing practical and reliable modeling frameworks for directly estimating freight transportation flows by commodity and mode between origin-destination pairs. The next chapter provides an overview of the various freight demand models that have been developed till date.
Chapter 3

Literature Review

3.1 Introduction

Freight transportation is a vital component of the economy. It supports production, trade, and consumption activities by ensuring the efficient movement and timely availability of raw materials and finished goods. In consequence, freight transportation represents a significant part of the cost of a product, as well as of the national expenditures of any country. Moreover, the significance of freight movement and activity has been increasing in terms of both its role in the economy and its potentially adverse impacts on safety and congestion on the transportation system (Pendyala et. al., 2000; Czerniak et. al, 2000; DeWitt et. al., 2000; Regan et. al., 2000). Thus, it is not surprising that freight transportation planning has attracted the attention of researchers since the early 1970s (Baumol et. al., 1970; Allen, 1977; Slavin et. al., 1976).

Freight travel demand and supply are key elements of the overall freight transportation planning process that also considers the socio-economic environment, intermodal transportation network, policy and regulatory environment, and system performance measures. Freight demand models can be used to support a host of planning applications including facility planning, corridor planning, strategic planning, business logistics planning, and economic development. Wide range of demand models from simple growth
factor models to more complex and accurate autoregressive integrated moving average models (ARIMA), elasticity models, network models of logistics, direct demand and aggregate demand models, disaggregate demand models, and economic input-output models have been developed (Ogden, 1991; Cambridge Systematics, 1997; Faris et. al., 1999; Hancock et. al., 2000; List et. al., 1995).

Historically, freight transportation demand models have been classified based on (a) the dimensions of freight demand and (b) the spatial levels of consideration. Holguin-Veras (undated) presented an extensive literature review on the dimension based freight demand modeling, and Regan and Garrido (2002) presented a similar one on the spatial resolution based freight demand modeling. The following sections offer a combined review of freight demand modeling based on these two literature reviews.

3.2 Freight Demand Modeling Based on the Dimension of Demand

One of the unique features of freight transportation planning is that there are a number of different dimensions to be taken into account, most notably: weight, volume, number of vehicle trips, and value of the commodities being transported. Each of these dimensions represents a different way to define and measure freight transportation demand, with important implications for freight demand modeling. The existence of these different dimensions has resulted into two major modeling platforms: vehicle-trip based modeling and commodity-based modeling. Various modeling approaches have been used on each of these platforms. The most widely used options include (a) variants of the Four Step Model, (b) direct demand models, and (c) input-output models. Jose Holguin-Veras and
Ellen Thorson (2000) summarize the major combinations as shown in Table 3.1. They also describe the processes for both the approaches as shown in Figures 3.1 and 3.2.

**Table 3.1**

**Modeling Platforms and Approaches Most Frequently Used**

<table>
<thead>
<tr>
<th>Modeling Platform</th>
<th>Modeling Approach</th>
<th>Variants of Four Steps Model</th>
<th>Direct Demand Models</th>
<th>Input-Output Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commodity-based</td>
<td></td>
<td>Used in both urban and regional applications</td>
<td>Frequently used in corridor analysis</td>
<td>Used in regional economic development studies, rarely in urban areas, though land use – transportation models are based on I-O</td>
</tr>
<tr>
<td>Trip-based</td>
<td></td>
<td>Used in both urban and regional applications</td>
<td>Frequently used in corridor analysis</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

*Source: Holguín-Veras and Thorson, 2000*

**Figure 3.1**

**Model Components of Trip-based Approaches**

<table>
<thead>
<tr>
<th>Step:</th>
<th>Approach:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trip generation rates or zonal regression models</td>
</tr>
<tr>
<td>Trip generation</td>
<td>Gravity models (simply or doubly constrained) or Intervening Opportunities</td>
</tr>
<tr>
<td>Trip distribution</td>
<td>Standard traffic assignment techniques</td>
</tr>
<tr>
<td>Traffic assignment</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Holguín-Veras and Thorson, 2000*
3.2.1 Trip-Based Models

As the name implies, trip-based models focus on modeling vehicle-trips. As shown in Figure 3.1, these models have three components: trip generation, trip distribution and traffic assignment. Trip-based models do not need mode split or vehicle loading models, since the focus is on vehicle-trips, which assumes that the mode selection and the vehicle selections were already done.

List and Turnquist (1995) presented a trip-based modeling method for estimating multi-class truck trip matrices from partial and fragmentary observations. Data sets of widely varying character were combined in an efficient and effective manner so that each piece of information had a role in developing the estimated flows. O-D matrices were estimated
from truck traffic counts, O-D synthesis. The technique assumed that the links in the analysis network consisted of at least three attributes: a directional flag, a use label (e.g. truck class) and a travel time which may vary according to the time of day. In addition, the technique assumed the study area is divisible into non-overlapping zones, each zone having a 'centroid', where trips originate and/or terminate. The input data were of three types namely: link volumes or classification counts, partial O-D estimates for various zones, including time periods and truck classification, and origin/termination information. In essence, nine O-D matrices were estimated for three time periods (6:00-10:00 A.M., 10:00 A.M.-3:00 P.M., and 3:00-8:00 P.M.) and three truck classifications (van, medium truck, and heavy truck).

Another example of trip-based models is the Quick Response Freight Manual (QRFM), developed by Cambridge Systematics, Inc. (1996). The model consists of the following steps:

- Obtaining data on economic activity for traffic analysis zones (including employment by type and the number of households);
- Applying trip generation rates to estimate the number of commercial vehicle trips for each traffic analysis zone;
- Estimation of commercial vehicle volumes at external stations;
- Estimation of the number of commercial vehicle trips between pairs of traffic analysis zones or external stations;
- Estimation of the mode share for each trip;
- Loading the O-D trip to the network; and
Comparison of control VMT with estimated VMT.

Jack Faucett Associates (1999b) illustrate the trip-based modeling process by generating truck trips as a function of different land uses and trip data from trip diaries or shipper surveys. They calculate the trip rates as a function of socio-economic data (trips per employee) and land use data (trip per acre). The generated trips are distributed using some form or other of spatial interaction models, most commonly a form of gravity model. The gravity model is typically calibrated using trip length frequency distributions obtained from trip diaries.

Holguín-Veras (2000) proposed the “Integrative Freight Market Simulation” (IFMS), currently being funded by the National Science Foundation (NSF) Exploratory Transport Industries (ETI) program (2000). The underlying assumption of IFMS is that urban good movements are to be modeled as a market in equilibrium in which the different players, such as trucking companies maximize profits. Thus, IFMS considers the fundamental interactions between the key participants (i.e., producers, consumers and freight companies) in a game theoretical formulation. IFMS deals with two different problems based on a bi-level formulation. The first problem, formulated as a Cournot-Nash equilibrium problem, entails the estimation of the transportation service (i.e., amount of loaded and empty trips that will be contributed to the market) provided by the different clusters of companies in order to maximize profits. The second problem involves a multi-vehicle routing problem that is intended to estimate the origin-destination patterns that, while consistent with the Cournot-Nash solution, also meet the other system constraints.
In essence, the proposed framework would attempt the estimation of the trips made by freight transportation providers in the study area, such that:

- Freight transportation companies maximize profits while market equilibrium conditions are met (Condition I)
- The user requirements are met, i.e., the commodities produced by and attracted to each TAZ are transported (Condition II)
- The resulting trip chains are consistent with trip chain patterns captured in travel diaries, or alternatively, known Trip Length Distributions (Condition III)
- The resulting commercial vehicle traffic is consistent with secondary data sources, e.g., ITS traffic data (Condition IV).

Houlguin-Veras (2000) terms conditions I and II as primary constraints, i.e., constraints that must be met. He refers to conditions III to IV as secondary constraints, which could be relaxed under certain circumstances. Condition I ensures proper consideration of the interactions among freight providers in the supply market. Condition II ensures consideration of user requirements. Conditions III and IV are information constraints expected to bound the solution.

All the studies reviewed above treat trips as aggregated in a zonal level such as a TAZ, county, state, etc. Watson (1975), however, presented an approach where each firm or industrious agency is viewed as a unit that has attributes of employee, floor acreage, etc. The trips from these agencies can be regressed to these attributes. This disaggregate approach is attractive due to its capability to capture the attributes that influence the trip
generation and attraction. This approach, however, is not adopted in practice, probably due to its extensive data need to develop these models.

### 3.2.2 Commodity-Based Models

Commodity-based modeling, on the other hand, focuses on the amount of commodities being transported, usually defined by its weight. The focus on commodities enables these models to depict the fundamental processes taking place and, in doing so, to take into account the economic characteristics of cargoes. The components of the modeling process are depicted in Figure 3.2.

Commodity based modeling is comprised of the following process. The first step is the commodity generation models that are used to estimate the total number of tons produced and attracted by each zone in the study area. The second step is the distribution phase, wherein the tonnage moving between each origin-destination pair is estimated using gravity models and other forms of spatial interaction models. The third step is the mode split component, intended to estimate the number of tons moved by the various modes which is done by applying discrete choice models and/or panel data from focus groups of business representatives or freighters (Cutler et. al., 2000). Finally, in the traffic assignment phase of commodity-based models, a combination of vehicle loading models and complementary models that capture empty trips, applied to origin-destination matrices by mode, are used to assign vehicle trips to the network. (Holguin-Veras et. al., 2000; Hautzinger, 1984).
Jack Faucett Associates (1999b) summarize commodity based modeling as follows: The starting point is a known region-to-region table of commodity flow tonnage based on economic output forecasts and established regional trade patterns. The region-to-region flows, depicting inbound and outbound flow patterns, are disaggregated to the zonal level based on economic data, reflective of the intensity of production and consuming industries. Economic data and input-output tables are used to estimate the quantity of each commodity produced and consumed within each geographic unit. Knowing the commodity being shipped, it becomes possible to link producers of a good with its consumers through these economic relationships. Once commodity flows are assigned to origins and destinations, they are converted to truck trips or vehicle trips.

3.2.3 Trip-Based vs. Commodity-Based Freight Models

Trip-based models have some advantages. The most important advantage is that traffic data is relatively easy to obtain. Furthermore, an increasing number of Intelligent Transportation Systems (ITS) applications are able to track the movements of vehicles through the highway networks, becoming an important source of traffic data. The other advantage is that these types of models consider both loaded and empty trips because of their focus on vehicle trips, unlike the commodity-based models (Holguin-Veras et. al., 2000; Holguin-Veras et. al., 1999; Cambridge Systematics, 1997; Ogden, 1992).

However, trip-based models have some significant limitations. As demonstrated by Holguin-Veras and Jara Diaz (1999) and McFadden et al (1986), they are unable to take into account the economic characteristics of the cargoes that play an important role in the
vehicle selection, mode choice and routing processes. The other limitation is that these models are of limited applicability to multimodal freight transportation systems because of their focus on the vehicle trip, which in itself is the result of a choice process that already took place (Holguin-Veras et. al., 2003).

In regard to these limitations of trip-based models, commodity-based models are attractive because of their focus on modeling the amount of freight measured in tons, or any comparable unit of weight. Thus, they capture more accurately the fundamental economic mechanisms driving freight movements, which are largely determined by the cargoes’ attributes (e.g., shape, specific weight, volume). Thus, this study focuses on developing statewide commodity-based freight demand models, rather than the vehicle-trip based models.

However, commodity based models are limited in their ability to model empty trips, that are the result of logistic decisions not directly explained by the commodity flows. Researchers address this limitation at the calibration stage by expanding the commodity distribution matrix so that the resulting traffic assignment resembles the calibration values (Houlguin-Veras et. al., 2000 and 2003). This approach is debatable, although it is widely used. First, there is no way to ensure that the resulting number of empty trips is consistent with the area wide estimates of the total number of empty trips. Second, expanding a commodity trip matrix to compensate for the missing empty trips implies that empty trips are directly correlated with the commodity flows. This assumption is
very weak because the commodity flow between two zones determines the amount of loaded trips between them, not the amount of empty trips.

Holguin-Veras and Thorson (2003) have overcome this limitation of commodity based models by developing complementary model formulations to depict empty trips as a function of the routing choices that the commercial vehicle operators make, which are based on the commodity flows in the study area. These formulations were based on probability principles and spatial interaction concepts. The models were based on the concept of order of a trip chain, defined as the number of additional stops with respect to the primary trip, and provided a statistical link between the first order and higher order trip chains. Three different destination choice probability functions were hypothesized based on different assumptions about the destination choice process. One of these formulations included a memory component that takes into account the amount of travel already done in the destination choice process. An example, based on data from an origin–destination study in Guatemala City, was included to show the practicality of the proposed models. The numerical results indicated a slight superiority of the formulation that takes into account the length of the previous trip. In all cases, their model outperformed the previous models which seem to be an indication of the reasonableness of its fundamental assumptions and specifically of the benefits of including a memory function. The paper also provided empirical evidence of the importance of modeling empty trips.
3.3 Freight Demand Modeling Based on the Spatial Resolution

Regan and Garrido (2002) classify freight transport models by spatial considerations into three broad categories: global (international), intercity, and urban.

3.3.1 Global Freight Transport Models

Global freight transport models aim to model the goods movement between different countries. In the recent years, multinational firms have dispersed all over the world to take advantage of competitive prices for both materials and labour. The goods components are manufactured in different locations and hence need to be transported to a certain location to be assembled and shipped abroad again. This has resulted in an explosive growth of global freight transport in the last decade.

Regan and Garrido (2002) identified three main approaches to model global demand for shipping. The first approach follows the standard theory of international trade (Cassing, 1978). The second approach relies on an aggregate cost function for a given industrial sector, from which a demand function for shipping is derived. The demand function is such that it minimises the cost function. This approach allows to work with an analytical expression for the demand function. Nevertheless, Regan and Garrido (2002) identified that this approach has two main drawbacks: the data requirement and the computational complexity of the solving process (a non-linear multidimensional minimization).

The third approach identified by Regan and Garrido (2002) is the use of spatial interaction models to estimate trade flows. This approach is attractive for practical use in
the medium and short run as it models vehicle movements directly, instead of modeling the demand for commodities. However, they are not adequate for forecasting purposes as they are cross-section models. These models are not data demanding as they reflect mere tendencies in spatial distribution according to an impedance function. However, these models do not capture behavioural aspects of freight demand and thus are less powerful than the more data-demanding approaches. Thus, it can be observed that the freight demand models developed till date need to compromise between the data requirements and the behavioural aspect. In this context, this study focuses on overcoming this limitation by developing a statewide behavioural freight demand model that is not data intensive.

Markusen and Venables (1998) used the industrial-organisation approach to model international trade. This model endogenously generates both national and multinational enterprises and goods flows. However, this model has not been applied in practice due to the extensive data requirement. The model requires estimates of demand elasticity for each type of good, wages, transport cost factors, as well as utility functions to represent the consumers in each country.

Garrido (2000) described a space-time autorregressive moving average model for truck flows through the Texas-Mexico border. The model data needs are series of international vehicle flows at different points in space, which is easily measured and available for public use. However, this model does not capture behavioural aspects of the freight movement.
Input-output analysis has been used for both intercity and global freight transport modeling since 1940s. The basic input-output model consists of a table that accounts the amount of a good involved in the production of another good, which is reflected by the purchases of an industrial sector from the rest of the industries within a given market. Leontief (1941) developed a standard approach assuming constant technical coefficients (i.e. the share of each good involved in the production of a given good), constant trade coefficients (i.e., ratio between the production of a good in a given location and the total production of that good), and constant modal split. These assumptions significantly lower the data requirements and the mathematical treatment. However, these assumptions rarely hold in practice and hence the prediction capability of this approach is rather scarce. Inamura and Srisurapanon (1998) developed a more practical approach by estimating a rectangular input-output model with fixed coefficients but disaggregated not only by products but also by region of origin and region of destination. The latter gives the model more flexibility than the original fixed implementation by Leontief.

3.3.2 Intercity Freight Transport Models

Intercity freight transport models have been widely addressed in the literature. Winston (1983) classifies these models into aggregate and disaggregate levels.

3.3.2.1 Aggregate Level Models

Quandt and Baumol (1966) developed one of the first aggregate models reported in the literature which is called "abstract mode" model. It assumes that the freight travel demand for a mode depends on the attributes of that specific mode and the attributes of
the available "best mode". However, even this model is data intensive that makes it impractical. Another early approach is the "aggregate logit" modal split model (Morton, 1969; Boyer, 1977; Levin, 1978). This model is a log-linear regression whose dependent variable is the ratio between the market shares of two modes. These models are attractive in practical applications, especially for large-scale problems, as the model's structure is very simple and not computationally demanding. However, the drawback is the lack of theoretical foundation.

Oum (1979) analysed two aggregate modal split models used in practice: the "price-difference" and "price-ratio" models. Oum showed that both specifications have weaknesses from the economic point of view, arising when logit models are estimated with aggregate data.

3.3.2.2 Disaggregate Level Models

Regan and Garrido (2002) identified two classes of disaggregate freight demand models reported in the literature: the so-called "behavioural" and "inventory" models. Behavioural models focus on the mode choice decision made by either the consignee or the shipping firm, whereas inventory models analyse the freight demand from the viewpoint of an inventory manager.

The behavioural models assume rational behaviour from the decision-maker and attempt to explain the freight travel demand as the result of a process of utility maximization made by the decision-maker. The drawback of this approach is that the decision maker
must be identified before the data is gathered. This is not an easy task, especially for complex enterprises within a complex supply chain, where some decisions are simultaneously made (for instance transport mode and shipment size) and many different actors participate in the decision. The data needed for these kinds of models are the components of the level of service offered by the different modes, such as rates, travel time, flexibility of the service, reliability, insurance costs, etc. In addition, the choice set of each decision maker must be known to the modeller.

The second type of disaggregate models are called inventory based models. These models attempt to integrate the mode choice and the production decisions made by a firm (Baumol et. al., 1970; Das, 1974; McFadden et. al., 1981). These type of disaggregate models can take the simultaneity of the decisions into consideration (McFadden et. al., 1985).

3.3.3 Urban Freight Transport Models

Regan and Garrido (2002) identified that the urban freight transport models are underdeveloped with only a handful of published works addressing the freight movement in the urban scope. Most of the literature on urban freight transport models deals primarily with vehicle flows, especially truck flows (He et. al., 1998; Gorys et. al., 1999). However, Harris and Liu (1998) predicted purchases and sales for different commodity categories, unlike the other studies, within and outside the city limits.
In conclusion, the freight demand models that were simple and practical did not capture the behavioural aspects of freight demand. Thus, these models are less powerful than the more data-demanding behavioural approaches. These practical approaches are based on several assumptions that significantly lower the data requirements and the mathematical treatment. However, these assumptions rarely hold in practice and hence the prediction capability of these approaches is rather limited. The models that were able to capture the behavioural aspects of freight demand suffered with two main drawbacks: the data requirement and the computational complexity of the model. This study addresses this problem by developing statewide freight demand models that are behaviourally valid and are less data intensive. Thus, this study proposes to use commodity-based modeling of inter-regional freight flows in Florida.
Chapter 4

Model Framework

4.1 Introduction

As can be concluded from the literature review in the previous chapter, the freight demand models that captured the behavioral aspects of freight demand are data intensive and impractical. Those models that are simple and practical do not capture the behavioral aspects of freight transportation in a comprehensive manner. Thus, there has been a compromise with the behavioral aspect and data requirements in the freight demand models that were developed till date.

As the objective of this thesis is to model statewide freight travel demand at a microscopic level, it is required to propose a relatively data simple, but behaviorally robust modeling framework in the spirit of an aggregate level four-step planning process. Thus, the current research focuses on a statewide freight demand model that takes the structure of a commodity-based model for the state of Florida. The model formulation and empirical analysis are specifically targeted toward the trip generation, trip distribution and mode choice steps. Thus, the goal is to propose a modeling framework that can quantify and predict freight flows by various modes between origin-destination pairs in the state of Florida. These origin-destination pairs may be traffic analysis zones, census tracts, zip codes, cities, counties, or even states depending on the particular freight
transportation planning context of interest. But, it is desired to conduct this study at the microscopic level of a zipcode unlike any of the earlier studies. The zipcode level is considered an appropriate level of disaggregation where the data can be considered to be reliable avoiding large amounts of missing data.

Thus, the intent of this chapter is to identify the data requirements, paradigms and freight transportation demand-supply relationships identified in the literature, and develop a model concept that will guide the model development effort of this study. The data commonly used in the statewide freight demand modeling and the underlying paradigms are identified in section 4.2. Section 4.3 presents the development of the model framework based on the literature that is used in this study.

4.2 Data Requirements for Inter-regional Freight Demand Models

The hypothesis commonly used in freight transportation planning is that population is assumed to affect the attraction of freight to an area, and industry employment is assumed to affect the generation of freight in an area. Thus, it can be easily learnt from the literature review in the previous chapter that the data mainly required in freight demand modeling is the socio-economic information of the origin and destination. The other data that is required for the estimation of freight demand models is the modal level of service characteristics.

Data on estimates of future dwelling construction and other major construction sites (e.g. new road or rail links, or major urban redevelopment sites) could be used to estimate the
demand for construction related commodities, which comprise a significant proportion of all overall freight transport. Moreover, land use data may also be used for estimating the location of production for agricultural production.

Garrido (undated) reviewed the data requirements for inter-regional freight demand models and proposed that the data on modal split, fleet’s attributes and composition, and network characteristics are required. At the aggregate level, models typically regress the proportion of market shares (between pure modes) against some aggregate attributes such as prices, travel time and cost, etc. Therefore, accurate data on modal split and some level of service attributes is required. Inter-regional models are especially sensitive to the network resolution and level of service. Routing options as well as the costs at each arc have a tremendous impact on the quality of model results. The network costs structure is especially relevant when the freight flows are found as a result of an equilibrium process – usually under Wardrop’s second principle (Friesz et. al., 1983).

Sivakumar and Bhat (2002) also propose that the data requirements for inter-regional freight demand models are freight origin-destination flow data, business and employment patterns, population projections, regional economic information and modal level of service variables. Using these data, they developed an approach that estimates the fraction of commodity consumed at each destination zone that originates from alternative production zones. The resulting fractional split model for commodity flow distribution is more general in structure than the typical gravity model used for statewide freight
planning. This empirical analysis applying the fractional split model was used to analyze inter-regional commodity flows in Texas.

Brogan et al (2001) also proposed to use data such as population, employment, regional size, per-capita income, population density, daily electric coal demand, KW capacity and Coal tons/KW. In their study, county-level commodity flow data were commercially procured to describe freight flows into, out of, within, and through Virginia. With the use of these data, they identified Virginia’s “key” commodities and the flows of these commodities were assigned to county-level origin-destination tables. Predictive equations of freight generation and attraction relationships for each of Virginia’s key commodities were developed. A strategy for developing regression equations was developed using a series of robust and stepwise regressions to minimize the effects of outliers. For each key commodity with a two-digit Standard Transportation Commodity Classification code, a set of generation and attraction equations was developed, including relationships for non-outliers, first-order outliers, and second-order outliers. In addition, the authors identified several socioeconomic variables that significantly affect freight generation and attraction within Virginia.

Cambridge Systematics, Inc (1996) also proposes obtaining data on economic activity for traffic analysis zones (including employment by type and the number of households) in their Quick Response Freight Manual (QRFM). Jack Faucett Associates (1999b) also propose their trip-based modeling process by generating truck trips as a function of different land uses and trip data from trip diaries or shipper surveys. They calculate the
trip rates as a function of socio-economic data (trips per employee) and land use data (trip per acre).

4.3 Model Framework

Thus, in order to be in line with paradigms and freight transportation demand-supply relationships identified in the literature, it is desired to use population characteristics, employment characteristics, and the modal level of service characteristics in the statewide freight demand modeling for Florida. Growth and land use data are not included in this study as inclusion of such data hinders the practical application of the models that will be developed. Moreover, relevant data sources could not be identified. However, population data indirectly captures the effects of these kinds of data. Thus, only socio-economic data and the modal level of service data are considered for model development.

Figure 4.1 shows the overall model framework that directed the model development effort of this study. The following assumptions are made in forming this model concept:

- Origin and destination employment characteristics are assumed to influence the flow of a commodity between an origin-destination pair and the amount of flow by each mode.
- Origin and destination population characteristics are assumed to influence the total flow of a commodity between an origin-destination pair and the amount of flow by each mode.
- Modal level of service characteristics including travel distance, travel time, and travel cost influence the total flow of a commodity between an origin-destination pair and the amount of flow by each mode.

- The total freight flow of a commodity between an origin destination pair has an influence on flows by each mode.

Figure 4.1

Conceptual Framework for Modeling Freight Transportation Demand

The motivation for these assumptions is that freight movement is fundamentally generated by the demand for consumption of commodities at the destination (or attraction) end, which is met by the flow of commodities from one or more origin (or
production) points (Ogden, 1978). This model framework represents a direct demand model where the movement of a commodity by a certain mode is estimated directly from socio-economic characteristics of the origin and destination and the modal level of service variables. A link is also provided from the total flow to the modal flows to accommodate any influence that total freight flow has on individual modal flows.

Thus the model framework provides a mechanism by which freight flows on various modes between an origin and destination can be estimated. The changes in freight flows can be determined in response to changes in the socio-economic characteristics of the origin or destination, and changes in modal attributes. The model framework is simple & practical, but behaviorally robust and can therefore be easily estimated on a database that can be assembled by any public agency that has resources to purchase some commercial databases.
Chapter 5

Database Preparation

5.1 Introduction

From the model framework developed in the previous chapter, it is required to obtain the freight data containing commodity flows by various modes for origin-destination pairs in Florida. The other data that is required to estimate these modal flows between O-D pairs in Florida are the socio-economic characteristics of the origin & destination and the modal level of service characteristics.

A review of the various freight data sources is conducted in order to choose an appropriate database for this study. The intent is to identify a database that supports commodity based modeling of statewide inter-regional flows at a microscopic level.

5.2 Available Freight Data Sources

5.2.1 Commodity Flow Survey

http://www.census.gov/econ/www/se0700.html

The Commodity Flow Survey (CFS) provides data on the flow of goods and materials by mode of transport. The CFS is sponsored by the Bureau of Transportation Statistics, United States Department of Transportation (USDOT), and U.S. Census Bureau,
Department of Commerce, and performed by the U.S. Census Bureau, Department of Commerce and Oak Ridge National Laboratory.

The CFS follows a series of publicly available datasets from 1963 through 1997. Samples of domestic establishments engaged in mining, manufacturing, wholesale, auxiliary establishments (warehouses) of multi-establishment companies, and some selected activities in retail and service were used to collect the data through the completion of a questionnaire. The current version of the CFS contains a geographic coverage of data at national level, stratified by State and Metropolitan Area (Garrido, undated). It provides information on commodities shipped, their value, weight and mode of transportation, as well as the origin and destination of shipments at the national, state, and large metro-area levels. Thus, it is quite a detailed aggregate level dataset that can be used to study overall trends in commodity flows between major geographic areas. It provides a convenient mechanism to obtain control totals regarding freight movements.

Although data from the Bureau of Transportation Statistics Commodity Flow Survey (CFS) is widely used in other types of studies, several inherent weaknesses of the CFS make it inappropriate for use in this study. First, CFS data are available only at the state level; Zipcode level data are more appropriate for use in a statewide freight planning process. If CFS data were to be used in this study, a methodology to disaggregate the statewide commodity flows to individual zipcodes would have to be developed. Such a disaggregation process, most likely based on zipcode-level employment and population, would affect the accuracy of the final (zipcode-level) commodity flow data.
The other drawback is that CFS data is not comprehensive. Because the CFS is published by the U.S Census Bureau, it must comply with federal law governing census reports, including the prohibition of publishing data that would disclose the operations of an individual firm or establishment. As a result, much of the data are not published, severely reducing the accuracy and scope of the CFS.

5.2.2 Transborder Surface Freight Dataset

http://www.bts.gov/ntda/tbscd/

Since 1993 the Bureau of Transportation Statistics (BTS) at the United States Department of Transportation (USDOT) has contracted with Bureau of the Census (Census) at the U.S. Department of Commerce (DOC) to provide previously unpublished surface transportation data (other than air or maritime vessel) for U.S. import and export trade with Canada and Mexico. This dataset is referred to as the Transborder Surface Freight Data. Under the contract, Census provides two sets of data tables to BTS; one provides detailed transportation flows while the other is commodity based without as much transportation detail. After Census processes and summarizes the data, BTS receives these monthly files and makes them publicly available as soon as possible.

The Transborder Surface Freight Dataset provides North American merchandise trade data by commodity type, by surface transport mode (including pipeline) with geographic detail for U.S. exports to and imports from Canada and Mexico, updated on a monthly basis. Its objective is to provide transportation information on North American trade flows. The source is the official U.S. international merchandise trade dataset.
Currently, these data are being used to monitor transborder freight flows since the beginning of the North American Free Trade Agreement (NAFTA) in 1994. Other uses of this database are: trade corridor studies, transportation infrastructure planning, logistics strategy analyses amongst other purposes.

The dataset is compiled from the Census Foreign Trade Statistics Program. Import and export data are collected from administrative records required by the Departments of Commerce and Treasury of the US.

Most of the imports data from Canada and Mexico, are collected electronically via an Automated Broker Interface, and the Customs entry documents collected by the Customs Service and transmitted to the Census Bureau. Information on U.S. exports of goods from the U.S. to all countries (except Canada) is compiled from copies of Shipper's Export Declarations (SEDs) and data collected from shippers, forwarders or carriers. On the export side about half of the data are collected electronically, through a U.S./Canada Data Exchange agreement and the Automated Export Reporting Program.

The official U.S. import and export statistics provide information on shipments of merchandise between foreign countries and the U.S. Customs Territory, U.S. Foreign Trade Zones, and the U.S. Virgin Islands, without regard to whether or not a commercial transaction is involved. The statistics record the physical movement of merchandise between the United States and foreign countries. Thus, this dataset is inappropriate for use in the statewide freight demand modeling for Florida.
5.2.3 Transportation Annual Survey

http://www.census.gov/econ/www/se0800.html

The Transportation Annual Survey is formerly known as the Motor Freight Transportation and Warehousing Survey. It is carried out annually by the US Census Bureau. It provides national estimates of revenue, expenses, and vehicle fleet inventories for commercial motor freight transportation and public warehousing service industries. This survey covers companies with employment that provide commercial motor freight transportation and public warehousing services. It excludes private motor-freight carriers operating as auxiliary establishments to non-transportation companies and independent owner-operators with no paid employees. The survey covers all employer firms with one or more establishments that are primarily engaged in providing commercial motor freight transportation or public warehousing services. The results of this survey are published in a report where statistics are summarised by kind-of-business classification based on the Standard Industrial Classification (SIC) Manual issued by the Office of Management and Budget. This survey is conducted annually since 1985. Data collection begins about 3 months after the reporting year and continues for about 4 months. Samples are selected every 5 years and updated annually. Even this dataset is inappropriate for use in the statewide freight demand modeling, as it provides only the national estimates of revenue, expenses, and vehicle fleet inventories for commercial motor freight transportation.
5.2.4 Vehicle Inventory and Use Survey

http://www.census.gov/econ/www/se0501.html

This survey is formerly known as the Truck Inventory and Use Survey (TIUS). The survey name was changed to account for areas of future expansion, including the addition of automobiles and buses. The aim of this survey is to measure the physical and operational characteristics of the Nation's truck population. This survey covers private and commercial trucks registered (or licensed) in the United States as of July 1 of the survey year. The survey excludes vehicles owned by Federal, state, or local governments; ambulances; buses; motor homes; farm tractors; unpowered trailer units; and trucks reported to have been sold, junked, or wrecked prior to July 1 of the year preceding the survey. The dataset on physical characteristics include date of purchase, weight, number of axles, overall length, type of engine, and body type. The operational characteristics data include type of use, lease characteristics, operator classification, base of operation, gas mileage, annual and lifetime miles driven, weeks operated, commodities hauled by type, and hazardous materials carried.

Several private and public agencies use these data on a regular basis. Public agencies such as the Department of Transportation use the data for analysis of cost allocation, safety issues, proposed investments in new roads and technology, and user fees. The Environmental Protection Agency uses the data to determine per mile vehicle emission estimates, vehicle performance and fuel economy, and fuel conservation practices of the trucking industry. The Bureau of Economic Analysis uses the data as a part of the
framework for the national investment and personal consumption expenditures component of the Gross Domestic Product.

Private agencies such as tire manufacturers use the data to calculate the longevity of products and to determine the usage, vocation, and applications of their products. Heavy machinery manufacturers use the data to track the importance of various parts distribution and service networks. Truck manufacturers use the data to determine the impact of certain types of equipment on fuel efficiency.

This survey is conducted every 5 years since 1963, for years ending in "2" and "7." Data collection begins in January following the census year and continues for approximately 9 months. Reported data are for activity during the census calendar year. This dataset is inappropriate for use in the statewide freight demand modeling, as it covers only the nation’s truck population.

5.2.5 Reebie TRANSEARCH Database

http://www.reebie.com/images/transearch.asp

The TRANSEARCH database contains origin-destination freight movements in the US covering major modes of transport, and suits best for statewide freight demand modeling. It is compiled and produced on an annual basis since 1980 by the firm Reebie Associates. Records are kept for freight traffic shipments across geographic markets and commodities for seven modes of transport, including truckload, less than truckload (LTL), private truck, rail, intermodal, rail carload, waterborne, and air. The database
contains the freight activity of U.S. domestic, Canada/U.S. and Mexico/U.S. This database has been used in various statewide freight models such as Texas and Virginia (Sivakumar and Bhat, 2002; Brogan et. al., 2001). This dataset is the best commodity flow data available, and has been chosen for this study.

The Florida Department of Transportation (FDOT), as part of its ongoing research into the development of urban and statewide freight transportation models, purchased the TRANSEARCH freight flow database at the zip code level. The TRANSEARCH data may also be prepared and purchased at other levels of aggregation; however, the zip code level was considered an appropriate level of disaggregation where the data could be considered reliable and large amounts of missing data could be avoided.

5.3 Preparation of the Freight Data from TRANSEARCH Database

Reebie Associates’ TRANSEARCH database at the zipcode level for the state of Florida was used as the primary source of commodity flow data in this study. Although it is the best commodity flow data currently available, the TRANSEARCH database suffers with several limitations:

- The commodity flow data consists of a national database built from company-specific data and other publicly available databases. These different data sources use different commodity classifications that must be converted to a consistent format. These conversions can sometimes lead to some data being put in the wrong category or left unreported.
The level of detail provided from particular companies when they report their freight shipment activities to Reebie Associates can limit the accuracy of the final TRANSEARCH dataset.

Specific origin-destination (O-D) information is not available for overseas waterborne traffic through marine ports. Overseas ports are not identified, and Reebie Associates estimates the domestic distribution of maritime imports and exports.

The TRANSEARCH 2000 database at the zip code level, purchased by the FDOT consists of commodity flows (by ton) into, out of, and through Florida. However, in order to keep the model estimation database tractable, only those commodity flows that originated and ended at zip codes in Florida were used for model estimation. Remaining freight flow data was available only at the county and Bureau of Economic Analysis level. This study utilizes only the zip code-zipcode level flow data for model estimation and thus captures only about 70 percent of the intra-state freight flow within Florida. At this point, it should be noted that the TRANSEARCH database is not necessarily a complete and comprehensive coverage of all freight transportation flows. There are certain types of movements that are not captured in the TRANSEARCH database.

Thus, the freight database prepared for this study contained commodity flows at the zip code to zip code level with commodities classified at the level of the two-digit Standard Transportation Commodity Classification (STCC) code. In order to reduce the commodity groups to a more manageable level, the commodities at the two digit STCC
level were collapsed into 17 commodity groups. The STCC codes that were collapsed into the 17 commodity groups are shown in Table 5.1.

**Table 5.1**

**STCC Commodity Classification Groups**

<table>
<thead>
<tr>
<th>Commodity Group</th>
<th>STCC in Commodity Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Code</td>
</tr>
<tr>
<td>1</td>
<td>1, 8, 9</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>13, 14, 19</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>21, 22, 23, 25, 27</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
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<tr>
<td>9</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>31, 36, 38, 39</td>
</tr>
<tr>
<td>12</td>
<td>32</td>
</tr>
<tr>
<td>13</td>
<td>33</td>
</tr>
<tr>
<td>14</td>
<td>34</td>
</tr>
<tr>
<td>15</td>
<td>37</td>
</tr>
<tr>
<td>17</td>
<td>5010, 5020, 5030</td>
</tr>
</tbody>
</table>

Commodity flows were broadly assigned to four modes: truck, rail, water, and air. The truck mode was further subdivided into full truck load, less than truck load, and private truck load. Full truck load was defined as a “for-hire” commodity flow on a truck with greater than 10,000 pounds, and less than truck load was defined as “for-hire” commodity load.
flow on a truck with less than 10,000 pounds. A Private Truck was defined as any company truck that is part of a private fleet. The Rail mode was also subdivided into rail intermodal and rail car load modes. Thus, the TRANSEARCH dataset consists of freight flows between pairs of zip codes in Florida by commodity (two-digit STCC code) and in annual weight (in tons) for each of the following modes of transport: full-truck-load, less-than-truckload, private truck, rail carload, rail intermodal, water, and air.

5.4 Socio-Economic Data

In order to model freight flows between zip codes, three more pieces of information were required as per the model construct presented in Figure 3. Socio-economic information represented by population and employment characteristics was needed. All population information was derived from the 2000 Census databases. Census data was obtained at the zip code level and appropriately matched to the TRANSEARCH commodity flow database so that each record contained the population characteristics of the origin zip code and the destination zip code. The following information for both origin and destination zipcodes was merged to the freight data:

- Overall Zipcode Population
- Number of Males
- Number of Females
- Number of Persons with Age between 0 and 5 years
- Number of Persons with Age between 6 and 10 years
- Number of Persons with Age between 11 and 15 years
- Number of Persons with Age between 16 and 21 years
- Number of Persons with Age between 22 and 24 years
- Number of Persons with Age between 25 and 29 years
- Number of Persons with Age between 30 and 34 years
- Number of Persons with Age between 35 and 39 years
- Number of Persons with Age between 40 and 44 years
- Number of Persons with Age between 45 and 49 years
- Number of Persons with Age between 50 and 54 years
- Number of Persons with Age between 55 and 59 years
- Number of Persons with Age between 60 and 64 years
- Number of Persons with Age between 65 and 69 years
- Number of Persons with Age between 70 and 79 years
- Number of Persons with Age between 80 and 84 years
- Number of Persons with Age 85 years or above
- Number of Households with Household Incomes less than $20,000
- Number of Households with Household Incomes between $20,000 and $39,999
- Number of Households with Household Incomes between $40,000 and $59,999
- Number of Households with Household Incomes between $60,000 and $99,999
- Number of Households with Household Incomes between $100,000 and $199,999
- Number of Households with Household Incomes $200,000 or above
- Number of Persons whose Occupations are Management, Business, or Financial Operations
- Number of Persons whose Occupations are Professional
- Number of Persons whose Occupations are related to Service
- Number of Persons whose Occupations are related to Sales or Office
- Number of Persons whose Occupations are Farming, Fishing, or Forestry
- Number of Persons whose Occupations are Construction, Extraction, or Maintenance
- Number of Persons whose Occupations are Production, Transportation, or Material moving
- Number of Households with One Person
- Number of Households with Two Persons
- Number of Households with Three Persons
- Number of Households with Four or more Persons
- Number of Families with Zero Workers
- Number of Families with One Worker
- Number of Families with Two Workers
- Number of Families with Three or more Workers
- Number of Households with Zero Vehicles
- Number of Households with One Vehicle
- Number of Households with Two Vehicles
- Number of Households with Three or more Vehicles
- Number of Persons whose Educational Attainment is below 9th grade
- Number of Persons whose Educational Attainment is between 9th and 12th grades, no diploma, High school graduate, Some college or no degree
- Number of Persons whose Educational Attainment is Associate's Degree or Bachelor's Degree
- Number of Persons whose Educational Attainment is Graduate or Professional Degree

Employment characteristics were derived from the InfoUSA 2000 database which is a commercial database that contains information on every employer in the state of Florida. This database was purchased by the Florida Department of Transportation for use by public agencies in developing employment characteristics for their travel demand models. This database has information about each employer, such as Company name, Contact name, Address, City, State, Zipcode, Phone, SIC code, Franchise code, and Employee size. Aggregation of this employer database was performed at the zip code level and information on employment by one digit SIC was obtained. This data was appropriately matched to the TRANSEARCH commodity flow database so that each record contained the employment characteristics of the origin zip code and the destination zip code. Thus, the following information for both origin and destination zipcodes was merged to the freight data:

- Overall Zipcode Employment
- Agricultural, Forestry and Fishery Employment
- Mining and Construction Products Employment
- Light Manufactured Products Employment
- Heavy Manufactured Products Employment
- Transportation, Communication and Utilities Employment
- Wholesale and Retail Trade Employment
- Finance, Insurance and Real Estate Employment
- Entertainment, Accommodation and Food Services Employment
- Other Services Employment
- Public Administration Employment

5.5 Modal Level of Service Data

Finally, as per the model construct, detailed information on modal level of service variables is needed. Different modes have different service characteristics, and the commodities carried by those modes differ. The truck and air modes tend to be dominated by low-weight, high-value commodities, such as automobile and computer parts. Conversely, the rail and water modes tend to be dominated by high-weight, low-value commodities, including coal, gravel, and timber. Thus, for every zip code pair, it would be ideal to have travel time, distance, and cost information by all modes identified in the database. This effort is currently ongoing and as such all modal level of service variables have not yet been merged into the database. Thus, at this time, the models are estimated using simple map distance (center of zip code to center of zip code) as a measure of impedance between them. However, in the future, modal level of service variables should be included in the model specification to make sure that the model is sensitive to modal level of service attributes. In its current form (as presented in this thesis), the model is sensitive only to distance. The importance of the role of distance and trip length in freight transportation modeling is well recognized (Holguin-Veras et. al., 2000; Garrido et. al., 2000).
5.6 Final Dataset

The origin & destination population & employment characteristics were merged to the freight flow database as separate variables such as origin population, origin employment, destination population, destination employment etc. The distance between the origin and destination zipcodes was also merged to the freight database. This database was developed using SPSS, which is a statistical software package developed for use in the social sciences. Each record in this database consists of the following data:

- Origin Zipcode
- Destination Zipcode
- Commodity Group
- Total Flow (in annual tons)
- Total Flow by Truck (in annual tons)
- Total Flow by Rail (in annual tons)
- Commodity Flow by Air (in annual tons)
- Commodity Flow by Water (in annual tons)
- Commodity Flow by Full Truck Load (in annual tons)
- Commodity Flow by Less-Than-Truck-Load (in annual tons)
- Commodity Flow by Private Truck (in annual tons)
- Commodity Flow by Rail Car (in annual tons)
- Commodity Flow by Rail Intermodal (in annual tons)
- Origin Population Characteristics (49 population variables shown in section 4.4)
- Destination Population Characteristics (49 population variables shown in section 4.4)
- Origin Employment (11 employment variables in section 4.4)
- Destination Employment (11 employment variables in section 4.4)
- Distance

Thus, the final dataset consists of commodity flows (by the 17 defined commodity groups) in annual tons by each mode (full truck load, less than truck load, private truck, rail car load, rail intermodal, air, water rail and truck), along with population, employment and distance information for all pairs of zip codes in Florida.
Chapter 6
Database Description

6.1 Introduction
As the basic objective of this study is to develop a statewide modeling framework for estimating freight flows for various commodities on various modes for origin-destination zipcodes, it is important to understand the distribution of freight flows by commodity, mode, region and socio-economic characteristics. Understanding these distributions can help identify and explain the fundamental relationships between among freight flows (by commodity, mode and region) and the socio-demographics. The following sections describe the data prepared for this study.

6.2 Distribution of Freight Flows by Commodity and Mode
The distribution of total annual flow (weight) by commodity group at the zipcode-zipcode level in Florida is shown in Table 6.1. As this database is focusing on intra-state movements, the warehousing commodity group is found to account for more than 50 % of the flows by weight. Other major commodity groups include other minerals (15.09 %), clay, concrete & glass (14.52 %), Chemicals (6.01 %), and Food (4.49 %).

The overall mode share of total annual commodity flow by weight at the zipcode-zipcode level in Florida is shown in Table 6.2. The truck mode accounts for the major portion of
overall freight flow, carrying 77.6 % of the total annual commodity flows. The truck mode is a combination of two types of trucks, for-hire and private truck. For-hire truck and private truck account for 37.3 % and 40.2 % of the total annual commodity flow respectively. Thus, for-hire truck and the private truck account for 48 % and 52 % of the total commodity flow carried by truck respectively. For-hire truck mainly constitutes of Full Truck Load which accounts for 36.1 % of the total annual commodity flow, while the Less-than-Truck Load accounts for a small share of 1.2 % of the total annual commodity flow. Rail mode accounts for about 20 % of the total annual commodity flow. Air accounts for a very small share of commodity flow by weight at less than one percent while water accounts for a slightly higher share at 2.8 %.

**Table 6.1**

**Distribution of Freight Flows by Commodity Group (Weight)**

<table>
<thead>
<tr>
<th>Commodity Group</th>
<th>Code</th>
<th>Name</th>
<th>Weight (tons)</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Agriculture</td>
<td>1</td>
<td>Agriculture</td>
<td>71,258</td>
<td>0.07</td>
</tr>
<tr>
<td>2 Coal</td>
<td>2</td>
<td>Coal</td>
<td>149,729</td>
<td>0.15</td>
</tr>
<tr>
<td>3 Other Minerals</td>
<td>3</td>
<td>Other Minerals</td>
<td>15,149,353</td>
<td>15.09</td>
</tr>
<tr>
<td>4 Food</td>
<td>4</td>
<td>Food</td>
<td>4,505,846</td>
<td>4.49</td>
</tr>
<tr>
<td>5 Non-Durable Manufacturing</td>
<td>5</td>
<td>Non-Durable Manufacturing</td>
<td>844,395</td>
<td>0.84</td>
</tr>
<tr>
<td>6 Lumber</td>
<td>6</td>
<td>Lumber</td>
<td>1,815,571</td>
<td>1.81</td>
</tr>
<tr>
<td>7 Paper</td>
<td>7</td>
<td>Paper</td>
<td>542,107</td>
<td>0.54</td>
</tr>
<tr>
<td>8 Chemicals</td>
<td>8</td>
<td>Chemicals</td>
<td>6,035,128</td>
<td>6.01</td>
</tr>
<tr>
<td>9 Petroleum</td>
<td>9</td>
<td>Petroleum</td>
<td>2,396,885</td>
<td>2.39</td>
</tr>
<tr>
<td>10 Rubber Plastics</td>
<td>10</td>
<td>Rubber Plastics</td>
<td>80,190</td>
<td>0.08</td>
</tr>
<tr>
<td>11 Durable Manufacturing</td>
<td>11</td>
<td>Durable Manufacturing</td>
<td>57,924</td>
<td>0.06</td>
</tr>
<tr>
<td>12 Clay, Concrete, Glass</td>
<td>12</td>
<td>Clay, Concrete, Glass</td>
<td>14,582,320</td>
<td>14.52</td>
</tr>
<tr>
<td>13 Primary Metals</td>
<td>13</td>
<td>Primary Metals</td>
<td>220,888</td>
<td>0.22</td>
</tr>
<tr>
<td>14 Fabricated Metal Products</td>
<td>14</td>
<td>Fabricated Metal Products</td>
<td>455,012</td>
<td>0.45</td>
</tr>
<tr>
<td>15 Transportation Equipment</td>
<td>15</td>
<td>Transportation Equipment</td>
<td>150,569</td>
<td>0.15</td>
</tr>
<tr>
<td>16 Miscellaneous Freight</td>
<td>16</td>
<td>Miscellaneous Freight</td>
<td>1,917,070</td>
<td>1.91</td>
</tr>
<tr>
<td>17 Warehousing</td>
<td>17</td>
<td>Warehousing</td>
<td>51,427,628</td>
<td>51.22</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>100,401,873</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>
Table 6.2

Distribution of Freight Flows by Mode

<table>
<thead>
<tr>
<th>Mode</th>
<th>Mode Share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight (tons)</td>
</tr>
<tr>
<td>Truck Load (TL)</td>
<td>36,242,617</td>
</tr>
<tr>
<td>Less Than Truck Load (LTL)</td>
<td>1,217,705</td>
</tr>
<tr>
<td>Private Truck (PVT)</td>
<td>40,411,201</td>
</tr>
<tr>
<td>Railcar (CL)</td>
<td>17,630,641</td>
</tr>
<tr>
<td>Rail Intermodal (IMX)</td>
<td>2,012,488</td>
</tr>
<tr>
<td>Air</td>
<td>120,521</td>
</tr>
<tr>
<td>Water</td>
<td>2,765,268</td>
</tr>
<tr>
<td>Truck *</td>
<td>77,872,937</td>
</tr>
<tr>
<td>Rail **</td>
<td>19,643,147</td>
</tr>
<tr>
<td>Total***</td>
<td>100,401,873</td>
</tr>
</tbody>
</table>

*Truck = TL + LTL + PVT
**Rail = CL + IMX
***Total = Air + Water + Truck + Rail

Table 6.3 presents mode shares by commodity group at the zipcode-zipcode level in Florida. This table shows the 17 commodity groups and the mode share for each commodity in percent by weight. Thus it can be observed that coal is carried completely by rail car while warehousing is completely moved by truck. It can be concluded that the truck mode is generally dominated by low-weight, high-value commodities, such as fabricated metal products and non-durable manufacturing. Conversely, the rail mode is dominated by high-weight, low-value commodities, such as coal. Differences across commodity groups with respect to modal share are quite important and noticeable. As the commodities vary with respect to density, value, and time-sensitivity, there may be fundamental differences in the relationships among variables that can be used to predict
their flows. Therefore, in this study, it is proposed to estimate freight flows separately for each commodity group.

Table 6.3

<table>
<thead>
<tr>
<th>Commodity Group</th>
<th>Truck</th>
<th>Rail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Name</td>
<td>TL</td>
<td>LTL</td>
</tr>
<tr>
<td>1</td>
<td>Agriculture</td>
<td>48.4</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>Coal</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>Other Minerals</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>4</td>
<td>Food</td>
<td>32.8</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>Non-Durable Manufacturing Lumber</td>
<td>29.8</td>
<td>2.8</td>
</tr>
<tr>
<td>6</td>
<td>Paper</td>
<td>45.9</td>
<td>0.8</td>
</tr>
<tr>
<td>7</td>
<td>Chemicals</td>
<td>55.3</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>Petroleum</td>
<td>30.8</td>
<td>7.0</td>
</tr>
<tr>
<td>9</td>
<td>Rubber Plastics</td>
<td>24.4</td>
<td>6.6</td>
</tr>
<tr>
<td>10</td>
<td>Durable Manufacturing Clay, Concrete, Glass</td>
<td>25.1</td>
<td>5.5</td>
</tr>
<tr>
<td>11</td>
<td>Primary Metals</td>
<td>30.2</td>
<td>0.1</td>
</tr>
<tr>
<td>12</td>
<td>Fabricated Metal Products</td>
<td>92.2</td>
<td>0.6</td>
</tr>
<tr>
<td>13</td>
<td>Transportation Equipment</td>
<td>42.4</td>
<td>2.1</td>
</tr>
<tr>
<td>14</td>
<td>Miscellaneous Freight Warehousing</td>
<td>86.7</td>
<td>2.8</td>
</tr>
<tr>
<td>15</td>
<td>Miscellaneous Freight</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>16</td>
<td>Miscellaneous Freight</td>
<td>48.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

6.3 Distribution of Freight Flows by Trip Length

Table 6.4 provides an overall trip length distribution across all commodity groups at the zipcode-zipcode level in Florida. This distribution should be viewed in light of the intra-state nature of the freight flow database. More than one-third (37.1%) of the freight flow
by weight travels less than 50 miles. Intra Zipcode flows constitute 12.5 % of the overall share of freight transport in Florida. Only about 20 % of the commodity flow by weight travels farther than 250 miles in this intra-state context. Obviously, this distribution will vary greatly from state to state; however, it is important to note that the trip length (distance between origin and destination) is likely to play a role in determining the freight flow. Therefore, the model systems developed in this study include distance as an explanatory variable. More ideally, future model systems should contain detailed modal level of service information to ensure that the models are sensitive to modal level of service attributes.

Table 6.4

Distribution of Freight Flows by Trip Length

<table>
<thead>
<tr>
<th>Trip Length</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight</td>
<td>Percentage</td>
</tr>
<tr>
<td>Intra Zipcode</td>
<td>12,563,003</td>
<td>12.5</td>
</tr>
<tr>
<td>Flows</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - 10</td>
<td>4,786,842</td>
<td>4.8</td>
</tr>
<tr>
<td>10 - 20</td>
<td>3,828,755</td>
<td>3.8</td>
</tr>
<tr>
<td>20 - 30</td>
<td>5,698,571</td>
<td>5.7</td>
</tr>
<tr>
<td>30 - 40</td>
<td>5,424,241</td>
<td>5.4</td>
</tr>
<tr>
<td>40 - 50</td>
<td>4,993,672</td>
<td>5.0</td>
</tr>
<tr>
<td>50 - 100</td>
<td>9,919,012</td>
<td>9.9</td>
</tr>
<tr>
<td>100 - 150</td>
<td>11,650,764</td>
<td>11.6</td>
</tr>
<tr>
<td>150 - 200</td>
<td>19,324,143</td>
<td>19.2</td>
</tr>
<tr>
<td>200 - 250</td>
<td>5,190,897</td>
<td>5.2</td>
</tr>
<tr>
<td>250 - 300</td>
<td>10,108,793</td>
<td>10.1</td>
</tr>
<tr>
<td>300 - 350</td>
<td>2,680,752</td>
<td>2.7</td>
</tr>
<tr>
<td>350 - 400</td>
<td>1,869,830</td>
<td>1.9</td>
</tr>
<tr>
<td>400 - 450</td>
<td>556,064</td>
<td>0.6</td>
</tr>
<tr>
<td>450 - 500</td>
<td>1,806,534</td>
<td>1.8</td>
</tr>
<tr>
<td>Total</td>
<td>100,401,873</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Table 6.5

Distribution of Freight Flows by Trip Length and Mode

<table>
<thead>
<tr>
<th>Trip Length</th>
<th>Truck</th>
<th>Rail</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For-Hire</td>
<td>Private</td>
<td>Car</td>
</tr>
<tr>
<td>Intra Zipcode</td>
<td>FTL</td>
<td>LTL</td>
<td>PVT</td>
</tr>
<tr>
<td>1 - 10</td>
<td>57.20</td>
<td>1.70</td>
<td>5.59</td>
</tr>
<tr>
<td>10 - 20</td>
<td>49.70</td>
<td>1.29</td>
<td>38.94</td>
</tr>
<tr>
<td>20 - 30</td>
<td>36.03</td>
<td>0.73</td>
<td>26.07</td>
</tr>
<tr>
<td>30 - 40</td>
<td>27.86</td>
<td>1.16</td>
<td>37.75</td>
</tr>
<tr>
<td>40 - 50</td>
<td>13.09</td>
<td>0.51</td>
<td>18.55</td>
</tr>
<tr>
<td>50 - 100</td>
<td>24.08</td>
<td>1.05</td>
<td>34.22</td>
</tr>
<tr>
<td>100 - 150</td>
<td>33.44</td>
<td>1.44</td>
<td>49.97</td>
</tr>
<tr>
<td>150 - 200</td>
<td>35.78</td>
<td>1.50</td>
<td>53.07</td>
</tr>
<tr>
<td>200 - 250</td>
<td>36.12</td>
<td>1.66</td>
<td>52.91</td>
</tr>
<tr>
<td>250 - 300</td>
<td>34.62</td>
<td>1.60</td>
<td>50.78</td>
</tr>
<tr>
<td>300 - 350</td>
<td>37.19</td>
<td>1.69</td>
<td>54.78</td>
</tr>
<tr>
<td>350 - 400</td>
<td>40.14</td>
<td>1.90</td>
<td>57.70</td>
</tr>
<tr>
<td>400 - 450</td>
<td>41.30</td>
<td>1.19</td>
<td>57.25</td>
</tr>
<tr>
<td>450 - 500</td>
<td>40.51</td>
<td>1.72</td>
<td>57.40</td>
</tr>
</tbody>
</table>

The distribution of flows by trip length and mode at the zipcode-zipcode level in Florida are presented in Table 6.5. In the intra-state nature of the freight flow database, it is evident from the table that truck dominates all other modes. Thus, truck is the most important mode to be considered in freight demand modeling. Rail is a dominant mode for trips with lengths around 30–40 miles. It also has a considerable mode share for all short trip lengths (0-50 miles) and trip lengths from 250-300 miles. Again, these distributions should be viewed in light of the intra-state nature of the freight flow database. The distribution of ton-miles in Florida is shown in Figure 6.1.
6.4 Distribution of Freight Flows by Region

The distribution of freight flows by county is presented in a tabular format in Table 6.6. The outflows and inflows at the county level are given in this table. It can be observed that Miami-Dade has the highest freight outflows in Florida, followed by Polk and Hillsborough counties. Miami-Dade accounts for about 22.4 % of freight exports in Florida, while Polk and Hillsborough account for 14.8 % and 8.7 % respectively. It can also be noticed that Hillsborough has the highest freight inflows in Florida, followed by Miami-Dade and Duval. Hillsborough accounts for about 18.5 % of freight imports in Florida, while Miami-Dade and Duval account for about 14.1 % and 11.7 % respectively.
Table 6.6 also presents the export to import ratio for counties in Florida. Hardee has the highest export to import ratio of 11.01, followed by Liberty and Suwannee at 4.42 and 2.78 respectively. It can be observed in general that Florida imports higher than what it exports. Thus, only a few counties with export to import ratio greater than 1 can be identified. The export to import ration for the entire state of Florida is 0.78. TRANSEARCH data indicates that only 287 million annual tons of freight is exported, while 367 million annual tons is imported at the county level in Florida. However, as mentioned earlier, this study focuses on zipcode-zipcode flows in Florida that account for about 100.5 million annual tons.

Table 6.7 presents the distribution of freight outflows by county and mode for the state of Florida. It can be observed that there are many counties such as Baker, Citrus, Dixie, Flagler etc. that export only by truck. It can also be observed that most of the counties have high shares of outflows using truck. Thus, it is evident that truck is the dominant mode in Florida. Rail is a dominant mode of export in a few counties such as Bradford, Gadsden, Glades, Hamilton, Hardee, Hernando, Liberty and Polk. Water is a dominant mode of export in the Charlotte and Wakulla counties. Air does not have a significant share in any of the counties.

Similarly, Table 6.8 presents the distribution of freight inflows by county and mode for the state of Florida. It can be observed as in the case of freight outflows, that most of the counties have high shares of inflows using truck. Rail comes next to truck and has a significant share in many counties.

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### Table 6.6

#### Distribution of Freight Flows by County

<table>
<thead>
<tr>
<th>FIPS</th>
<th>COUNTY</th>
<th>Outflows</th>
<th>Percentage</th>
<th>Inflows</th>
<th>Percentage</th>
<th>Export to Import Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>12001</td>
<td>ALACHUA</td>
<td>2,834,631</td>
<td>0.99</td>
<td>2,324,574</td>
<td>0.63</td>
<td>1.22</td>
</tr>
<tr>
<td>12003</td>
<td>BAKER</td>
<td>351,227</td>
<td>0.12</td>
<td>192,723</td>
<td>0.05</td>
<td>1.82</td>
</tr>
<tr>
<td>12005</td>
<td>BAY</td>
<td>3,356,830</td>
<td>1.17</td>
<td>4,441,292</td>
<td>1.21</td>
<td>0.76</td>
</tr>
<tr>
<td>12007</td>
<td>BRADFORD</td>
<td>535,762</td>
<td>0.19</td>
<td>256,580</td>
<td>0.07</td>
<td>2.09</td>
</tr>
<tr>
<td>12009</td>
<td>BREVARD</td>
<td>5,403,695</td>
<td>1.88</td>
<td>7,542,605</td>
<td>2.06</td>
<td>0.72</td>
</tr>
<tr>
<td>12011</td>
<td>BROWARD</td>
<td>13,587,432</td>
<td>4.73</td>
<td>17,073,597</td>
<td>4.65</td>
<td>0.80</td>
</tr>
<tr>
<td>12013</td>
<td>CALHOUN</td>
<td>91,818</td>
<td>0.03</td>
<td>189,697</td>
<td>0.05</td>
<td>0.48</td>
</tr>
<tr>
<td>12015</td>
<td>CHARLOTTE</td>
<td>704,604</td>
<td>0.25</td>
<td>754,040</td>
<td>0.21</td>
<td>0.93</td>
</tr>
<tr>
<td>12017</td>
<td>CITRUS</td>
<td>314,058</td>
<td>0.11</td>
<td>4,577,157</td>
<td>1.25</td>
<td>0.07</td>
</tr>
<tr>
<td>12019</td>
<td>CLAY</td>
<td>531,527</td>
<td>0.19</td>
<td>996,165</td>
<td>0.27</td>
<td>0.53</td>
</tr>
<tr>
<td>12021</td>
<td>COLLIER</td>
<td>1,612,798</td>
<td>0.56</td>
<td>7,367,182</td>
<td>2.01</td>
<td>0.22</td>
</tr>
<tr>
<td>12023</td>
<td>COLUMBIA</td>
<td>765,840</td>
<td>0.27</td>
<td>2,031,142</td>
<td>0.55</td>
<td>0.38</td>
</tr>
<tr>
<td>12027</td>
<td>DE SOTO</td>
<td>173,558</td>
<td>0.06</td>
<td>112,450</td>
<td>0.03</td>
<td>1.54</td>
</tr>
<tr>
<td>12029</td>
<td>DIXIE</td>
<td>169,395</td>
<td>0.06</td>
<td>521,867</td>
<td>0.14</td>
<td>0.32</td>
</tr>
<tr>
<td>12031</td>
<td>DUVAL</td>
<td>23,598,933</td>
<td>8.22</td>
<td>42,804,554</td>
<td>11.67</td>
<td>0.55</td>
</tr>
<tr>
<td>12033</td>
<td>ESCAMBIA</td>
<td>6,759,714</td>
<td>2.36</td>
<td>8,222,440</td>
<td>2.24</td>
<td>0.82</td>
</tr>
<tr>
<td>12035</td>
<td>FLAGLER</td>
<td>180,979</td>
<td>0.06</td>
<td>432,164</td>
<td>0.12</td>
<td>0.42</td>
</tr>
<tr>
<td>12037</td>
<td>FRANKLIN</td>
<td>55,794</td>
<td>0.02</td>
<td>110,658</td>
<td>0.03</td>
<td>0.50</td>
</tr>
<tr>
<td>12039</td>
<td>GADSDEN</td>
<td>3,849,211</td>
<td>1.34</td>
<td>1,429,757</td>
<td>0.39</td>
<td>2.69</td>
</tr>
<tr>
<td>12041</td>
<td>GILCHRIST</td>
<td>157,807</td>
<td>0.05</td>
<td>66,920</td>
<td>0.02</td>
<td>2.36</td>
</tr>
<tr>
<td>12043</td>
<td>GLADES</td>
<td>126,137</td>
<td>0.04</td>
<td>1,678,406</td>
<td>0.46</td>
<td>0.08</td>
</tr>
<tr>
<td>12045</td>
<td>GULF</td>
<td>806,073</td>
<td>0.28</td>
<td>1,321,435</td>
<td>0.36</td>
<td>0.61</td>
</tr>
<tr>
<td>12047</td>
<td>HAMILTON</td>
<td>3,976,920</td>
<td>1.39</td>
<td>3,970,531</td>
<td>1.08</td>
<td>1.00</td>
</tr>
<tr>
<td>12049</td>
<td>HARDEE</td>
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<td>379,378</td>
<td>0.10</td>
<td>11.01</td>
</tr>
<tr>
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<td>HENDRY</td>
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<td>428,691</td>
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</tr>
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<td>HERNANDO</td>
<td>1,041,478</td>
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<td>2,324,267</td>
<td>0.63</td>
<td>0.45</td>
</tr>
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<td>12055</td>
<td>HIGHLANDS</td>
<td>700,822</td>
<td>0.24</td>
<td>754,780</td>
<td>0.21</td>
<td>0.93</td>
</tr>
<tr>
<td>12057</td>
<td>HILLSBOROUGH</td>
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<td>8.73</td>
<td>68,016,048</td>
<td>18.54</td>
<td>0.37</td>
</tr>
<tr>
<td>12059</td>
<td>HOLMES</td>
<td>156,471</td>
<td>0.05</td>
<td>112,227</td>
<td>0.03</td>
<td>1.39</td>
</tr>
<tr>
<td>12061</td>
<td>INDIAN RIVER</td>
<td>753,147</td>
<td>0.26</td>
<td>1,084,462</td>
<td>0.30</td>
<td>0.69</td>
</tr>
<tr>
<td>12063</td>
<td>JACKSON</td>
<td>305,961</td>
<td>0.11</td>
<td>966,552</td>
<td>0.26</td>
<td>0.32</td>
</tr>
<tr>
<td>Code</td>
<td>County</td>
<td>Population</td>
<td>Density</td>
<td>Total Population</td>
<td>Density</td>
<td>Change</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td>------------</td>
<td>----------</td>
<td>-----------------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>12065</td>
<td>JEFFERSON</td>
<td>34,274</td>
<td>0.01</td>
<td>65,022</td>
<td>0.02</td>
<td>0.53</td>
</tr>
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Table 6.9 presents the distribution of freight outflows and inflows by truck at the county level. From this table, it can be observed that Miami-Dade has the highest outflows by truck, followed by Duval and Hillsborough. Thus Miami-Dade accounts for about 25.57% of freight exports by truck in Florida, while Duval and Hillsborough account for 9.2% and 7.32% respectively. It can also be noticed that these three counties have the highest shares of freight imports by truck in the state of Florida with the figures of 20.74%, 10.35%, and 7.94% respectively.

Table 6.10 presents the distribution of freight outflows and inflows by rail at the county level. From this table, it can be identified that Polk has the highest outflows by rail, followed by Miami-Dade and Hamilton. Polk accounts for a very high 45.37% of freight exports by rail in Florida, while Miami-Dade and Hamilton account for 16.97% and 5.47% respectively. For freight imports by rail, Hillsborough has the highest share with 27.97%, followed by Polk at 16.38% and Duval at 12.72%.

Table 6.11 presents the distribution of freight outflows and inflows by air at the county level. It can be easily seen that only a few counties use air as a mode of freight transport. Miami-Dade has the highest share of freight outflows by air accounting for 51.48%. Broward and Orange follow Miami-Dade with shares of 15.83% and 12.49% respectively. For freight imports by air, Miami-Dade has the highest share with 48.8%, followed by Orange at 16.27% and Hillsborough at 14.72%. Table 6.12 presents the distribution of freight outflows and inflows by water at the county level.
Table 6.12 presents the distribution of freight outflows and inflows by water at the county level. It can be easily seen that only a few counties use water as a mode of freight transport. Hillsborough has the highest share of freight outflows by water accounting for 44.45 %. Pinellas and Duval follow Hillsborough with shares of 19.38 % and 11.2 % respectively. For freight imports by water, Hillsborough has the highest share with 39.37 %, followed by Duval at 14.54 % and Collier at 11.16 %.

Appendix A contains an extensive descriptive analysis of freight flows in Florida both at the zipcode level and the county level. The distribution of freight outflows (exports) in annual tons at the zipcode level in Florida is shown in Figure A.1, while Figure A.2 depicts the distribution of freight inflows (imports) in annual tons by zipcode in Florida. The freight outflows to inflows ratio (export to import ratio) distribution is shown in Figure A.3. Figures A.4 - A.15 illustrate the distributions of freight outflows, freight inflows and the ratio of outflows to inflows for truck, rail, water and air respectively for zipcodes in Florida. Similar distributions at the county level are shown in Figures A.16 – A.30.


Table 6.7

Distribution of Freight Outflows by County and Mode

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Table 6.8
Distribution of Freight Inflows by County and Mode

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Total | 366,841,517 | 55.94 | 28.06 | 0.20 | 15.80
Table 6.9

Distribution of Truck Outflows and Inflows by County

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<th>Percentage</th>
<th>Truck Inflows</th>
<th>Percentage</th>
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Table 6.10

Distribution of Rail Outflows and Inflows by County

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Table 6.10 (Continued)

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| Total           | 71,911,136 | 100.00     | 102,942,583 | 100.00 |
# Table 6.11

## Distribution of Air Outflows and Inflows by County

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### Table 6.12

Distribution of Water Outflows and Inflows by County

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80

Table 6.12 (Continued)
6.5 Distribution of Freight Flows by Region and Socio-Economic Characteristics

The population distribution in Florida at the zipcode level is shown in the Appendix A in Figure A.31. Figure A.32 depicts freight export in annual tons per person at the zipcode level in Florida, while Figure A.33 depicts freight import in annual tons per person at the zipcode level in Florida. Similar figures at the county level are also included in the Appendix A.

The employer locations, as given in the InfoUSA database, are also shown in Appendix A. Figure A.39 presents the total employment by zipcode, while Figures A.40 – A.49 present the employment by various industry types at the zipcode level. Figure A.50 presents the freight exports in annual tons per employee at the zipcode level in Florida, while Figure A.51 presents the freight imports in annual tons per employee at the zipcode level in Florida.

6.6 Conclusions

As it is determined to model each commodity group separately, databases for each of the 17 commodity groups were created. Each of these 17 databases used in this study consist of 859,329 records. Each record consists of flows by various modes for each origin-destination zipcode pair in Florida along with the socio-economic characteristics of the origin & destination and distance between the origin and destination zipcodes.

The freight flow variables in each of these databases had high number of zeros (around 97%) as many zipcode pairs do not exchange freight flows. Thus, these freight flow
variables in the databases unduly skew the variable distribution. However, the socio-economic variables in the databases were normally distributed.

In conclusion, the exploratory analysis conducted on the database suggests that the database offers variables with plausible statistical distributions and summaries consistent with expectations. Although the TRANSEARCH freight database has its share of errors and omissions, many states are investing in the purchase of this data to develop statewide freight travel demand models. In this context, it was felt that it is not inappropriate to develop models of freight flow using the TRANSEARCH databases, as the objective of this paper is to develop practical models of freight flow that utilize data available at many state and local agencies. However, readers should note the potential limitations of the database used in this study and interpret model results presented in the next section with appropriate caution.
Chapter 7
Modeling Methodology

7.1 Introduction

The modeling of multimodal freight movements involves dealing with multiple endogenous variables in a simultaneous equations framework. Commodity flows on different modes are travel demand related endogenous variables that are inter-related with one another. When modeling the interactions among several inter-dependent endogenous variables, simultaneous equations systems offer an appropriate framework for model development and hypothesis testing (Bollen, 1989). In this study, the structural equations modeling methodology is adopted for estimating simultaneous equations systems that capture the inter-dependencies among multimodal freight movements.

Thus, the modeling methodology adopted in this paper is centered on the structural equations modeling framework that can be used to determine and model relationships among several dependent (endogenous) variables simultaneously. As the model framework described in Chapter 3 includes a number of endogenous variables (freight movements by mode), it was considered appropriate to adopt this modeling methodology. In a structural analysis approach, also known as causal analysis, path analysis, or simply simultaneous equations, the phenomenon under study is cause-and-effect relationships. The relationships are either unidirectional, that is, they each postulate that one variable
influences another, or reciprocal where relationships are specified in both directions. In this way, many structural equation models incorporate both direct and feedback influences. This chapter attempts a review of the best current practice in specifying and estimating such sophisticated models.

However, as described in the previous chapter, it is found that there are many origin-destination pairs that do not exchange freight flows of a certain commodity at all. Thus, there is a high number of zero flows in the database. As the presence of zeros unduly skews the dependent variable distribution (a spike at zero in the freight flow distribution), this study employs a structural equations estimation methodology that accommodates skewed non-normal endogenous variables.

7.2 Structural Equations Modeling

A typical structural equations model (with ‘G’ number of endogenous variables) is defined by a matrix equation system as shown in Equation 1.

\[
\begin{pmatrix}
Y_1 \\
\vdots \\
Y_G
\end{pmatrix} =
\begin{bmatrix}
Y \\
X
\end{bmatrix}
\begin{bmatrix}
B \\
\Gamma
\end{bmatrix} +
\begin{bmatrix}
\varepsilon_1 \\
\vdots \\
\varepsilon_G
\end{bmatrix}
\tag{7.1}
\]

This can be rewritten as

\[
Y = BY + \Gamma X + \varepsilon
\tag{7.2}
\]

(or)

\[
Y = (I - B)^{-1} (\Gamma X + \varepsilon)
\tag{7.3}
\]

where \( Y \) is a column vector of endogenous variables,
\[ B \text{ is a matrix of parameters associated with right-hand-side endogenous variables,} \]
\[ X \text{ is a column vector of exogenous variables,} \]
\[ \Gamma \text{ is a matrix of parameters associated with exogenous variables, and} \]
\[ \varepsilon \text{ is a column vector of error terms associated with the endogenous variables.} \]

Structural equations systems are estimated by covariance-based structural analysis, also called method of moments. In this methodology, instead of minimizing the sum of squared differences between observed and predicted individual values, the difference between the sample covariances and the covariances predicted by the model is minimized. The observed covariances minus the predicted covariances form the residuals. The fundamental hypothesis for the covariances-based estimation procedures is that the covariance matrix of the observed variables is a function of a set of parameters as shown in Equation 4:

\[ \Sigma = \Sigma(\theta) \]  
(7.4)

where \( \Sigma \) is the population covariance matrix of observed variables,
\( \theta \) is a vector that contains the model parameters, and
\( \Sigma(\theta) \) is the covariance matrix written as a function of \( \theta \).

Equation 4 implies that each element of the covariance matrix is a function of one or more model parameters. The relation of \( \Sigma \) to \( \Sigma(\theta) \) is basic to an understanding of identification, estimation, and assessments of model fit. The matrix \( \Sigma(\theta) \) has three
components, namely, the covariance matrix of $Y$, the covariance matrix of $X$ with $Y$, and the covariance matrix of $X$.

Let $\Phi = \text{covariance matrix of } X$, and $\Psi = \text{covariance matrix of } \varepsilon$. Then it can be shown that [29]:

$$
\Sigma(\theta) = 
\begin{bmatrix}
(I - B)^{-1}(\Gamma \Phi \Gamma' + \Psi)(I - B)^{-1} & (I - B)^{-1} \Gamma \Phi \\
\Phi \Gamma'(I - B)^{-1} & \Phi
\end{bmatrix} 
$$

(7.5)

Before estimating model parameters, it is first necessary to ensure that the model is identified. Model identification in simultaneous structural equations systems is concerned with the ability to obtain unique estimates of the structural parameters. The identification problem is typically resolved by using theoretical knowledge of the phenomenon under investigation to place restrictions on model parameters. The restrictions usually employed are zero restrictions where selected endogenous variables and certain exogenous variables do not appear on the right hand side of certain equations and selected error correlations are specified to be zero. There are several rules that can be used to check whether a structural equation model system is identified. Detailed discussions on these identification rules may be found in Bollen (1989), Judge et al (1985) and Johnston et al (1997).

The unknown parameters in $B$, $\Gamma$, $\Phi$, and $\Psi$ are estimated so that the implied covariance matrix, $\hat{\Sigma}$, is as close as possible to the sample covariance matrix, $S$. In order to achieve this, a fitting function $F(S, \Sigma(\theta))$ which is to be minimized is defined. The fitting
function has the properties of being scalar, greater than or equal to zero if and only if $\Sigma(\theta) = S$, and continuous in $S$ and $\Sigma(\theta)$.

7.3 ADF-WLS Estimation

Available methods for parameter estimation include maximum likelihood (ML), unweighted least squares (ULS), generalized least squares (GLS), scale free least squares (SLS), and asymptotically distribution-free weighted least squares (ADF-WLS). Each of these methods minimizes the fitting function and leads to consistent estimators of $\theta$. The ADF-WLS method of estimation was used to estimate parameters of structural equations models as the univariate distributions of the endogenous variables are non-normal in that there are substantial numbers of observations for each variable with zero value, which denotes no commodity flow between a zip code pair. For such distributions, the ML coefficient estimates will be consistent, but the estimates of parameter standard errors and the overall model $\chi^2$ goodness-of-fit will likely be biased (Golob et. al., 1997). Unbiased estimates of standard errors and goodness-of-fit can be generated using the ADF-WLS method (Golob et. al., 1997).

The ADF-WLS estimation method proceeds in three distinct steps. First, it is assumed that each observed endogenous variable is generated by an unobserved normally distributed latent variable. If the latent variable is greater than a censoring level, it is observed; otherwise the censoring level is observed. Each latent variable is assumed to be conditional on the other variables in the system. The problem is to determine the conditional unknown mean and variance of each censored latent variable. This can be
done using the Tobit model. An appropriate maximum likelihood estimation procedure for the Tobit model is described in Maddala (1983). Second, estimates of the correlations between the latent censored endogenous variables, and the correlations between each of the latent variables and the continuous exogenous variables in the system are derived. Finally, parameters of the structural equation model are estimated such that the model-implied correlation matrix is as close as possible to the sample correlation matrix, where the sample correlation matrix is determined in the previous steps. The fitting function is then:

\[ F_{\text{WLS}} = [s - \sigma(\theta)]' W^{-1} [s - \sigma(\theta)] \quad (7.6) \]

where \( s \) is a vector of censored correlation coefficients for all pairs of endogenous and exogenous variables, \( \sigma(\theta) \) is a vector of model-implied correlations for the same variable pairs, and \( W \) is a positive-definite weight matrix. Minimizing \( F_{\text{WLS}} \) implies that the parameter estimates are those that minimize the weighted sum of squared deviations of \( s \) from \( \sigma(\theta) \). This is analogous to weighted least squares regression, but here the observed and predicted values are variances and covariances rather than raw observations. The best choice of the weight matrix is a consistent estimator of the asymptotic covariance matrix of \( s \):

\[ W = ACOV(s_{ij}, s_{gh}) \quad (7.7) \]

Under very general conditions:

\[ W = \frac{1}{N} (s_{ijgh} - s_{ij} s_{gh}) \quad (7.8) \]

is a consistent estimator, where \( s_{ijgh} \) denotes the fourth-order moments of the variables around their means, and \( s_{ij} \) and \( s_{gh} \) denote covariances. Browne (1984) demonstrated that
$F_{WLS}$ with such a weight matrix will yield consistent estimates, which are asymptotically efficient with correct parameter test statistics. These properties hold for very general conditions, and consequently such estimators are known as arbitrary distribution function, or asymptotically distribution free (ADF) estimators. ADF-WLS estimators are available in several structural equation model estimation packages including AMOS (Arbuckle, 2000) and LISREL (Joreskog et. al., 1993). AMOS was used to estimate the structural equations models for each of the 17 commodity groups in this study. The estimation results are presented in the next chapter.
Chapter 8
Model Estimation Results

8.1 Introduction
This chapter describes the model specification and estimation results for each of the 17 structural equations models developed. The models employed a host of exogenous (explanatory) and endogenous (dependent) variables to model freight flows by zip code pair. Exogenous variables may be divided into three groups: population demographic characteristics of the origin and destination, employment characteristics of the origin and destination, and the impedance (distance) between the origin and destination. All population demographic variables were derived from the 2000 Census and all employment characteristics were derived from the InfoUSA 2000 database. Exogenous variables to be included in the models were selected based on earlier research (Sivakumar et. al., 2002; Brogan et. al., 2001; Cambridge Systematics, 1996; Jack Faucett Associates, 1999b; Garrido, undated). Endogenous variables are commodity flows between origin-destination zip codes by various modes. The commodity flow on each mode is a different endogenous variable. As mentioned earlier, the distributions of the endogenous variables are highly skewed and non-normal with a large number of zero observations. Nearly 97 percent of the observations are zero observations in the data set. Even within the context of the ADF-WLS estimation method, such a heavily zero-inflated distribution leads to computational intractability. To help with computational tractability, log transformations
of the variables are used in the estimation process. For all observations and variables, unity was added to the raw variable value to avoid having to take the logarithm of zero which is undefined. Thus all zero observations appear as zeros in the log-transformed data set as well because the logarithm of unity is zero.

8.2 Model Estimation Results

In this study, models were estimated for all commodity groups except the coal commodity group. This commodity group had only two zip-code pairs that exchange coal flow between them. Thus, the demand for coal was not estimated. Models were estimated for the remaining 16 commodity groups.

For these 16 commodity groups, various model structures with different variable combinations were considered to test for a structure that performs the best. It was found that aggregate population and employment of the origin and destination zipcodes were enough to be used in the model structures. All the other socio-economic variables listed in Chapter 4 were insignificant in describing the modal flows between an origin-destination pair. Overall employment was found to be significant as opposed to employment for the industry which produces the commodity, because many different types of industrial, service and household sectors may each consume some amount of that commodity.

Thus, the final models developed for each of the 16 commodity groups consist of 5 exogenous variables: Destination Employment, Destination Population, Origin
Employment, Origin Population, and Distance. The endogenous variables were the Total Freight Flow between the O-D pair, and the Freight Flows by various modes between the O-D pair.

Table 8.1 presents the structural equation model estimation results for all commodities combined. Tables B.1 – B.16 in Appendix B present the structural equation model estimation results for all the 16 commodity groups. The path diagram showing the relationships depicted in Table 8.1 is shown in Figure 8.1, while those depicted in Tables B.1 – B.16 (Appendix B) are shown in Figures C.1 – C.16 (Appendix C). The models provided excellent goodness-of-fit measures with the $\chi^2$ statistic indicating that the model can not be rejected with a high degree of confidence (95 percent or higher) and with the goodness-of-fit index (GFI) equal to unity. Thus the models are clearly capable of capturing the key relationships influencing freight flows, even within the context of a large database (more than 859,329 records) where endogenous variables are highly skewed, zero-inflated, and non-normal.

The indications provided by all the models are quite consistent with expectations and plausible. The tables show the direct effects and total effects that constitute relationships among variables. A direct effect is one where a variable directly affects another variable as depicted by a direct arrow linking the two variables in the path diagram. On the other hand, an indirect effect is one where a variable influences another variable through a mediating variable. For example, in Figure 8.1, one can see that origin employment does not directly affect the total freight movement by rail. However, origin employment
affects both total flow and total truck flow. In turn, total flow and total truck flow affect total flow by rail. Thus origin employment affects the total flow by rail through the intermediate variables, total flow and total truck flow. In some cases, a variable may have both a direct and an indirect effect on another variable. Then the total effect is the sum of the direct and indirect effects. Only Total and Direct effects are shown in tables presented. Indirect effects can be obtained as the difference between the total and direct effects.

From Table 8.1, which presents the Structural Equations Model estimation results for all commodity groups, some of the important findings are as follows:

- Employment, both at the origin and destination end, has a positive impact on freight flows by various modes
- Population, both at the origin and destination, has a negative impact on freight flows by various modes
- Distance has a negative impact on freight flows by various modes
- Total flow affects the total truck and rail flows with coefficients less than one.
- The total flow by truck has a negative effect on the total flow by rail

All the other commodity groups yielded models rather similar to this model (Tables B.1 – B.16). As such, this model may be considered illustrative of the types of the models that can be developed and applied using the database and methods described in this study.
Table 8.1

Structural Equations Model Estimation Results for All Commodity Groups

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<td>0.000</td>
<td>-0.001</td>
<td>1.702</td>
<td>-1.545</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Full Truck Load</td>
<td>0.003</td>
<td>Total</td>
<td>0.084</td>
<td>-0.021</td>
<td>-0.007</td>
<td>0.083</td>
<td>-0.021</td>
<td>0.845</td>
<td>0.886</td>
<td>0.028</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.001</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.001</td>
<td>0.000</td>
<td>-0.069</td>
<td>0.930</td>
<td>0.028</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Private Truck Load</td>
<td>-0.001</td>
<td>Total</td>
<td>0.090</td>
<td>-0.023</td>
<td>-0.007</td>
<td>0.090</td>
<td>-0.023</td>
<td>0.899</td>
<td>0.949</td>
<td>0.017</td>
<td>-0.106</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.001</td>
<td>0.000</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.065</td>
<td>1.074</td>
<td>0.020</td>
<td>-0.106</td>
<td>0.000</td>
</tr>
<tr>
<td>Rail Car Load</td>
<td>0.001</td>
<td>Total</td>
<td>0.017</td>
<td>-0.004</td>
<td>-0.011</td>
<td>0.018</td>
<td>-0.006</td>
<td>0.191</td>
<td>-1.505</td>
<td>0.999</td>
<td>-0.008</td>
<td>-0.006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>-0.039</td>
<td>0.052</td>
<td>1.000</td>
<td>-0.008</td>
<td>-0.006</td>
</tr>
</tbody>
</table>

Note:
N = 859,329; chi-square = 1.064 with df = 6; p-value = 0.983; CFI = 1; RMSEA = 0.000
All Variables Significant at 95% level
All Variables are in Logarithmic Form
Figure 8.1
Path Diagram for the Total Commodity Group Structural Equations Model

- Log of Origin Population
- Log of Origin Employment
- Log of Distance
- Log of Destination Population
- Log of Destination Employment

Log of Total Flow
Log of Total Truck Flow
Log of Total Rail Flow
Log of FTL Flow
Log of PVT Flow
Log of Rail Car Load Flow

ε₁
ε₂
ε₃
ε₄
ε₅
ε₆
8.3 Validity of the Model Estimation Results

The hypothesis commonly used in freight transportation planning is that population is assumed to affect the attraction of freight to an area, and industry employment is assumed to affect the generation of freight in an area. The generation of a particular commodity in an area has traditionally been tied to employment within the commodity’s industry. Thus, the positive effect of employment on flows by various modes is plausible and is as expected. One can hypothesize that as the employment increases, the total flow as well as modal flows between an origin-destination pair increase. The variation in the total freight flow as a result of the variation in employment is estimated in the next chapter.

Distance is found to have a negative impact on freight flows between origin-destination pairs. Once again, this finding is consistent with expectations as distance constitutes a measure of impedance. While there are certainly strategic level decisions regarding facility location and customer clustering that tends to make distance a secondary variable in influencing freight flows, one can not ignore the possibility that distance is correlated with the quantity of freight flow between an origin-destination pair. For the state of Florida, recent Commodity Flow Surveys have indicated that about 60 percent of freight movements by value and 80 percent of freight movements by weight occur within the state. Clearly, distance is playing a major role in shaping the distribution and quantity of freight flows in Florida. In fact, about 70 percent (by weight) of all commodity flows originating in Florida travel less than 100 miles. The distance variable in the models simply reflects this tendency in the freight flow database and is found to offer statistically significant and intuitively plausible coefficients.
Moreover, as expected, total flow affects the total truck and rail flows with coefficients less than one. These coefficients represent how the total flow between an origin-destination pair contributes to the different types of modal flows between an origin-destination pair.

A rather surprising finding is that the origin and destination population variables are found to have a negative impact on freight flows in both the models. It was originally expected that population variables would have a positive impact on the quantity of flow. However, estimation results show that population variables are associated with negative coefficients. On the other hand, the employment variables have positive coefficients. Thus, it appears that employment is the key driver of freight flow activity while resident population is not a key driver of statewide freight flow activity. This could be explained by the following arguments.

Business establishments, manufacturing & production operations, and other industrial land uses contribute to heavier volumes of freight flow. Many of these industrial sites are located in zip codes with minimal residential population, but attract and generate large amounts of freight flow. The negative coefficients for population variables may be due to the fact that freight is more likely to be produced and attracted in such rural areas with small populations that have more land available to support large-scale manufacturing activities. Thus, the presence of a residential population does not necessarily contribute positively to freight flows between origin-destination pairs at a statewide level.
Freight flows made up of finished products may be expected to be shipped directly to consumers rather than being transported to warehouses or other industries for further distribution. Within an urban area context, where one is concerned with movement of finished goods, one may conjecture that both business establishments and residential population contribute positively to truck trip generation. However, within the context of a statewide freight flow analysis where the freight flows are mostly industrial raw goods, residential population is not likely to attract freight trips. Thus, it appears that this finding may have some merit in the statewide modeling context. This finding also lends credence to the approach taken by many states and urban areas that try to attract “jobs” to their area to promote economic activity. The notion is that people will then come to where the “jobs” are located.

Moreover, zipcodes with higher populations have lesser growth related activities, thus diminishing the demand for construction related commodities. This explains the negative coefficients for population in the case of construction related commodity groups. Thus, as mentioned in Chapter 3, inclusion of growth related variables such as data on estimates of future dwelling construction and other major construction sites (e.g. new road or rail links, or major urban redevelopment sites) could be used in modeling the demand for construction related commodities. In the future, growth variables should be included in the model specification for construction related commodity groups to make sure that the model is sensitive to these attributes. Future researchers may also wish to investigate the shipment characteristics of commodities to provide a more precise explanation of the negative coefficients of population variables.
Finally, it should be noted that previous research in the development of statewide freight trip generation models also found negative coefficients associated with the population variables. In a similar piece of work, Brogan, et al (2001) provides freight trip generation equations (single production and attraction equations by commodity group) estimated on the TRANSEARCH database. In their equations, the population variables are found to have negative coefficients and employment variables are found to have positive coefficients. Thus the models developed in this study appear to provide very robust indications of the effects of residential population on origin-destination freight flows by commodity and mode. Sensitivity analysis can be performed on these estimated models to estimate the effects of population along with the other exogenous variables on the freight flows.

Overall, the SEMs specified and estimated in this chapter corroborated their potential effectiveness in unraveling complex structural relationships among socio-economic characteristics, modal level of service characteristics and freight flows on various modes. It is also found that freight travel demand can well be addressed using the structural equations framework. The ensuing chapter focuses on the sensitivity analysis for these models to estimate the variations in freight demand in response to hypothetical variations in the exogenous variables.
Chapter 9

Sensitivity Analysis

9.1 Background

Mathematical and computational models are used in a variety of settings and purposes, often to gain insight of possible outcomes of one or more courses of action. These courses of action may be a policy action, the assessment of industrial practices or environmental impacts.

Sensitivity analysis is the study of how the variation in the output of a model (numerical or otherwise) can be apportioned, qualitatively or quantitatively, to different sources of variation. Sensitivity analysis aims to ascertain how the model depends upon the information fed into it, upon its structure and upon the framing assumptions made to build it. This information can be invaluable, as

- Different level of acceptance (by the decision-makers and stakeholders) may be attached to different types of uncertainty.
- Different uncertainties impact differently on the reliability, the robustness and the efficiency of the model.

Originally, sensitivity analysis was created to deal simply with uncertainties in the input variables and model parameters. Over the course of time the ideas have been extended to
incorporate model conceptual uncertainty, i.e. uncertainty in model structures, assumptions and specifications. As a whole, sensitivity analysis is now being used to increase the confidence in the model and its predictions, by providing an understanding of how the model response variables respond to changes in the inputs, be they data used to calibrate it, model structures, or factors, i.e. the model independent variables. Sensitivity analysis is thus closely linked to uncertainty analysis, which aims to quantify the overall uncertainty associated with the response as a result of uncertainties in the model input.

In this chapter, sensitivity analysis is performed to examine changes in the total flow of a commodity brought about by changes in explanatory variables. The intent of this chapter is to demonstrate the applicability of the 17 SEM models described in the previous chapter.

9.2 Sensitivity Analysis

In order to perform sensitivity analysis, variations in commodity flows with regard to different hypothetical increments of the explanatory variables (destination employment, origin employment, distance, destination population, and origin population) are predicted using the models developed. In all, increments from 10% to 100% of the explanatory variables are considered. Two base cases have been considered:

- Base Case I: All the explanatory variables are at their mean values and
- Base Case II: All explanatory variables are at their maximum values
In the data set that was prepared for modeling, the mean value for origin and destination employment is 6739, while the mean distance between the zipcodes is 153 miles and the mean value for origin and destination population is 17238 (used in Base Case I). The maximum value for origin and destination employment is 53604, while the maximum distance between the zipcodes is 509 miles and the maximum value for origin and destination population is 74476 (used in Base Case II).

9.3 Results of Sensitivity Analysis

The sensitivity analysis for all commodity groups combined for the first base case where all explanatory variables are at their mean values is presented in Table 9.1.

Table 9.1

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>3.30</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.39</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.82</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.83</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

From Table 9.1, it can be seen that the total freight flow increases by 3.3%, as the destination employment increases by 10%. Likewise, as the destination employment increases by 100%, the total freight flow increases by 24.68%. The increments in total
freight flow for other increments in the destination employment can be seen from the table. Similarly, as the origin employment increases by 10%, the total freight flow increases by 3.26%. Also, as the origin employment increases by 100%, the total freight flow increases by 24.4%. Thus, it can be seen that the increments in the total freight flow are roughly the same for origin and destination employments.

It can also be seen from Table 9.1 that increase in distance by 10% decreases the total freight flow by 0.39%. The decrease in the total freight flow is only 2.91% for 100% increase in distance. For the destination population, the decrease in the total freight flow is 0.82% and 5.97% for an increase by 10% and 100% respectively. Quite similar to these figures is the origin population which when increased by 10% and 100% respectively, decreases the total freight flow by 0.83% and 6.04% respectively.

Thus, it can be clearly seen that employment, both at the origin and destination is a key driver of freight flows. When a region’s employment at the mean value is doubled, the total freight flow increases by around 25%. The distance has a very small effect on the total freight flow, as can be seen from the fact that in spite of doubling the distance of travel from the mean value, the total freight flow decreases by a mere 3%. Also, population, both at the origin and destination has a nominal effect by decreasing the total freight flow by 6% in spite of doubling the population from the mean value.

One finds the same kind of effects from Table 9.2, which presents the sensitivity analysis for all commodity groups combined for the second base case where all explanatory
variables are at their maximum values. In this table, it can be noticed that the effects of all the variables remain same. However, the magnitudes of the effects are considerably lesser than those found in the base case where all the explanatory variables are assumed to be at their mean values. In this case, it can be observed that the total freight flow increases by 14.76% when the destination employment increases by 100%. The origin employment also has similar magnitude and effect in that the total freight flow increases by 14.60% when the origin employment increases by 100%. Distance has a negligible effect on the freight flow, as an increase in distance by 100% decreases the freight flow only by 1.75%. Destination and origin populations also have a negligible effect. An increase in destination population by 100% decreases the freight flow only by 3.57%. Similarly, an increase in destination population by 100% decreases the freight flow only by 3.61%.

Table 9.2

Percentage Increase in Total Freight Flow (Base Case II)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>1.97</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.95</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.24</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.49</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.50</td>
</tr>
</tbody>
</table>

It can be also seen easily that the changes in the freight flow are higher when the explanatory variables are around their means than at maximum values. For example, the destination employment when incremented by 100% from the mean increases the freight flow roughly by 25%, while the same when incremented by 100% from the maximum value increases the freight flow roughly by 15%. Tables D.1 to D.32 present the sensitivity analysis for each of the 16 commodity groups for which SEM models have been estimated. The results are quite similar to the results in Tables 9.1 and 9.2.

The results presented in this chapter clearly add evidence to the fact that employment is the key factor influencing freight flows between two regions. It is to be noted that shifts in freight flows due to hypothetical increments in employment are very high compared to the other variables considered. The distance and population, both at the origin and destination only have a small effect. Nevertheless, significant causal relationships among socio-economics, modal level of service characteristics, and freight flows by various modes are discerned which are critical to the designing of new and complex transportation policies.

In conclusion, this chapter has established the role of the structural equation modeling methodology in assessing impacts of socio-economic characteristics and modal level of service characteristics on freight flows between two regions. The sensitivity analysis discussed in this chapter has thus demonstrated that the SEM methodology is capable of providing a practical tool for estimating freight flows in the context of a statewide freight demand modeling framework.
Chapter 10

Conclusions and Further Research

10.1 Background

Freight transportation lies at the heart of our economic life. In industrialized countries, it accounts for significant share of the gross national product. In developing countries, it is the essential ingredient of sustainable development. With free trade zones emerging in several parts of the world and with the globalization of the economic system, freight transportation will in all likelihood play an even more major role in years to come. The trend towards larger, more integrated and more efficient transportation systems is likely to remain and should create the need for better planning at the strategic, tactical and operational levels. Thus, major advances have been made in the development of freight transportation modeling methods and frameworks to assist in freight transportation planning efforts.

Freight transportation model development is now a critical component of the overall transportation planning process as urban areas, states, and the nation consider mobility strategies for enhancing the safety and efficiency of freight transportation. Metropolitan Planning Organizations, transportation planners and researchers have attempted to forecast future freight supply and demand in order to estimate future needs. However, the successful implementation of freight demand modeling is hampered by the lack of
appropriate transportation modeling methodologies. The advanced methods developed have not seen application in practice partially due to the lack of adequate data to support their estimation and application to forecasting.

The most significant hurdle to the inclusion of freight transportation into the transportation modeling process is related to the prevailing lack of knowledge on the fundamental mechanisms conditioning freight demand and supply. In order to develop reliable freight demand models, it is essential to understand the mechanisms driving freight demand and incorporate the behavior into the modeling process. However, the development of behavioral freight demand models faces significant hurdles which are a consequence of the inherent complexity of the mechanisms driving freight demand.

A number of factors add complexity to freight demand: a) there are multiple dimensions (i.e., value, weight, volume, trips) to be considered; b) there are multiple decision makers (e.g., drivers, dispatchers) that interact dynamically and take decisions that affect freight demand; c) these interactions takes place in a private context, for the most part not accessible to transportation planners; d) the opportunity costs of the cargoes exhibit a wide range, resulting in multiple user classes ranging from products such as gypsum with a market value of $9/ton; to products such as computer chips that cost in excess of $500,000/ton; and e) freight demand data is for the most part considered to be commercially sensitive. Freight transportation data has been traditionally difficult to collect due to the proprietary nature of the data and due to the difficulty with identifying the proper entity to which a freight transportation survey needs to be administered.
In this regard, the state of freight demand modeling suffers from a compromise between the behavioral validity and the data requirements. It has been identified in the literature review that the models that are able to capture the behavioral aspects of freight demand suffered with two main drawbacks: the data requirement and the computational complexity of the solving process. In contrast, those models that are simple and practical do not capture the behavioral aspects of freight transportation in a comprehensive manner.

10.2 Conclusions

In this context, the objective of this study was to propose a relatively data simple, but behaviorally robust statewide modeling framework for the state of Florida, in the spirit of an aggregate level four-step planning process. The model formulation and empirical analysis in this study were specifically targeted toward the trip generation, trip distribution and mode choice steps. The goal was to propose a modeling framework that can quantify and predict freight flows by various modes between origin-destination pairs in the state of Florida. These origin-destination pairs may be traffic analysis zones, census tracts, zip codes, cities, counties, or even states depending on the particular freight transportation planning context of interest. But, it was desired to conduct this study at the microscopic level of a zipcode unlike any of the earlier studies. The zip code level is considered an appropriate level of disaggregation where the data can be considered to be reliable avoiding large amounts of missing data.
Contrary to passenger transportation, in which there is only one unit of demand, (i.e., the passenger who is also the decision maker) in freight transportation there are multiple dimensions (e.g., volume, weight, and vehicle-trips) to be taken into account when modeling freight movements. The multiple variables that could be used to measure and define freight demand, have given rise to two major modeling platforms: commodity-based and trip-based modeling. In order to develop a behaviorally robust statewide modeling framework that considers the cargoes’ economic characteristics, commodity-based modeling has been adopted in this study.

The hypothesis used in this study is largely in line with paradigms and freight transportation demand-supply relationships identified in the literature. It is assumed that freight movement is fundamentally generated by the demand for consumption of commodities at the destination (or attraction) region, which is met by the flow of commodities from one or more origin (or production) regions. Thus a model concept that predicts freight flows on various modes between two zipcodes based on the population characteristics, employment characteristics, and the modal level of service characteristics has been developed. The model framework is simple & practical, but behaviorally robust and can therefore be easily estimated on a database that can be assembled by any public agency that has resources to purchase some commercial databases.

After a review of the various freight data sources, it was found that the TRANSEARCH database suits best for statewide freight demand modeling of Florida. Thus, the model development in this study is based on the TRANSEARCH freight flow database that is
commercially available from Reebie Associates. This database, providing freight flow information at the zip code level, was merged with population information from the Census 2000 database and employment information from the InfoUSA 2000 database. The resulting database constituted a comprehensive database for modeling freight flows between origin-destination pairs. The only missing component in the database is modal level of service attributes that would potentially influence freight flows by mode (by commodity) between origin-destination pairs. The process of merging modal level of service attributes is currently ongoing and will result in further enhancement of the models developed in this paper. However, simple map distance between zipcodes has been used in this study.

The exploratory analysis conducted on the database suggested that the database offers variables with plausible statistical distributions and summaries consistent with expectations. The modeling methodology consisted of a structural equations modeling framework that can accommodate multiple dependent variables simultaneously. This structural equations model can be applied to all origin-destination zip code pairs in a region. In this model system, explanatory variables representing origin and destination population and employment characteristics and impedance (distance between the origin-destination pair) are included.

The models for various commodity groups are found to offer statistically valid indications and plausible interpretations suggesting that these models may be suitable for application in freight transportation demand forecasting applications. Likelihood ratio $\chi^2$
tests showed that population, employment and distance are all important and significant in explaining the freight demand and its mode choice.

The analysis results for all the commodity groups demonstrated positive relationship between freight demand and employment both at the origin and destination. Consistent significant positive relationships between employment and freight flow for all the commodity groups indicate that employment has a strong influence on all kinds of commodity flows. Similarly, for all the commodity groups, distance is found to have a negative impact on freight flows by various modes as expected.

A rather surprising finding was that the origin and destination population variables are found to have a negative impact on freight flows in all the models. Based on the hypothesis used in this study, it was originally expected that population variables would have a positive impact on the quantity of flow. However, it appears that this finding may have some merit in the statewide modeling context. Within the context of a statewide freight flow analysis where the freight flows are mostly industrial raw goods, residential population is not likely to attract freight trips. However, a more in-depth exploration is required to base this conclusion on a better standpoint.

Sensitivity analysis has been conducted in order to examine changes in the total flow of a commodity brought about by changes in explanatory variables. The results obtained clearly add evidence to the fact that employment is the key factor influencing freight flows between two regions. Shifts in freight flows due to hypothetical increments in
employment were very high compared to the other variables considered. This indicates that employment variables are extremely important in explaining the freight demand and that their omission from the models may be more serious than the omission of demographic and modal level of service variables.

In conclusion, sensitivity analysis has established the role of the structural equation modeling methodology in assessing impacts of socio-economic characteristics and modal level of service characteristics on freight flows between two regions. Significant causal relationships among socio-economics, modal level of service characteristics, and freight flows by various modes were discerned which are critical to the designing of new and complex transportation policies. Thus it has been demonstrated that the SEM methodology is capable of providing a practical tool for estimating freight flows in the context of a statewide freight demand modeling framework.

10.3 Role in the Overall Planning Process

This research focuses on a statewide freight demand model for the state of Florida that takes the structure of a commodity-based model. The Structural Equations Modeling methodology developed in this study is specifically targeted toward the commodity generation, commodity distribution and commodity mode split steps. These three steps in a typical commodity-based model are combined in a unique SEM methodology. Thus the outputs of this model system are Origin-Destination commodity volume matrices for various modes. The inputs to the modeling system are the socio-economic characteristics
and the modal level of service characteristics. The role of SEM methodology in the overall planning process is depicted in Figure 10.1.

Figure 10.1

Flow Diagram for the Planning Process

Structural Equations Modeling

Commodity Generation

Commodity Distribution

Commodity Mode Split

O-D Commodity Volumes by Mode

Vehicle-trip Estimation

Traffic Assignment

Socio-Economic Characteristics

Modal Level of Service Characteristics

The outputs of the SEM model system, as can be seen from Figure 10.1 are Origin-Destination commodity volume matrices by various modes. The next step in the overall planning process is the traffic assignment phase which is a combination of vehicle loading models and complementary models that capture empty trips, using the origin-destination matrices by mode. These vehicle trips are then assigned to the network.
10.4 Model Responsiveness

The model responsiveness in comparison to other methodologies is presented in Table 10.1. As tabulated in this table, SEM has modest data requirements and is behaviorally robust compared to other practical approaches such as growth factor models and log-linear regression.

Table 10.1 Model Responsiveness in Comparison to Other Methodologies

<table>
<thead>
<tr>
<th></th>
<th>Structural Equations Modeling</th>
<th>Growth Factor Models</th>
<th>Log-Linear Regression</th>
<th>Aggregate Cost Function Approaches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Needs</td>
<td>Modest</td>
<td>Minimal</td>
<td>Minimal</td>
<td>Large</td>
</tr>
<tr>
<td>Practicality</td>
<td>Modest</td>
<td>Easy-to-use</td>
<td>Easy-to-use</td>
<td>Complex</td>
</tr>
<tr>
<td>Computational Complexity</td>
<td>Modest</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Theoretical Foundation</td>
<td>Modest</td>
<td>Low</td>
<td>Partial</td>
<td>High</td>
</tr>
<tr>
<td>Predictive Capability</td>
<td>Modest</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Sensitivity to</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Socio-Demographics</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Modal LOS</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Industrial Organization</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

10.5 Further Research

A limitation of this research is that some important variables were not included in the modeling in order to strike a balance between the behavioral capture and data simplicity of the statewide model framework. For example, data on estimates of future dwelling construction and other major construction sites (e.g. new road or rail links, or major urban redevelopment sites) could be used to estimate the demand for construction related commodities. Moreover, land use data may also be used for estimating the agricultural freight demand. Inclusion of such variables will enhance the model reliability, even though the modeling framework might tend to be data intensive.
The development of freight databases and collection of freight movement data continues to be a challenge for model development and estimation. There is always a degree of uncertainty regarding the coverage of the database with respect to geography, commodity groups, and modes and regarding the accuracy of the data as one goes to greater levels of spatial detail. Undoubtedly, further research in understanding the underlying behavior of freight flows is important. Data collection efforts can be targeted based on such research. These days, massive volumes of data are being collected everyday around the globe, hence the co-ordination between different actors collecting similar data has become a new challenge, as the same data measured by different entities do not always match.

The development of freight transportation models is making great strides, but there is some question as to how transferable these models are between geographic contexts and between geographic scales within the same context. How applicable is it to use a model system estimated at the zip code level at another level of aggregation such as census tract or traffic analysis zone? Research into these issues will greatly enhance our ability to develop freight transportation models and estimate freight flows accurately while analyzing the effects of alternative freight mobility strategies and policies.
References


Garrido, R. A. Spatial interaction between the truck flows through the Mexico-Texas border”. Transportation Research A, Volume 34, Number 1, 23-33, 2000


Appendices
Appendix A

Figure A.1

Freight Outflows in Annual Tons by Zipcode
Appendix A (Continued)

Figure A.2

Freight Inflows in Annual Tons by Zipcode
Appendix A (Continued)

Figure A.3

Ratio of Freight Outflows to Inflows by Zipcode
Appendix A (Continued)

Figure A.4

Truck Outflows in Annual Tons by Zipcode
Appendix A (Continued)

Figure A.5

Truck Inflows in Annual Tons by Zipcode
Appendix A (Continued)

Figure A.6

Ratio of Truck Outflows to Truck Inflows by Zipcode
Appendix A (Continued)

Figure A.7

Rail Outflows in Annual Tons by Zipcode
Appendix A (Continued)

Figure A.8

Rail Inflows in Annual Tons by Zipcode

Legend
Rail Inflows in Annual Tons
- 0
- 1 - 2662
- 2663 - 5707
- 5708 - 9645
- 9646 - 15383
- 15384 - 22818
- 22819 - 36157
- 36158 - 54875
- 54876 - 116513
- 116514 - 448625

0 50 100 200 300 400 Miles
Appendix A (Continued)

Figure A.9

Ratio of Rail Outflows to Rail Inflows by Zipcode
Appendix A (Continued)

Figure A.10

Water Outflows in Annual Tons by Zipcode
Appendix A (Continued)

Figure A.11

Water Inflows in Annual Tons by Zipcode
Appendix A (Continued)

Figure A.12

Ratio of Water Outflows to Water Inflows by Zipcode
Figure A.13

Air Outflows in Annual Tons by Zipcode

Legend
Air Outflows in Annual Tons
- 0
- 1 - 211
- 212 - 547
- 548 - 949
- 950 - 1365
- 1366 - 1730
- 1731 - 3987
- 3988 - 7656
- 7657 - 44984
- 44985 - 59664

0 50 100 200 300 400 Miles
Appendix A (Continued)

Figure A.14

Air Inflows in Annual Tons by Zipcode
Appendix A (Continued)

Figure A.15

Ratio of Air Outflows to Air Inflows by Zipcode

Legend

Export by Air to Import by Air Ratio

- 0.00
- 0.01 - 0.99
- 1.00
- 1.01

0 50 100 200 300 400 Miles

Florida Map with Zipcodes showing the ratio of air outflows to air inflows.
Appendix A (Continued)

Figure A.16

Freight Outflows in Annual Tons by County
Appendix A (Continued)

Figure A.17

Freight Inflows in Annual Tons by County
Appendix A (Continued)

Figure A.18

Ratio of Freight Outflows to Inflows by County
Appendix A (Continued)

Figure A.19

Truck Outflows in Annual Tons by County
Figure A.20
Truck Inflows in Annual Tons by County
Appendix A (Continued)

Figure A.21

Ratio of Truck Outflows to Truck Inflows by County
Appendix A (Continued)

Figure A.22

Rail Outflows in Annual Tons by County
Appendix A (Continued)

Figure A.23

Rail Inflows in Annual Tons by County
Appendix A (Continued)

Figure A.24

Ratio of Rail Outflows to Rail Inflows by County
Appendix A (Continued)

Figure A.25

Water Outflows in Annual Tons by County
Appendix A (Continued)

Figure A.26

Water Inflows in Annual Tons by County
Appendix A (Continued)

Figure A.27

Ratio of Water Outflows to Water Inflows by County

Legend

Counties

Export by Water to Import by Water Ratio

- 0.00
- 0.01
- 0.02 - 0.03
- 0.04 - 0.17
- 0.18 - 0.21
- 0.22 - 0.28
- 0.24 - 0.31
- 0.32 - 1.00
- 1.04 - 1.22
- 1.38 - 2.25
- 3.23 - 2.72

0  50  100  200  300  400  Miles

N

149
Appendix A (Continued)

Figure A.28

Air Outflows in Annual Tons by County
Figure A.29
Air Inflows in Annual Tons by County
Appendix A (Continued)

Figure A.30

Ratio of Air Outflows to Air Inflows Ratio by County

Legend

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<tr>
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<th>Export by Air to Import by Air Ratio</th>
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<tr>
<td>Orange</td>
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<td>Hernando</td>
<td>0.01 - 0.40</td>
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<tr>
<td>Dade</td>
<td>0.41</td>
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<tr>
<td>Santa Rosa</td>
<td>0.42</td>
</tr>
<tr>
<td>Escambia</td>
<td>0.43 - 0.47</td>
</tr>
<tr>
<td>Brevard</td>
<td>0.48 - 0.86</td>
</tr>
<tr>
<td>Martin</td>
<td>0.57 - 0.76</td>
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<td>Citrus</td>
<td>0.76 - 0.84</td>
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<tr>
<td>Glades</td>
<td>0.85</td>
</tr>
<tr>
<td>Palm Beach</td>
<td>0.86 - 5.36</td>
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0 50 100 200 300 400 Miles
Figure A.31

Population by Zipcode
Appendix A (Continued)

Figure A.32

Annual Tons Exported per Person by Zipcode
Appendix A (Continued)

Figure A.33

Annual Tons Imported per Person by Zipcode
Appendix A (Continued)

Figure A.34

Population by County
Appendix A (Continued)

Figure A.35

Population Density by County
Appendix A (Continued)

Figure A.36

Annual Tons Exported per Person by County

Legend

Counties

Annual Tons Exported per Person

1.63 - 3.63
3.64 - 5.57
5.58 - 7.38
7.39 - 9.40
8.44 - 10.63
10.64 - 12.86
12.70 - 16.29
16.24 - 25.06
25.08 - 47.96
48.08 - 298.41

0 50 100 200 300 400 Miles
Appendix A (Continued)

Figure A.37

Annual Tons Imported per Person by County
Appendix A (Continued)

Figure A.38

Employer Locations in Florida
Figure A.39

Employment by Zipcode
Figure A.40

Agricultural, Forestry and Fishery Employment by Zipcode
Appendix A (Continued)

Figure A.41

Mining and Construction Products Employment by Zipcode
Appendix A (Continued)

Figure A.42

Light Manufactured Products Employment by Zipcode
Appendix A (Continued)

Figure A.43

Heavy Manufactured Products Employment by Zipcode
Appendix A (Continued)

Figure A.44

Transportation, Communication and Utilities Employment by Zipcode
Figure A.45

Wholesale and Retail Trade Employment by Zipcode
Appendix A (Continued)

Figure A.46

Finance, Insurance and Real Estate Employment by Zipcode
Appendix A (Continued)

Figure A.47

Entertainment, Accommodation and Food Services Employment by Zipcode
Appendix A (Continued)

Figure A.48

Other Services Employment by Zipcode
Appendix A (Continued)

Figure A.49

Public Administration Employment by Zipcode

Legend

SIC 9 Employment

- 0 - 1
- 2 - 14
- 15 - 37
- 38 - 71
- 72 - 119
- 120 - 202
- 203 - 346
- 347 - 614
- 615 - 1185
- 1186 - 15527

0 50 100 200 300 400 Miles
Appendix A (Continued)

Figure A.50

Freight Exports in Annual Tons per Employee by Zipcode

Legend

<table>
<thead>
<tr>
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<tr>
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<td>9.04 - 15.75</td>
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<td>15.76 - 24.83</td>
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<td>24.84 - 46.85</td>
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<td>76.51 - 138.87</td>
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<tr>
<td>138.88 - 1607.41</td>
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</table>
Appendix A (Continued)

Figure A.51

Freight Imports in Annual Tons per Employee by Zipcode

Legend

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<tr>
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<td>3.56 - 7.27</td>
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<td>7.28 - 11.76</td>
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<tr>
<td>11.77 - 16.78</td>
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<tr>
<td>16.79 - 27.42</td>
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<tr>
<td>27.43 - 40.00</td>
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<tr>
<td>40.01 - 94.07</td>
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<td>94.08 - 142.16</td>
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<td>142.17 - 1489.65</td>
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0  50  100  200  300  400  Miles
### Table B.1

**Structural Equations Model Estimation Results for Agriculture Commodity Group**

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</thead>
<tbody>
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<td>Total</td>
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<td>-0.0008</td>
<td>-0.0007</td>
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<td></td>
<td></td>
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<td>0.0018</td>
<td>-0.0008</td>
<td>-0.0007</td>
<td>0.0015</td>
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<td>Total</td>
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<td>0.0000</td>
<td>0.9901</td>
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**Note:**

*N = 859,329; chi-square = 11.041 with df = 9; p-value = 0.273; CFI = 1; RMSEA = 0.001*

*All Variables Significant at 95% level*

*All Variables are in Logarithmic Form*
### Table B.2

Structural Equations Model Estimation Results for Other Minerals Commodity Group

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<tr>
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<td></td>
<td>Direct</td>
<td>0.0101</td>
<td>-0.0019</td>
<td>-0.0092</td>
<td>0.0130</td>
<td>-0.0048</td>
<td>0.9991</td>
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<tr>
<td>Total Rail Flow</td>
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<td>Total</td>
<td>0.0101</td>
<td>-0.0019</td>
<td>-0.0092</td>
<td>0.0130</td>
<td>-0.0048</td>
<td>0.9991</td>
</tr>
<tr>
<td></td>
<td></td>
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**Note:**

*N = 859,329; chi-square = 5.743 with df = 9; p-value = 0.765; CFI = 1; RMSEA = 0.000

*All Variables Significant at 95% level*

*All Variables are in Logarithmic Form*
### Table B.3

**Structural Equations Model Estimation Results for Food Commodity Group**

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<td>0.002</td>
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<tr>
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<td></td>
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<td>Total Rail Flow</td>
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<td>Total</td>
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<td>-0.001</td>
<td>0.000</td>
<td>0.002</td>
<td>-0.001</td>
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<td>-1.568</td>
<td>1.010</td>
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**Note:**

\[ N = 859,329; \text{chi-square} = 0.619 \text{ with df} = 8; p-value = 1; \ CFI = 1; \ RMSEA = 0.000 \]

*All Variables Significant at 95% level*

*All Variables are in Logarithmic Form*
### Structural Equations Model Estimation Results for Non-Durable Manufacturing Commodity Group

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<tbody>
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<td>Total Flow</td>
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<td>0.0192</td>
<td>-0.0074</td>
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</tr>
<tr>
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<td></td>
<td>Direct</td>
<td>0.0192</td>
<td>-0.0074</td>
<td>-0.0105</td>
<td>0.0173</td>
<td>-0.0055</td>
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<tr>
<td>Total Truck Flow</td>
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<td>0.0191</td>
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<td></td>
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<td>0.0000</td>
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<tr>
<td>Full Truck Load</td>
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**Note:**

- \( N = 859,329 \); chi-square = 7.344 with df = 9; \( p \)-value = 0.601; CFI = 1; RMSEA = 0.000
- All Variables Significant at 95% level
- All Variables are in Logarithmic Form
## Appendix B (Continued)

### Table B.5

Structural Equations Model Estimation Results for Lumber Commodity Group

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</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>-0.1032</td>
<td>Total</td>
<td>0.0322</td>
<td>-0.0108</td>
<td>-0.0019</td>
<td>0.0260</td>
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<td>0.0322</td>
<td>-0.0108</td>
<td>-0.0019</td>
<td>0.0260</td>
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<td>Total Truck Flow</td>
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<td>Total</td>
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<td>-0.0066</td>
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<td>Direct</td>
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<td>0.9932</td>
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<td>Total Rail Flow</td>
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<td></td>
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<td>0.0000</td>
<td>0.0012</td>
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<td>0.0002</td>
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<td>0.0795</td>
<td>0.0030</td>
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</table>

**Note:**

$N = 859,329; \ chi-square = 5.033 \text{ with df } = 8; \ p-value = 0.754; \ CFI = 1; \ RMSEA = 0.000$

All Variables Significant at 95% level

All Variables are in Logarithmic Form
Appendix B (Continued)

Table B.6

Structural Equations Model Estimation Results for Paper Commodity Group

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</tr>
<tr>
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<td>-0.0058</td>
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<tr>
<td>Total Truck Flow</td>
<td>-0.0009</td>
<td>Total</td>
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<td>0.0002</td>
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<td>0.9825</td>
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<td>0.0103</td>
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<td>0.7236</td>
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<tr>
<td></td>
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<td>0.0001</td>
<td>0.0000</td>
<td>-0.0002</td>
<td>0.0000</td>
<td>-0.0754</td>
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<td>0.5961</td>
<td>0.0041</td>
<td>0.3787</td>
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Note:
N = 859,329; chi-square = 11.248 with df = 10; p-value = 0.339; CFI = 1; RMSEA = 0.000
All Variables Significant at 95% level
All Variables are in Logarithmic Form

179
### Appendix B (Continued)

#### Table B.7

**Structural Equations Model Estimation Results for Chemicals Commodity Group**

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<td>Total</td>
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<td>-0.0135</td>
<td>-0.0113</td>
<td>0.0431</td>
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<tr>
<td>Total Truck Flow</td>
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<td>Total</td>
<td>0.0449</td>
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<td>0.0008</td>
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<td>0.9643</td>
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<td>0.0023</td>
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<tr>
<td></td>
<td></td>
<td>Direct</td>
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<td>0.0004</td>
<td>-0.0036</td>
<td>-0.0006</td>
<td>0.0006</td>
<td>1.7142</td>
<td>-1.6782</td>
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<td>0.0000</td>
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<td>Full Truck Load</td>
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<td>0.0448</td>
<td>-0.0133</td>
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<td>0.9990</td>
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<td>Less Than Truck Load</td>
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<td>Direct</td>
<td>-0.0011</td>
<td>0.0004</td>
<td>-0.0013</td>
<td>-0.0005</td>
<td>0.0000</td>
<td>-0.0199</td>
<td>4.7910</td>
<td>0.0140</td>
<td>-4.6235</td>
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**Note:**

\[ N = 859,329; \text{chi-square} = 9.503 \text{ with df} = 7; \text{p-value} = 0.219; \text{CFI} = 1; \text{RMSEA} = 0.001 \]

All Variables Significant at 95% level

All Variables are in Logarithmic Form
### Table B.8

Structural Equations Model Estimation Results for Petroleum Commodity Group

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</tr>
</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>-0.0379</td>
<td>Total</td>
<td>0.0135</td>
<td>-0.0048</td>
<td>-0.0046</td>
<td>0.0133</td>
<td>-0.0039</td>
<td>0.0000</td>
<td>0.0000</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0135</td>
<td>-0.0048</td>
<td>-0.0046</td>
<td>0.0133</td>
<td>-0.0039</td>
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<td>Total Truck Flow</td>
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<td>Total</td>
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<td>-0.0044</td>
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<tr>
<td></td>
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<td>Direct</td>
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<td>0.0000</td>
<td>0.0002</td>
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<td>0.0000</td>
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<td>0.0003</td>
<td>Total</td>
<td>0.0122</td>
<td>-0.0042</td>
<td>-0.0041</td>
<td>0.0120</td>
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<td>0.9341</td>
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</tr>
<tr>
<td></td>
<td></td>
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<td>0.0001</td>
<td>0.0000</td>
<td>-0.0001</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.9341</td>
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<td>-0.0002</td>
<td>0.0004</td>
<td>-0.0003</td>
<td>0.0443</td>
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<td>0.0155</td>
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<td>1.0068</td>
<td>-1.0212</td>
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</table>

**Note:**

N = 859,329; chi-square = 9.359 with df = 14; p-value = 0.807; CFI = 1; RMSEA = 0.000

All Variables Significant at 95% level

All Variables are in Logarithmic Form
## Appendix B (Continued)

### Table B.9

**Structural Equations Model Estimation Results for Rubber Plastics Commodity Group**

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<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>-0.0119</td>
<td>Total</td>
<td>0.0043</td>
<td>-0.0019</td>
<td>0.0000</td>
<td>0.0038</td>
<td>-0.0015</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0043</td>
<td>-0.0019</td>
<td>0.0000</td>
<td>0.0038</td>
<td>-0.0015</td>
<td>0.0000</td>
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<tr>
<td>Full Truck Load</td>
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<td>Total</td>
<td>0.0024</td>
<td>-0.0010</td>
<td>-0.0002</td>
<td>0.0021</td>
<td>-0.0009</td>
<td>0.6149</td>
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<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.0003</td>
<td>0.0002</td>
<td>-0.0002</td>
<td>-0.0002</td>
<td>0.0001</td>
<td>0.6149</td>
<td>0.0000</td>
</tr>
<tr>
<td>Private Truck</td>
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<td>0.0000</td>
<td>0.6898</td>
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</table>

**Note:**

\( N = 859,329; \ chi\text{-}square = 2.162 \text{ with df} = 5; \ p\text{-}value = 0.826; \ CFI = 1; \ RMSEA = 0.000 \)

*All Variables Significant at 95% level*

*All Variables are in Logarithmic Form*
### Appendix B (Continued)

#### Table B.10

**Structural Equations Model Estimation Results for Durable Manufacturing Commodity Group**

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</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>0.0014</td>
<td>Total</td>
<td>0.0014</td>
<td>-0.0007</td>
<td>-0.0017</td>
<td>0.0013</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0014</td>
<td>-0.0007</td>
<td>-0.0017</td>
<td>0.0013</td>
<td>-0.0006</td>
<td>0.0000</td>
</tr>
<tr>
<td>Total Truck Flow</td>
<td>0.9023</td>
<td>Total</td>
<td>0.0013</td>
<td>-0.0006</td>
<td>-0.0012</td>
<td>0.0012</td>
<td>-0.0005</td>
<td>0.9023</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
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<td>0.0000</td>
<td>0.0003</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.9023</td>
</tr>
</tbody>
</table>

*Note:*

*N = 859,329; chi-square = 0.974 with df = 6; p-value = 0.987; CFI = 1; RMSEA = 0.000*

*All Variables Significant at 95% level*

*All Variables are in Logarithmic Form*
Appendix B (Continued)

Table B.11

Structural Equations Model Estimation Results for Clay, Concrete & Glass Commodity Group

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</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>-0.2728</td>
<td>Total</td>
<td>0.0744</td>
<td>-0.0208</td>
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<td>-0.0177</td>
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<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0744</td>
<td>-0.0208</td>
<td>-0.0079</td>
<td>0.0723</td>
<td>-0.0177</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Full Truck Load</td>
<td>0.0026</td>
<td>Total</td>
<td>0.0578</td>
<td>-0.0161</td>
<td>-0.0058</td>
<td>0.0563</td>
<td>-0.0137</td>
<td>0.7922</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.0011</td>
<td>0.0003</td>
<td>0.0005</td>
<td>-0.0010</td>
<td>0.0003</td>
<td>0.7922</td>
<td>0.0000</td>
</tr>
<tr>
<td>Private Truck</td>
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<td>Total</td>
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<td>0.0002</td>
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<td>0.0000</td>
<td>0.6934</td>
<td>0.3037</td>
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Note:

N = 859,329; chi-square = 7.252 with df = 5; p-value = 0.203; CFI = 1; RMSEA = 0.001

All Variables Significant at 95% level

All Variables are in Logarithmic Form
### Table B.12

**Structural Equations Model Estimation Results for Primary Metals Commodity Group**

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</thead>
<tbody>
<tr>
<td>Total Flow</td>
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<td>Total</td>
<td>0.0097</td>
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<td>0.0087</td>
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<tr>
<td></td>
<td></td>
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<td>0.0087</td>
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<tr>
<td>Full Truck Load</td>
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<td>Total</td>
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<td>0.0000</td>
<td>0.0000</td>
<td>0.9842</td>
</tr>
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</table>

**Note:**

- N = 859,329; chi-square = 1.856 with df = 7; p-value = 0.967; CFI = 1; RMSEA = 0.000
- All Variables Significant at 95% level
- All Variables are in Logarithmic Form
Table B.13

Structural Equations Model Estimation Results for Fabricated Metal Products Commodity Group

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</thead>
<tbody>
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<td>Total</td>
<td>0.0143</td>
<td>-0.0058</td>
<td>0.0000</td>
<td>0.0126</td>
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<td>0.0000</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0143</td>
<td>-0.0058</td>
<td>0.0000</td>
<td>0.0126</td>
<td>-0.0040</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Total Truck Flow</td>
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<td>0.0125</td>
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<td>0.9937</td>
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<tr>
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<td>Direct</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.003</td>
<td>0.0000</td>
<td>0.9937</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Full Truck Load</td>
<td>0.0008</td>
<td>Total</td>
<td>0.0112</td>
<td>-0.0045</td>
<td>0.0002</td>
<td>0.0100</td>
<td>-0.0032</td>
<td>0.8044</td>
<td>0.8095</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.0003</td>
<td>0.0002</td>
<td>0.0000</td>
<td>-0.0002</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.8095</td>
<td>0.0000</td>
</tr>
<tr>
<td>Private Truck</td>
<td>-0.0002</td>
<td>Total</td>
<td>0.0118</td>
<td>-0.0047</td>
<td>0.0003</td>
<td>0.0105</td>
<td>-0.0033</td>
<td>0.8409</td>
<td>0.8462</td>
<td>0.7162</td>
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<td></td>
<td></td>
<td>Direct</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.2664</td>
<td>0.7162</td>
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</tr>
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Note:
N = 859,329; chi-square = 11.399 with df = 12; p-value = 0.495; CFI = 1; RMSEA = 0.000
All Variables Significant at 95% level
All Variables are in Logarithmic Form
Appendix B (Continued)

Table B.14

Structural Equations Model Estimation Results for Transportation Equipment Commodity Group

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>-0.0161</td>
<td>Total</td>
<td>0.0063</td>
<td>-0.0025</td>
<td>-0.0009</td>
<td>0.0055</td>
<td>-0.0020</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0063</td>
<td>-0.0025</td>
<td>-0.0009</td>
<td>0.0055</td>
<td>-0.0020</td>
<td>0.0000</td>
</tr>
<tr>
<td>Total Truck Flow</td>
<td>-0.0014</td>
<td>Total</td>
<td>0.0062</td>
<td>-0.0025</td>
<td>-0.0004</td>
<td>0.0053</td>
<td>-0.0020</td>
<td>0.9717</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0004</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.9717</td>
</tr>
</tbody>
</table>

Note:
N = 859,329; chi-square = 4.59 with df = 6; p-value = 0.597; CFI = 1; RMSEA = 0.000
All Variables Significant at 95% level
All Variables are in Logarithmic Form
### Structural Equations Model Estimation Results for Miscellaneous Freight Commodity Group

<table>
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<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Flow</td>
<td>-0.0052</td>
<td>Total</td>
<td>0.0025</td>
<td>-0.0012</td>
<td>-0.0007</td>
<td>0.0021</td>
<td>-0.0006</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0025</td>
<td>-0.0012</td>
<td>-0.0007</td>
<td>0.0021</td>
<td>-0.0006</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Total Rail Flow</td>
<td>-0.0019</td>
<td>Total</td>
<td>0.0024</td>
<td>-0.0012</td>
<td>-0.0001</td>
<td>0.0020</td>
<td>-0.0006</td>
<td>0.9237</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0005</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.9237</td>
<td>0.0000</td>
</tr>
<tr>
<td>Rail Car Load</td>
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<td>Total</td>
<td>0.0022</td>
<td>-0.0010</td>
<td>-0.0002</td>
<td>0.0019</td>
<td>-0.0005</td>
<td>0.8372</td>
<td>0.9064</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0001</td>
<td>0.0000</td>
<td>-0.0001</td>
<td>0.0000</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.9064</td>
</tr>
</tbody>
</table>

**Note:**

- \(N = 859,329\); \(\text{chi-square} = 3.463\) with \(df = 8\); \(p\)-value = 0.902; \(CFI = 1\); \(RMSEA = 0.000\)
- All Variables Significant at 95% level
- All Variables are in Logarithmic Form
## Appendix B (Continued)

### Table B.16

Structural Equations Model Estimation Results for Warehousing Commodity Group

<table>
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<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Flow</td>
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<td>Total</td>
<td>0.0625</td>
<td>-0.0157</td>
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<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>0.0625</td>
<td>-0.0157</td>
<td>-0.0116</td>
<td>0.0685</td>
<td>-0.0208</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Full Truck Load</td>
<td>0.0053</td>
<td>Total</td>
<td>0.0524</td>
<td>-0.0131</td>
<td>-0.0097</td>
<td>0.0577</td>
<td>-0.0177</td>
<td>0.8598</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.0014</td>
<td>0.0003</td>
<td>0.0003</td>
<td>-0.0012</td>
<td>0.0002</td>
<td>0.8598</td>
<td>0.0000</td>
</tr>
<tr>
<td>Private Truck</td>
<td>-0.0030</td>
<td>Total</td>
<td>0.0564</td>
<td>-0.0140</td>
<td>-0.0087</td>
<td>0.0621</td>
<td>-0.0188</td>
<td>0.9148</td>
<td>0.1912</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>-0.0005</td>
<td>0.0003</td>
<td>0.0019</td>
<td>-0.0004</td>
<td>0.0002</td>
<td>0.7505</td>
<td>0.1912</td>
</tr>
</tbody>
</table>

*Note:*  
\[ N = 859,329; \text{chi-square} = 0 \text{ with } df = 4; \text{ p-value} = 1; \text{CFI} = 1; \text{RMSEA} = 0.000 \]  
*All Variables Significant at 95% level*  
*All Variables are in Logarithmic Form*
Appendix C

Figure C.1

Path Diagram for the Agriculture Commodity Group Structural Equations Model

- Log of Origin Population
- Log of Origin Employment
- Log of Distance
- Log of Destination Population
- Log of Destination Employment
- Log of Total Flow
- Log of Total Truck Flow
- $\varepsilon_1$
- $\varepsilon_2$
Appendix C (Continued)

Figure C.2

Path Diagram for the Other Minerals Commodity Group Structural Equations Model

Log of Origin Population

Log of Origin Employment

Log of Distance

Log of Destination Population

Log of Destination Employment

Log of Total Flow

Log of Total Rail Flow

$\varepsilon_1$

$\varepsilon_2$
Appendix C (Continued)

Figure C.3

Path Diagram for the Food Commodity Group Structural Equations Model

Log of Origin Population

Log of Origin Employment

Log of Distance

Log of Destination Population

Log of Destination Employment

Log of Total Flow

Log of Total Truck Flow

Log of Total Rail Flow

Log of FTL Flow

Log of PVT Flow

Log of Rail Car Load Flow

ε₁

ε₂

ε₃

ε₄

ε₅

ε₆
Figure C.4
Path Diagram for the Non-Durable Manufacturing Commodity Group Structural Equations Model
Appendix C (Continued)

Figure C.5

Path Diagram for the Lumber Commodity Group Structural Equations Model

Log of Origin Population

Log of Origin Employment

Log of Distance

Log of Destination Population

Log of Destination Employment

Log of Total Flow

Log of Total Truck Flow

Log of Total Rail Flow

Log of FTL Flow

Log of PVT Flow

ε₁

ε₂

ε₃

ε₄

ε₅
Appendix C (Continued)

Figure C.6

Path Diagram for the Paper Commodity Group Structural Equations Model

- Log of Origin Population
- Log of Origin Employment
- Log of Distance
- Log of Destination Population
- Log of Destination Employment
- Log of Total Flow
- Log of Total Truck Flow
- Log of Total Rail flow
- Log of FTL Flow
- Log of PVT Flow

ε1, ε2, ε3, ε4, ε5
Appendix C (Continued)

Figure C.7

Path Diagram for the Chemicals Commodity Group Structural Equations Model

Log of Origin Population

Log of Origin Employment

Log of Distance

Log of Destination Population

Log of Destination Employment

Log of Total Flow

Log of Total Truck Flow

Log of Total Rail flow

Log of FTL Flow

Log of LTL Flow

ε₁

ε₂

ε₃

ε₄

ε₅
Figure C.8

Path Diagram for the Petroleum Commodity Group Structural Equations Model

Appendix C (Continued)
Appendix C (Continued)

Figure C.9

Path Diagram for the Rubber Plastics Commodity Group Structural Equations Model

- Log of Origin Population
- Log of Origin Employment
- Log of Distance
- Log of Destination Population
- Log of Destination Employment
- Log of Total Flow
- Log of FTL Flow
- Log of PVT Flow

$\boldsymbol{\varepsilon}_1$
$\boldsymbol{\varepsilon}_2$
$\boldsymbol{\varepsilon}_3$
Appendix C (Continued)

Figure C.10

Path Diagram for the Durable Manufacturing Commodity Group Structural Equations Model

Log of Origin Population → Log of Total Flow

Log of Origin Employment

Log of Distance

Log of Destination Population

Log of Destination Employment

Log of Truck Flow

ε₁

ε₂
Appendix C (Continued)

Figure C.11

Path Diagram for the Clay, Concrete & Glass Commodity Group Structural Equations Model
Appendix C (Continued)

Figure C.12

Path Diagram for the Primary Metals Commodity Group Structural Equations Model
Appendix C (Continued)

Figure C.13

Path Diagram for the Fabricated Metal Products Commodity Group Structural Equations Model

- Log of Origin Population
- Log of Origin Employment
- Log of Distance
- Log of Destination Population
- Log of Destination Employment
- Log of Total Flow
- Log of Total Truck Flow
- Log of FTL flow
- Log of PVT Flow

\[ \varepsilon_1 \]
\[ \varepsilon_2 \]
\[ \varepsilon_3 \]
\[ \varepsilon_4 \]
Appendix C (Continued)

Figure C.14

Path Diagram for the Transportation Equipment Commodity Group Structural Equations Model

- Log of Origin Population
- Log of Origin Employment
- Log of Distance
- Log of Destination Population
- Log of Destination Employment
- Log of Total Flow
- Log of Total Truck Flow
- $\varepsilon_1$
- $\varepsilon_2$
Figure C.15

Path Diagram for the Miscellaneous Freight Commodity Group Structural Equations Model

- Log of Origin Population
- Log of Origin Employment
- Log of Distance
- Log of Destination Population
- Log of Destination Employment
- Log of Total Flow
- Log of Total Rail Flow
- Log of CL flow

Greek letters:
- $\varepsilon_1$
- $\varepsilon_2$
- $\varepsilon_3$
Appendix C (Continued)

Figure C.16

Path Diagram for the Warehousing Commodity Group Structural Equations Model
Appendix D

Table D.1

Percentage Increase in Agriculture Flow (Base Case I)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>2.33</td>
</tr>
<tr>
<td>Distance</td>
<td>-1.53</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.69</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-1.38</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

Table D.2

Percentage Increase in Agriculture Flow (Base Case II)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>1.31</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.02</td>
</tr>
<tr>
<td>Distance</td>
<td>-1.05</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.15</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.96</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476

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### Appendix D (Continued)

#### Table D.3

**Percentage Increase in Other Minerals Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
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<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>2.77</td>
<td>5.23</td>
<td>7.49</td>
<td>9.59</td>
<td>11.54</td>
<td>13.37</td>
<td>15.10</td>
<td>16.72</td>
<td>18.25</td>
<td>19.71</td>
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<tr>
<td>Distance</td>
<td>-2.36</td>
<td>-4.58</td>
<td>-6.63</td>
<td>-8.52</td>
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<td>-13.47</td>
<td>-14.93</td>
<td>-16.31</td>
<td>-17.61</td>
</tr>
<tr>
<td>Destination Population</td>
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<td>-1.71</td>
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<td>-2.74</td>
<td>-3.05</td>
<td>-3.33</td>
<td>-3.60</td>
</tr>
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Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

#### Table D.4

**Percentage Increase in Other Minerals Flow (Base Case II)**

<table>
<thead>
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<th>Explanatory Variable</th>
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<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
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<td>4.30</td>
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<td>6.65</td>
<td>7.71</td>
<td>8.71</td>
<td>9.66</td>
<td>10.55</td>
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<td>9.94</td>
<td>11.23</td>
<td>12.45</td>
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<td>14.69</td>
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<tr>
<td>Distance</td>
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<td>-2.72</td>
<td>-3.92</td>
<td>-5.02</td>
<td>-6.04</td>
<td>-7.00</td>
<td>-7.91</td>
<td>-8.75</td>
<td>-9.56</td>
<td>-10.32</td>
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<td>-0.82</td>
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<td>-1.46</td>
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<td>-1.83</td>
<td>-1.99</td>
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</tr>
<tr>
<td>Origin Population</td>
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<td>-2.64</td>
<td>-3.17</td>
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<td>-4.15</td>
<td>-4.59</td>
<td>-5.01</td>
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</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
Appendix D (Continued)

Table D.5

Percentage Increase in Food Flow (Base Case I)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
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</thead>
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<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>3.63</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.43</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.12</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.97</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

Table D.6

Percentage Increase in Food Flow (Base Case II)

<table>
<thead>
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<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
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<td>10%</td>
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<tr>
<td>Destination Employment</td>
<td>1.89</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.72</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.24</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.60</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.52</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
### Table D.7

**Percentage Increase in Non-Durable Manufacturing Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>3.58</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>3.22</td>
</tr>
<tr>
<td>Distance</td>
<td>-1.92</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.36</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-1.01</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

### Table D.8

**Percentage Increase in Non-Durable Manufacturing Flow (Base Case II)**

<table>
<thead>
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<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
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<td></td>
<td>10%</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.77</td>
</tr>
<tr>
<td>Distance</td>
<td>-1.09</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
Appendix D (Continued)

Table D.9
Percentage Increase in Lumber Flow (Base Case I)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin Employment</td>
<td>2.73</td>
<td>5.21</td>
<td>7.49</td>
<td>9.61</td>
<td>11.58</td>
<td>13.44</td>
<td>15.18</td>
<td>16.82</td>
<td>18.38</td>
<td>19.86</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.17</td>
<td>-0.35</td>
<td>-0.52</td>
<td>-0.67</td>
<td>-0.81</td>
<td>-0.95</td>
<td>-1.07</td>
<td>-1.19</td>
<td>-1.30</td>
<td>-1.41</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.10</td>
<td>-2.12</td>
<td>-3.07</td>
<td>-3.94</td>
<td>-4.75</td>
<td>-5.50</td>
<td>-6.21</td>
<td>-6.88</td>
<td>-7.52</td>
<td>-8.12</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.66</td>
<td>-1.29</td>
<td>-1.87</td>
<td>-2.40</td>
<td>-2.89</td>
<td>-3.36</td>
<td>-3.79</td>
<td>-4.20</td>
<td>-4.59</td>
<td>-4.96</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

Table D.10
Percentage Increase in Lumber Flow (Base Case II)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>1.76</td>
<td>3.39</td>
<td>4.90</td>
<td>6.30</td>
<td>7.60</td>
<td>8.83</td>
<td>9.98</td>
<td>11.06</td>
<td>12.09</td>
<td>13.07</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.42</td>
<td>2.73</td>
<td>3.95</td>
<td>5.08</td>
<td>6.13</td>
<td>7.11</td>
<td>8.04</td>
<td>8.91</td>
<td>9.74</td>
<td>10.53</td>
</tr>
<tr>
<td>Distance</td>
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<td>-0.22</td>
<td>-0.31</td>
<td>-0.39</td>
<td>-0.47</td>
<td>-0.54</td>
<td>-0.61</td>
<td>-0.67</td>
<td>-0.73</td>
<td>-0.78</td>
</tr>
<tr>
<td>Destination Population</td>
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<td>-1.66</td>
<td>-2.13</td>
<td>-2.56</td>
<td>-2.96</td>
<td>-3.34</td>
<td>-3.69</td>
<td>-4.03</td>
<td>-4.35</td>
</tr>
<tr>
<td>Origin Population</td>
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<td>-0.72</td>
<td>-1.03</td>
<td>-1.31</td>
<td>-1.57</td>
<td>-1.82</td>
<td>-2.05</td>
<td>-2.27</td>
<td>-2.48</td>
<td>-2.67</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476

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## Appendix D (Continued)

### Table D.11

**Percentage Increase in Paper Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin Employment</td>
<td>3.08</td>
<td>5.96</td>
<td>8.61</td>
<td>11.07</td>
<td>13.37</td>
<td>15.51</td>
<td>17.53</td>
<td>19.44</td>
<td>21.24</td>
<td>22.95</td>
</tr>
<tr>
<td>Distance</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-1.07</td>
<td>-1.97</td>
<td>-2.81</td>
<td>-3.58</td>
<td>-4.30</td>
<td>-4.97</td>
<td>-5.60</td>
<td>-6.19</td>
<td>-6.75</td>
<td>-7.28</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

### Table D.12

**Percentage Increase in Paper Flow (Base Case II)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>1.67</td>
<td>3.19</td>
<td>4.60</td>
<td>5.90</td>
<td>7.11</td>
<td>8.25</td>
<td>9.32</td>
<td>10.33</td>
<td>11.28</td>
<td>12.19</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.58</td>
<td>3.02</td>
<td>4.36</td>
<td>5.59</td>
<td>6.74</td>
<td>7.82</td>
<td>8.83</td>
<td>9.79</td>
<td>10.69</td>
<td>11.55</td>
</tr>
<tr>
<td>Distance</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.63</td>
<td>-1.20</td>
<td>-1.73</td>
<td>-2.22</td>
<td>-2.67</td>
<td>-3.10</td>
<td>-3.50</td>
<td>-3.87</td>
<td>-4.23</td>
<td>-4.56</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.50</td>
<td>-0.96</td>
<td>-1.37</td>
<td>-1.76</td>
<td>-2.12</td>
<td>-2.46</td>
<td>-2.77</td>
<td>-3.07</td>
<td>-3.35</td>
<td>-3.62</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
# Appendix D (Continued)

## Table D.13

### Percentage Increase in Chemicals Flow (Base Case I)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>-0.86</td>
<td>-1.62</td>
<td>-2.32</td>
<td>-2.96</td>
<td>-3.56</td>
<td>-4.13</td>
<td>-4.66</td>
<td>-5.15</td>
<td>-5.62</td>
<td>-6.07</td>
<td></td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.03</td>
<td>-1.94</td>
<td>-2.78</td>
<td>-3.55</td>
<td>-4.27</td>
<td>-4.95</td>
<td>-5.58</td>
<td>-6.18</td>
<td>-6.74</td>
<td>-7.27</td>
<td></td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.92</td>
<td>-1.73</td>
<td>-2.47</td>
<td>-3.16</td>
<td>-3.80</td>
<td>-4.40</td>
<td>-4.97</td>
<td>-5.50</td>
<td>-6.00</td>
<td>-6.47</td>
<td></td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

## Table D.14

### Percentage Increase in Chemicals Flow (Base Case II)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>1.84</td>
<td>3.53</td>
<td>5.10</td>
<td>6.55</td>
<td>7.91</td>
<td>9.18</td>
<td>10.38</td>
<td>11.51</td>
<td>12.58</td>
<td>13.61</td>
<td></td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.73</td>
<td>3.32</td>
<td>4.78</td>
<td>6.15</td>
<td>7.42</td>
<td>8.61</td>
<td>9.74</td>
<td>10.80</td>
<td>11.81</td>
<td>12.76</td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>-0.45</td>
<td>-0.87</td>
<td>-1.25</td>
<td>-1.60</td>
<td>-1.92</td>
<td>-2.23</td>
<td>-2.51</td>
<td>-2.78</td>
<td>-3.04</td>
<td>-3.28</td>
<td></td>
</tr>
<tr>
<td>Destination Population</td>
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<td>-1.04</td>
<td>-1.49</td>
<td>-1.91</td>
<td>-2.30</td>
<td>-2.67</td>
<td>-3.01</td>
<td>-3.33</td>
<td>-3.64</td>
<td>-3.92</td>
<td></td>
</tr>
<tr>
<td>Origin Population</td>
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<td>-0.92</td>
<td>-1.33</td>
<td>-1.70</td>
<td>-2.05</td>
<td>-2.37</td>
<td>-2.68</td>
<td>-2.96</td>
<td>-3.23</td>
<td>-3.49</td>
<td></td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
## Table D.15

### Percentage Increase in Petroleum Flow (Base Case I)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>3.23</td>
<td>6.16</td>
<td>8.86</td>
<td>11.37</td>
<td>15.88</td>
<td>17.94</td>
<td>19.87</td>
<td>21.71</td>
<td>23.45</td>
<td></td>
</tr>
<tr>
<td>Origin Employment</td>
<td>3.18</td>
<td>6.07</td>
<td>8.73</td>
<td>11.20</td>
<td>15.65</td>
<td>17.67</td>
<td>19.58</td>
<td>21.39</td>
<td>23.10</td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>-1.07</td>
<td>-2.06</td>
<td>-2.97</td>
<td>-3.81</td>
<td>-4.60</td>
<td>-5.33</td>
<td>-6.03</td>
<td>-6.68</td>
<td>-7.29</td>
<td>-7.88</td>
</tr>
<tr>
<td>Destination Population</td>
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<td>-2.16</td>
<td>-3.12</td>
<td>-4.00</td>
<td>-4.83</td>
<td>-5.60</td>
<td>-6.32</td>
<td>-7.00</td>
<td>-7.65</td>
<td>-8.26</td>
</tr>
<tr>
<td>Origin Population</td>
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<td>-1.75</td>
<td>-2.53</td>
<td>-3.25</td>
<td>-3.92</td>
<td>-4.54</td>
<td>-5.13</td>
<td>-5.69</td>
<td>-6.21</td>
<td>-6.71</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

## Table D.16

### Percentage Increase in Petroleum Flow (Base Case II)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>1.75</td>
<td>3.32</td>
<td>4.76</td>
<td>6.09</td>
<td>7.33</td>
<td>8.50</td>
<td>9.59</td>
<td>10.63</td>
<td>11.60</td>
<td>12.53</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.73</td>
<td>3.27</td>
<td>4.69</td>
<td>6.00</td>
<td>7.23</td>
<td>8.37</td>
<td>9.45</td>
<td>10.47</td>
<td>11.43</td>
<td>12.35</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.54</td>
<td>-1.07</td>
<td>-1.55</td>
<td>-2.01</td>
<td>-2.43</td>
<td>-2.82</td>
<td>-3.19</td>
<td>-3.54</td>
<td>-3.87</td>
<td>-4.18</td>
</tr>
<tr>
<td>Destination Population</td>
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<td>-1.12</td>
<td>-1.63</td>
<td>-2.10</td>
<td>-2.54</td>
<td>-2.95</td>
<td>-3.34</td>
<td>-3.70</td>
<td>-4.04</td>
<td>-4.37</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.45</td>
<td>-0.90</td>
<td>-1.32</td>
<td>-1.70</td>
<td>-2.06</td>
<td>-2.39</td>
<td>-2.70</td>
<td>-3.00</td>
<td>-3.28</td>
<td>-3.54</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
### Table D.17

**Percentage Increase in Rubber Plastics Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>3.80</td>
</tr>
<tr>
<td>Distance</td>
<td>0.00</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.68</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-1.33</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

### Table D.18

**Percentage Increase in Rubber Plastics Flow (Base Case II)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.71</td>
</tr>
<tr>
<td>Distance</td>
<td>0.00</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.72</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
Appendix D (Continued)

Table D.19

Percentage Increase in Durable Manufacturing Flow (Base Case I)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.18</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-1.01</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

Table D.20

Percentage Increase in Durable Manufacturing Flow (Base Case II)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>1.39</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.26</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.30</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
### Appendix D (Continued)

#### Table D.21

**Percentage Increase in Clay, Concrete & Glass Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>-0.32</td>
<td>-0.63</td>
<td>-0.92</td>
<td>-1.18</td>
<td>-1.43</td>
<td>-1.65</td>
<td>-1.87</td>
<td>-2.07</td>
<td>-2.26</td>
<td>-2.45</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.88</td>
<td>-1.70</td>
<td>-2.45</td>
<td>-3.14</td>
<td>-3.79</td>
<td>-4.39</td>
<td>-4.95</td>
<td>-5.48</td>
<td>-5.99</td>
<td>-6.46</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.75</td>
<td>-1.44</td>
<td>-2.08</td>
<td>-2.67</td>
<td>-3.22</td>
<td>-3.73</td>
<td>-4.22</td>
<td>-4.67</td>
<td>-5.10</td>
<td>-5.50</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

#### Table D.22

**Percentage Increase in Clay, Concrete & Glass Flow (Base Case II)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>1.85</td>
<td>3.54</td>
<td>5.11</td>
<td>6.57</td>
<td>7.93</td>
<td>9.22</td>
<td>10.43</td>
<td>11.58</td>
<td>12.67</td>
<td>13.71</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.80</td>
<td>3.44</td>
<td>4.96</td>
<td>6.38</td>
<td>7.71</td>
<td>8.95</td>
<td>10.13</td>
<td>11.25</td>
<td>12.30</td>
<td>13.31</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.19</td>
<td>-0.37</td>
<td>-0.53</td>
<td>-0.68</td>
<td>-0.82</td>
<td>-0.95</td>
<td>-1.08</td>
<td>-1.19</td>
<td>-1.30</td>
<td>-1.41</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.51</td>
<td>-0.97</td>
<td>-1.40</td>
<td>-1.80</td>
<td>-2.17</td>
<td>-2.51</td>
<td>-2.84</td>
<td>-3.14</td>
<td>-3.43</td>
<td>-3.70</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.43</td>
<td>-0.83</td>
<td>-1.19</td>
<td>-1.53</td>
<td>-1.85</td>
<td>-2.14</td>
<td>-2.42</td>
<td>-2.67</td>
<td>-2.92</td>
<td>-3.15</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
Table D.23

Percentage Increase in Primary Metals Flow (Base Case I)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>3.42</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.50</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.53</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

Table D.24

Percentage Increase in Primary Metals Flow (Base Case II)

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>1.81</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.62</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.16</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.68</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
### Table D.25

**Percentage Increase in Fabricated Metal Products Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>3.61</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>3.19</td>
</tr>
<tr>
<td>Distance</td>
<td>0.00</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.34</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.90</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

### Table D.26

**Percentage Increase in Fabricated Metal Products Flow (Base Case II)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.49</td>
</tr>
<tr>
<td>Distance</td>
<td>0.00</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.77</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.55</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476


### Appendix D (Continued)

#### Table D.27

**Percentage Increase in Transportation Equipment Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>3.26</td>
<td>6.25</td>
<td>9.00</td>
<td>11.54</td>
<td>13.92</td>
<td>16.14</td>
<td>18.22</td>
<td>20.19</td>
<td>22.06</td>
<td>23.82</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>2.84</td>
<td>5.45</td>
<td>7.85</td>
<td>10.07</td>
<td>12.15</td>
<td>14.08</td>
<td>15.90</td>
<td>17.62</td>
<td>19.25</td>
<td>20.79</td>
</tr>
<tr>
<td>Distance</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.31</td>
<td>-2.50</td>
<td>-3.59</td>
<td>-4.60</td>
<td>-5.53</td>
<td>-6.41</td>
<td>-7.24</td>
<td>-8.01</td>
<td>-8.75</td>
<td>-9.45</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-1.05</td>
<td>-2.00</td>
<td>-2.87</td>
<td>-3.68</td>
<td>-4.43</td>
<td>-5.13</td>
<td>-5.79</td>
<td>-6.41</td>
<td>-7.00</td>
<td>-7.56</td>
</tr>
</tbody>
</table>

**Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238**

#### Table D.28

**Percentage Increase in Transportation Equipment Flow (Base Case II)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Employment</td>
<td>1.62</td>
<td>3.20</td>
<td>4.65</td>
<td>6.00</td>
<td>7.25</td>
<td>8.43</td>
<td>9.53</td>
<td>10.57</td>
<td>11.55</td>
<td>12.49</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.40</td>
<td>2.78</td>
<td>4.05</td>
<td>5.22</td>
<td>6.32</td>
<td>7.34</td>
<td>8.30</td>
<td>9.21</td>
<td>10.07</td>
<td>10.88</td>
</tr>
<tr>
<td>Distance</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.79</td>
<td>-1.42</td>
<td>-1.99</td>
<td>-2.53</td>
<td>-3.02</td>
<td>-3.49</td>
<td>-3.92</td>
<td>-4.33</td>
<td>-4.72</td>
<td>-5.09</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.66</td>
<td>-1.16</td>
<td>-1.62</td>
<td>-2.04</td>
<td>-2.44</td>
<td>-2.81</td>
<td>-3.16</td>
<td>-3.49</td>
<td>-3.80</td>
<td>-4.09</td>
</tr>
</tbody>
</table>

**Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476**

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## Appendix D (Continued)

### Table D.29

**Percentage Increase in Miscellaneous Freight Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>3.50</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.59</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.47</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

### Table D.30

**Percentage Increase in Miscellaneous Freight Flow (Base Case II)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>1.42</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.14</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.83</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-1.19</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.77</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476
### Table D.31
**Percentage Increase in Warehousing Flow (Base Case I)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>3.16</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.57</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.78</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-1.04</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 6739, Origin Employment = 6739, Distance = 153 miles, Destination Population = 17238, Origin Population = 17238

### Table D.32
**Percentage Increase in Warehousing Flow (Base Case II)**

<table>
<thead>
<tr>
<th>Explanatory Variable</th>
<th>Percentage Increase in the Explanatory Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Destination Employment</td>
<td>1.75</td>
</tr>
<tr>
<td>Origin Employment</td>
<td>1.92</td>
</tr>
<tr>
<td>Distance</td>
<td>-0.33</td>
</tr>
<tr>
<td>Destination Population</td>
<td>-0.45</td>
</tr>
<tr>
<td>Origin Population</td>
<td>-0.59</td>
</tr>
</tbody>
</table>

Base Case: Destination Employment = 53604, Origin Employment = 53604, Distance = 509 miles, Destination Population = 74476, Origin Population = 74476