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**BEHAVIORAL FREIGHT MOVEMENT MODELING: Methodology and Data Needs**

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**Abstract**

Freight transportation modeling has commonly been performed in the well-known four-step framework that was primarily designed for the passenger transportation modeling. This approach has an aggregate nature and does not take into account the critical role of individual firms as the actual decision makers. Therefore, the four-step freight model may lead to questionable estimates that could result in misguided policy measures and investments. There have been some notable achievements in developing behavioral freight models at urban level that mainly focuses on truck trip activities. Although those models may be able to meet the need for the analysis tool at the regional level, national-level policy assessments require a larger picture of commodity shipping behaviors in the country. As an alternative, an activity-based framework that can take into account the complexities of current logistic supply chain activities is discussed in this paper. Supply chain specifications, shipments characteristics, and transport networks’ conditions are considered in order to provide more realistic estimates of shipping behaviors. The gap in the behavioral freight data is a fundamental barrier in disaggregate freight modeling that is also discussed in this paper. The discussion of publicly available freight data in the US and the supplementary cost-effective online establishment survey that was conducted for our study should prove useful to the practitioners and researchers.

1. **Introduction**

Freight transportation is a vital element in the economic prosperity of any country. A wide variety of products need to be efficiently transported within and among the consumer markets, industry sectors, and international trade networks, while addressing adverse impacts on congestion, environment, safety, etc., to the extent possible. Bryan, *et al*, (2007) argued that transportation planners should consider different costs of road freight transport including environmental, maintenance and security, and congestion costs to formulate and offer practical solutions. As the businesses increasingly adopt sophisticated supply chain management strategies, freight shipment decision-making process is becoming ever more complicated.

On the other hand, population increase, economic growth, proliferation of e-commerce, and greater dependence on transportation in the production process, are driving freight movements in many nations, including the US, to reach unprecedented levels, a considerable share of which is long distance and international shipments (Southworth, 2003). Furthermore, in response to the global demand growth, some of the key freight infrastructure nodes and links, such as Panama Canal, will undergo major improvements in the next few years. Such improvements will certainly affect the overall movement of goods in the US. Although the need to incorporate movement of freight in the broader framework of national transportation policy is recognized (US House of Representatives, 2009), providing satisfactory analysis tools to facilitate decision making has been met with significant technical challenges. Major research efforts in travel demand modeling have mainly concentrated on the passenger transportation in the past. As a result, the state-of-the-art in behavioral freight modeling is far behind the advancements in the passenger transportation arena (Pendyala, *et al*, 2000). Complexity of the decision-making process, lack of an acceptable freight modeling framework, and freight data scarcity are the major obstacles.

Hensher and Figliozzi (2007) argued that the rapid changes in the supply chain structures, logistics and technological advancements, and freight systems are the primary causes of obsoleteness of the current freight models and policy making tools. They, in line with many other researchers, strongly believe that the conventional four-step approach, primarily designed for passenger transport modeling, cannot adequately capture the complexity of the international, national, and urban freight movements. Southworth (2003) also argued that a successful freight forecasting tool must be able to incorporate the rapid changes in the supply chain logistics into the planning procedure, either by adopting the traditional methodologies or introducing entirely new frameworks of freight demand forecasting tools. Taylor (2001) highlights the growing trend toward new delivery methods that place premium on the transit time and reliability by utilizing the uncovered capacities of intermodal transport system. Just-in-time (JIT), a cornerstone of contemporary customer-order-driven markets is one example (Hensher and Figliozzi, 2007). As the goods transport becomes ever more complex and sophisticated, many shippers have resorted to outsourcing all or many of the supply chain functions to third-party logistics companies, or 3PLs. Song and Regan (2001)<<not referenced in the references section>> looked into the role of 3PL companies, to which many freight transportation services such as carriage and warehousing are outsourced. Selviaridis and Spring (2007) also provided a recent comprehensive review on the topic. Southworth (2003) argued that 3PLs and IT-based logistic service providers are moving toward more integration and globalization by linking different firms’ logistics management, which makes the prediction of the shipping decision behaviors even more complicated. Kumar and Kockelman (2008) believe that firms and households are the “key drivers of urban growth”. In their view, like households, firms have life cycles that includes their birth, death, migration, etc., each of which has to be studied closely so that a realistic picture of firms’ behavior in goods movement could be obtained and modeled.

Gray (1982) provided a review of behavioral models, and highlighted the importance of identifying the decision makers in the freight demand modeling procedure. In a comparison with passenger activity-based modeling approach, Liedtke and Schepperle (2004) argued that one of the problems with the current state-of-the-practice in commodity transport modeling is that it lacks actor-based microsimulation. Although freight transport decision making process is extremely difficult to reproduce, some valuable efforts have been conducted to develop an agent-based approach. However, it is quite obvious that freight demand modeling framework is not as well-developed as the passenger’s and the establishment of a practical and theoretically sound method is yet to come.

A review of literature revealed that modeling efforts are categorized based on varying criteria in different papers. The most commonly used categorization is the vehicle-based versus commodity-based models. In the commodity-based models, the model starts with the estimation of tonnage of commodity, and then converted into truck trip by “converting annual commodity tonnage into daily truck trips using a payload conversion factor” (Fischer and Han, 2001). Luk and Chen (1997) argued that freight demand is derived from a system in which different types of materials need to be at different locations and thus commodity should be considered as the unit of observation instead of vehicles. Holguin-Veras and Thorson (2000) argued that both commodity-based and vehicle-based approaches lead to conceptual inconsistencies since actual freight demand should be represented by commodity flows but the logistic decisions should be represented by vehicles.

In a recent study, Yang, *et al*, (2009) categorized current models into seven classes and reviewed the pros and cons of each approach. They also introduced three hybrid models, termed commodity supply chain, urban logistics tour, and economic tour, as the future modeling trend. In other review Harker (1985) and Strong, *et al*, (1996), and Regan and Garrido (2001) provided similar modeling classification. Geographic resolution and also the extent of the study area are additional categorization criteria that add to the methodological diversity of the freight studies. Regan and Garrido (2001) discussed several freight demand modeling approaches and found that the literature lacks integration. Winston (1983) also classified the freight models into aggregate and disaggregate approaches based on the types of the data used. This paper aims at providing a review of the inter-city or national-level models and follows the Winston's (1983) classification in the following sections. In the next two sections, some aggregate and disaggregate models are reviewed. Then an entire section is devoted to the review of some practices of freight microsimulation and the relative framework. A five-step activity-based freight microsimulation framework is discussed.

Data scarcity is another major issue that causes severe barriers for the researches and specifically prevents behavioral freight modeling development. Freight data are proprietary in nature and many business establishments are not willing to share such information. Furthermore, knowledgeable persons who can provide input to such surveys tend to have a high value of time, which could seriously decrease the response rate and thereby endanger credibility of the survey. However, aggregate data are usually available but not sufficient for behavioral freight modeling efforts. This is the primary reason for hindering the development of disaggregate freight studies (Kumar and Kockelman, 2008). Data gaps and some cost-effective solutions to satisfy freight data needs in the US are also discussed in the coming sections.

1. **Aggregate Models**

Aggregate approach is still the state-of-the-practice in the modeling of freight transport (Liedtke and Schepperle, 2004). One important reason for such tendency is argued by Pendyala, *et al*, (2000) as the simplicity of aggregate models to be developed based upon non-intensive data and only historical trends. Although many practitioners and decision-makers are aware of the drawbacks of aggregate models, they have to keep the cost of data collection efforts low and comprise between modeling quality and project expenses. NCHRP report 606 (Cambridge Systematics, Inc., *et al*, 2008) recently provided a review of current freight model classes and their components with an indirect emphasis on the conventional four-step approach. This section of the study reviews some previous practices with an aggregate nature.

Two aggregate models were discussed by Oum (1979) <<not referenced in the references section>> for predicting modal demands under different pricing scenarios. The main argument of the study that challenges many recent researches of the time was that logit modeling approach is not appropriate for such purposes. Regan and Garrido (2001) indicated that Oum (1979) )<<not referenced in the references section>> introduced a family of aggregate economic models using data from Census of Transportation that was used in other studies. For instance Lewis and Widup (1982) proposed a dynamic truck-rail modal split model using Oum’s transport cost function. Another aggregate study was conducted by Abdelwahab (1998), who looked into the joint decisions of mode choice and shipment size. Aggregate elasticities were computed in 80 freight transport market segments, made up of five geographical and eight commodity groups. Both aggregate and disaggregate elasticities of mode choice probabilities were obtained and found to be in line with previous researches. Estimation results are discussed in a separate study (Abdelwahab and Sargious, 1992).

As mentioned earlier, some states in the US have developed their freight forecast tool in a four-step framework. A vast majority of their components have an aggregate nature with a significant focus on freight road transport. A simple example was a truck trip forecasting tool that was developed to model the current and future demand in some critical corridors of Minnesota (NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008)). Historical truck data, regional employment data, and some other aggregate trip generation rates were utilized in the study. Annual employment growth of the study area was used for estimating truck growth rate for the year 2020. More extensive efforts have been carried out for the state of Florida to better handle the freight traffic of the major seaports. The model inputs aggregate monthly freight flows and provides truck trip generated to carry the import and export commodities. Both efforts heavily focused on truck trip generation modeling and used historical aggregate data for calibration. More details could be found in NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008).

According to NCHRP synthesis 230 (Coogan, 1996), only seven states incorporated a fright component in their transportation planning effort at the time. Even that limited effort did not cover intermodal freight planning. A four-step intermodal freight forecast framework developed for the state of Ohio (Ohio Department of Transportation, 2009<<The document referred to dates to year 2000>>) provides a picture of current and future freight movement on the major regional corridors. Although the Ohio model covered different modes of freight transportation, trip generation and attraction were heavily based on the TRANSEARCH data and the modal split was performed using the current observed modal share. In a similar fashion, Virginia Transportation Research Council developed its own intermodal freight forecast tool (Brogan, *et al*, 2001). County-level commodity data was obtained from TRANSEARCH and along with some socioeconomic information, transport demand freight generation and attraction models were developed. The primary focus of this research was on the first two steps of the framework, and the mode choice component is open to serious questions. TRANSEARCH data was also used to develop a passenger and freight demand forecast tool for the state of Wisconsin (Proussaloglou, *et al*, 2007). Similar to many other researches, this study mainly focuses on the freight demand generation and attraction and pays a little attention to the modal split. This trend is very common in aggregate four-step approaches and is rooted to the aggregate nature of the data which is not able to capture the behavioral complexities of modal selection decisions. Zhang, *et al*, (2003) also presented a freight forecast tool for the state of Mississippi. Although Mississippi is relatively small in size, it has extensive freight flow from nearby states. Zhang, *et al*, (2003) preferred the 1997 CFS data over TRANSEARCH database to make the study more cost-effective and estimated the county-level freight flows based on the population and zonal economic activity. There are also other states (e.g., Texas, Pennsylvania, Iowa, Oregon, and Alabama) that have developed a four-step freight model, but it is out of the scope of this study to review all of them. More details on the four-step freight demand modeling is provided in the Quick Response Freight Manual by the US Department of Transportation. NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008), Yang, *et al*, (2009), and Pendyala, *et al*, (2000), also provided valuable reviews of similar past practices.

Tavasszy, *et al*, (1998) were one of the pioneers in considering logistics decisions in freight transportation planning. They developed Strategic Model for Integrated Logistic Evaluations (SMILE) in the Netherlands for Dutch Ministry of Transport, Public Works, and Water Management. SMILE is an aggregate model (Yang, *et al*, 2009), yet containing some disaggregate logistics components.

1. **Disaggregate Models**

This section provides a short review of some disaggregate modeling efforts in freight demand modeling. Regan and Garrido (2001) pointed out some drawbacks of aggregate models in general and discussed two types of disaggregate freight models, namely behavioral and inventory. Behavioral models strive to capture the utility maximization process for certain decision-makers, while the inventory approach attempts to model firms' production and logistic decisions based on the principle of economic optimization. Pendyala, *et al*, (2000) argued, however, that approximations are unavoidable in developing logistic cost functions for practical inventory models. Although disaggregate models are more appealing and considered theoretically sounder, limited availability of disaggregate data prevents the development and implementation of such models in many cases. Nevertheless, a considerable number of disaggregate models have focused on urban freight movement and modal selection, and recently on supply chain and logistic decisions.

The inventory approach treats production-related variables such as shipment size endogenously with mode choice decisions (Pendyala, *et al*, 2000). Pendyala, *et al*, (2000) argued that some approximations in the inventory models could make them very similar to the behavioral mode choice model. Baumol and Vinod (1970) conducted a disaggregate analysis of freight demand in an inventory theoretic model. Their model explained the optimal choice of mode from the perspective of an inventory manager, who considers potential inventory cost reduction resulting from a faster and more reliable service. Daughety and Inaba (1978) developed a method for estimating freight demand that is based on the shipper's perception of the transport system’s risk. McFadden, *et al*, (1985) also jointly modeled shipment size and transport mode in the similar fashion. Tyworth (1991) and Vernimmen and Witlox (2003) reviewed studies that implemented these models.

The literature of disaggregate freight demand modeling includes a number of mode choice models. Abdelwahab and Sargious (1992) simultaneously modeled the shipment size and mode choice (truck and rail) in a binary probit model and two linear regression equations. Their finding supports the interdependency between that transport mode and size of the shipment for intercity freight movements. Information on individual shipments of manufactured goods was obtained from the US Commodity Transportation Survey for calibrating the model. Results of this study were utilized by Abdelwahab (1998) to examine the elasticities of mode choice probabilities for the intercity freight transport. Nam (1997) also looked into the effects of commodity aggregation schemes on freight mode choice models. Six logit models were calibrated for different commodity groups, among which no significant difference was found for accessibility, frequency, and rate of each mode. However, commodity disaggregation seemed necessary to obtain meaningful coefficients for transit time. A disaggregate discrete choice model was also introduced by Jiang, *et al*, (1999) to the freight demand modeling literature. Their paper documents the development of a nationwide disaggregated freight mode choice model for France. A nested logit specification was used to account for taste differences between freight transport on shipper’s own account versus purchased road, rail, and intermodal transport. Catalani (2001) also analyzed the modal competitiveness in the Italian domestic freight transport market. A multinomial logit formulation, calibrated by a stated preference survey of shippers, was used for this national-level study. A stated preference survey of freight mode choice in India paved the ground for Shinghal and Fowkes (2002) to look into the truck, rail, and intermodal competition in a six-product sector. They found that intermodal could be a viable option for high value and finished commodities if adequate levels of frequency, reliability, and velocity are provided. In a similar effort, Norojono and Young (2003) embarked upon the development of a mode choice model for Java, Indonesia. A stated preference survey covering four different commodity groups was undertaken. Some quantitative measures for quality and flexibility of the service were introduced, and they were found to be the most influential factors in modal selection. Frequency, departure time and responsiveness were used to explain flexibility, while safety and reliability were the major attributes of quality of service. Using the same set of data, Arunotayanun and Polak (2007) investigated the way that commodity specifications influence shipping mode decisions. Their mixed-multinomial logit model showed difference across various commodity groups. Patterson, *et al*, (2008) explored potential differences in carrier and modal selection between 3PLs and other shippers. The study was based on a stated preference survey that targeted around 400 shippers in Canada. The resulting mixed-logit model revealed that 3PLs and other shippers have similar behaviors in most aspects, except that 3PLs showed more sensitivity to the inventory costs.

Urban freight studies are major contributors of disaggregate models. Commercial vehicle movements are a significant portion of urban traffic in some areas and have a large impact on congestion, safety, environment, etc. Many large cities are looking into this issue and are seeking policies to mitigate negative impacts by controlling and managing truck movements. A series of logit models developed by Stefan, *et al*, (2005) provided a better understanding of vehicle type selection, trip chaining behaviors, tour duration, etc., for the city of Calgary, Canada. Hunt and Stefan (2007) shed light on some urban freight movements, including the treatment of empty trips, less-than-full-load movements, shipment allocation to vehicles, and conversion of commodity flows to shipments. They developed a behavioral urban freight model, capable of predicting commercial vehicle movements under different policy scenarios. Their model also integrated an aggregate passenger travel component, so the interdependencies of urban freight movement and passenger transportation could be accounted for. Similar study in Australia was undertaken by Figliozzi (2007), providing a disaggregate analysis of commercial vehicle tour formation. He collected extensive data on urban freight movements and developed a tour-based model that included a tour generation component to estimate the tour types, duration, stops, etc. Similar efforts with different scopes have been undertaken in the US (Holguin-Veras and Patil, 2005) and the Netherlands (Vleugel and Janic, 2004). Qian and Holguin-Veras (2008) explicitly addressed trip chaining behavior in the urban freight systems by introducing the variables that have a determining affect in trip chaining behaviors.

Recently, there has been a growing interest in supply chain and logistics modeling. Some of these models were developed for urban freight studies. Fischer, *et al*, (2005) and Yang, *et al*, (2009) provided summaries of recent developments in supply chain models. Tavasszy, *et al*, (1998) is a prominent example of supply chain and logistics modeling effort. They developed a series of disaggregate logistics models, called Strategic Model for Integrated Logistics Evaluation (SMILE), together with an economic input-output model to provide a decision tool for policy evaluation for the Netherlands. Also, Boerkamps, *et al*, (2000) developed an urban supply chain model, called GoodTrip, for the city of Groningen in the Netherlands. The GoodTrip is a disaggregate model that defines supply chain patterns and urban truck tours, and thereby provides insights into how the logistics decisions affect the urban truck traffic. de Jong and Ben-Akiva (2007) also embarked upon the development of a logistics module to be included in the existing freight demand model for Norway and Sweden. However, they only discussed the model structure and identified the data sources but did not provide estimation results. Holguin-Veras (2000) also discussed an urban freight modeling framework capable of incorporating logistic information and trip chaining behaviors. A recent study by Samimi, *et al*, (2010a) also proposed a framework for integrating supply chain management concepts in freight movement modeling at a national level. They discussed potential data sources including a complementary survey and the overall framework, but did not provide specific findings.

1. **Behavioral Freight Microsimulation**

This section provides a brief review of the state-of-the-practice in freight microsimulation and also discusses a conceptual framework of a nationwide behavioral freight microsimulation. Liedtke and Schepperle (2004) argued that freight transportation modeling literature lacks appropriate “actor-based” micro-level models, and as a result, the role of actual decision-makers is mostly overlooked. Many others have emphasized the need for a better understanding of decision-making procedures including Gray (1982), Southworth (2003), Wisetjindawat, *et al*, (2005), de Jong and Ben-Akiva (2007), Hensher and Figliozzi (2007), Samimi (2010), Yang, *et al*, (2009), and Roorda, *et al*, (2010). Liedtke and Schepperle (2004) argued that a sound microsimulation freight model could provide a valid forecast tool and pave the way for more reliable policy assessments compared to currently available decision tools. Today, the prospect for developing a fairly disaggregate freight simulation is enhanced by various factors including: high-speed computing devices, growing volume of different data sources, the emergence of online surveys as an affordable data collection technique, and successful practices of microsimulation in passenger transportation. Simulation-based models could better account for the complex interactions among many agents by replicating the individual behavior of the decision makers (Wisetjindawat, *et al*, 2005) and could be integrated with passenger microsimulation models to provide a realistic picture of current and future traffic patterns.

**4.1 Review of Freight Microsimulation Efforts**

GoodTrip was one of the early commodity-based freight microsimulation efforts. Their study focused on urban freight and considered some characteristics of the markets, actors, and supply chains. Supply chains were formed between different entities such as consumers, stores, distribution centers, and factories. The model starts with simulating consumer commodity demand and commodity flow in different mode supply chains and in the end produces the vehicle tours in the city. GoodTrip provided reliable estimates for commodity and vehicle flow and was utilized for analyzing three alternative urban commodity distribution systems. Boerkamps, *et al*, (2000) noted that GoodTrip has an open architecture and could be expanded further. Wisetjindawat and Sano (2003) developed an urban truck microsimulation model for Tokyo, Japan based on the GoodTrip framework. This model is a modification of the conventional four-step approach but disaggregate enough to incorporate individual behaviors. They only focused on urban truck movements and used observed truck volumes from the Road Traffic Census survey for the validation, which was quite promising. They simulated five percent of the actual firms operating in the study area and reported truck origin-destination demand matrixes along with the vehicle kilometer traveled by each truck type (Wisetjindawat, *et al*, 2007). However, they left complex supply chain consideration (e.g., role of 3PLs, JIT) for future improvement.

Hunt, *et al*, (2006) undertook an extensive establishment survey and developed an agent-based commercial vehicle microsimulation for the Calgary region in Canada, based on information from roughly 37,000 tours and 185,000 trips (Stefan, *et al*, 2005). A series of logit models were developed to account for service delivery, trip chaining behaviors, vehicle type, tour duration, etc. (Hunt and Stefan, 2007). The study provided very valuable and detailed information about commercial vehicle movements, including route choice, empty vehicle, and less-than-truck load treatment and also integrated commercial vehicle movements with an aggregate passenger travel model. Other regions in Canada (Edmonton) and the US (Ohio) have also applied the findings of the Calgary study (Yang, *et al*, 2009). The Oregon Department of Transportation developed a Transportation and Land Use Model Integration Program (TLUMIP) that includes a commercial travel model component (Donnelly, 2007). Passenger and road freight were integrated in this economic and land use behavioral model to simulate micro-level truck movements more effectively (Hunt, *et al*, 2001). Commodity flows were generated using economic models and then converted into vehicle flow using land use activities and zonal data. Unlike the Calgary study that undertook an extensive data collection effort (Hunt, *et al*, 2006), Oregon model was based on a diverse range of data sources with different levels of spatial and temporal resolution.

In another study, Kumar and Kockelman (2008) proposed a framework for simulating firm entry, exit, evolution, and location in Texas using employment point data and some aggregate statistics for the local businesses. Two scenarios of low-growth and high-growth of firms were tested and showed a tendency for the firms to move toward the central zones. Kumar and Kockelman (2008) believed that this study could be a starting point to unravel firms’ behaviors and possibly be integrated in household microsimulation studies as a valuable component.

Liedtke (2009) presented an agent-based microsimulation that accounts for logistics reaction patterns. Firm generation, supplier choice, shipment-size choice, carrier choice and tour generation are the main components of this behavioral micro model. Model is calibrated with disaggregate German data was used for calibrating INTERLOG model, primarily used for this simulation purpose. Similar to former microsimulation effort, this study focused on the urban commodity movements and overlooked the rail and other freight transport markets. In a recent study Roorda, *et al*, (2010) proposed a comprehensive agent-based freight microsimulation framework and discussed a diverse range of actors. Although the study is still in progress and no modeling output was reported, some new aspects of freight demand modeling was emphasized. The proposed framework has explicit treatments for outsourcing of logistics services to 3PLs, impact of new supply channels, and general logistics costs, which makes it different from other studies. They, however, indicate that making this conceptual framework operational is a very challenging task. This firm-level microsimulation would be able to predict effects of different scenarios on explicit firm with a known location, industry type, and size. Since the current freight market has a growing tendency in outsourcing freight services to 3PLs, the framework seems suitable for obtaining insights and for future policy making.

Although there are valuable findings in the literature of freight microsimulation, a vast majority of them deal with urban freight movements. Such studies are necessary for urban transportation planning, but not enough for long term policies and infrastructure investments planning. Beside the limited geographical coverage, many previous efforts only focused on the truck movements. Recent adoption of e-commerce and information technologies also affects the freight shipping behaviors and led to new partnerships between manufactures, shippers, carriers, and 3PLs (Southworth, 2003). This requires the policy makers to have access to behavioral micro-level models not only in urban and regional level but also in the country level. Developing a nationwide freight microsimulation could be rewarding and provides valuable insights for future infrastructure investments, a big picture of freight modal shift, and a better understanding of potential impacts of freight activities in a larger scale.

**4.2 FAME: Freight Activity Microsimulation Estimator**

A nationwide freight microsimulation framework is proposed and discussed in this section. The primary goal of the simulation effort is to provide a behavioral picture of the current and future modal split in the US freight transport market. Several applications of a behavioral freight modal split is discussed in the literature such as rail and road infrastructure policy assessment, environmental impacts control, sensitivity of mode choice decisions to different components of transport cost, etc. FAME, however, has an open structure and could benefit from different components that may be added later. Unlike the reviewed microsimulation efforts, FAME has an extensive geographical coverage and aims at covering all the industry types in the US This framework does not discuss the developments of the origin-destination commodity flow in the US and uses the Federal Highway Administration’s Freight Analysis Framework (FAF) (2006) as the base line. However, economic activity models could be used to generate the OD matrixes, in case suitable data is available for this purpose. Developing such component could be very challenging, but rewarding in many respects such as illustrating the production growth and retraction of different industries under various policies of freight infrastructure investment. A challenging module of the microsimulation, however, is the large number of individual firms in the US that should be synthesized. This can impose an extremely heavy computational burden to the model. According to the 2002 Economic Census (US Census Bureau, 2008) there were over seven million establishments in the country with paid employees. Theoretically all the firms can be synthesized, however, by considering just a handful number of supply chains for each firm and breaking down the annual commodity flows into individual shipments, the dataset would become extremely large. Furthermore, such disaggregation requires a great deal of appropriate data for calibration that is not available for the whole country. If there is no valid data to distinguish the effects of some firm’s characteristics on their shipping decisions, there is no benefit in disaggregating the data and replicating those characteristics. Therefore, firm-types are generated instead of actual firms to represent a more realistic unit of decision making in the framework. FAME has five modules that are further discussed below.

Firm generation is the first module where firm-types are defined and their basic characteristics are introduced. Two major tasks should be performed in this step defining the scope of each firm-type, and obtaining information about actual firms in the study area. Individual firms with similar geographic location, industry type, and size are supposed homogenous and grouped into one firm-type. However, categorization method of location, industry sector, and establishment size should be performed and remains a critical task. Since FAME is based on the FAF data, FAF regions could be used as the location categories. However, some recent studies have embarked on disaggregating FAF data into smaller geographic zones (i.e., county) (Ruan and Lin, 2010). North American Industry Classification System (NAICS) suggests an industry sector categorization that can be used in FAME as well. The first eight categories of 2-digit NAICS codes have a high share of freight movements in the US and are suggested to be used in the FAME model. Categorization of company size could be made based on the number of employees, square footage of the establishment, annual turnover or similar measures. Categorization method should be performed considering availability of data and could vary in different studies. However, number of employees is a valid proxy that can be easily found in public data sources. Besides location, primary industry type and size of the firm type, other information such as annual sale, credit score, number of franchises, etc., could be helpful. Firm-types should be defined in this module with three mandatory characteristic (location, industry, size) in addition to the number of actual firms within each firm-type.

Supply chains should be replicated at the second module with their annual commodity flow. Thus the first task is to obtain annual commodity OD flow in terms of dollar value and weight. This information is provided in FAF for the year 2002 and is publicly available. Next step is to find dollar and weight amount of incoming and outgoing commodities in each industry. It is desirable to have such bridge for every geographic zone, but serious data gaps motivates researchers to either use aggregate public data or make their own survey. Due to the large geographical coverage of the study, performing a survey is a very costly option and needs a considerable effort itself. In the absence of such disaggregate information, one can use rough national estimates or utilize local studies. However, upon availability of such information, FAME can easily adapt it and provide more realistic outputs. At this step annual amount of each commodity type that should be transported between each zone pair is known. Also, firm-types that should send or receive such commodity are determined. The last task of this module would be to connect the firm-types and form the supply chains. This task could be performed by a simple rule-based model, expert opinion, econometrics models or complex optimization method. Data availability is the key in determining the supply chain formation method. In case of the availability of a rich dataset, one can take several factors into consideration to model supplier choice process. This may include, financial position of the company, past experience with the supplier, size of the company, number of branches, type of commodity and industry, logistic costs, inventory and stockout costs, and several other sensitive information that companies are very reluctant to share. Well-developed econometrics models or complex optimization method are data intensive and considering scope of the microsimulation, it seems overly optimistic to expect such models at this steps. However, fuzzy rule-based approach or simple choice models are practical options for FAME at this early stage of development. It should be noted that these three tasks are the minimum requirements of this module and several other optional components could be added to this module. This may include some components for adding 3PLs in some chains, considering the effects of international supply chains, adding a cost efficient warehousing component, taking into account the role of consolidation and distribution centers, and several other logistic components that could be added to the FAME framework upon development.

Individual shipment forecasting would be carried out in the third module. Having the annual commodity flow between the firm-type pairs, every single shipment should be generated. In other words, shipping frequency or shipment size should be determined. It should be noted that there is a tradeoff between logistic costs and inventory costs. Large shipments require higher amount of inventory costs, while smaller and more frequent shipments require higher logistic costs. Determining the shipment size, requires a good understanding of optimal inventory strategies that companies adapt and could be performed with different levels of accuracy. If enough information is available about the inventory decisions of different supply chains, optimizing the total logistic costs could be a very reliable strategy for predicting shipment size. This approach, however, is well documented by de Jong and Ben-Akiva (2007). In the absence of sufficient disaggregate data, other modeling approaches such as simple choice models, fuzzy rule-based methods, machine-learning approaches, or even observed distribution of shipment size could somehow be utilized. At this early stage of development, rule-based methods or distribution of shipment size seems to be more realistic. Next generations of FAME are expected to take into consideration the impact of supply chain attributes on the shipment size determination. If appropriate data is available one may consider modeling the shipment size jointly with the transport mode. This usually provides more realistic results and considers the inter-relative nature of these two decisions (Pendyala, *et al*, 2000). McFadden, *et al*, (1985) has one of the earliest joint models of shipment size and mode choice.

Logistic decisions are simulated in the fourth module. Logistic decisions could have a wide range of components that may be adapted in each specific study. Many detailed information about individual shipments are obtained from the past three module including commodity type, weight and value of the shipment, origin and destination, and supply chain characteristics. This information should be utilized in this module to simulate the way that shipments will be delivered to final destinations. This process could be as simple as loading a truck at the origin and unloading it at the destination. It could also be more complicated and evolve several modal shifts and use of consolidation and distribution centers. Based on the nature of each study, this module could be customized to provide the desirable outputs. The basic incentive for developing FAME was to obtain a behavioral picture from the mode choice behaviors in the US freight transport market. Therefore the core of this module is to develop a behavioral mode choice model. A prototype mode choice model has been developed based on an online establishment survey in the US conducted at the University of Illinois at Chicago in April and May 2009 (Samimi, *et al*, 2010b). Other logistic decisions could be modeled endogenously with the shipping mode or added to this module as a separate component. Shipping time, cost, loading unit, outsourcing the freight transport services to a 3PL, route choice, etc., could be looked into as important information in many studies.

Effects of freight movement on the transportation network should be analyzed at this module. Commodity flows should be loaded to the road, rail, water, and air networks and transformed into the appropriate transportation unit. Treatment of LTL, empty trucks, should be included in the road freight transport. A variety of performance measures should be developed to provide a better understanding from different effects (i.e., congestion, safety, environmental impacts) of freight transport on the networks. These should enable policy makers to gain a more tangible understanding of different alternative scenarios. Nevertheless, many interesting components could be added to this module in the next generations of FAME.

1. **Data**

Data quality and availability is a vital key to develop and validate the models and methods in all forms of planning (Meyburg and Mbwana 2002)<<not referenced in the references section>>, however, there are several factors that make the freight data collection efforts costly and limited in scale and scope. Estimated freight flows will not be reliable, if the basic database is not complete and accurate. Information on the large scale commodity movements is usually available in an aggregate level. However, data on disaggregate shipping decisions are very scarce, primarily because such information has a proprietary nature and understandably companies are reluctant to share such information to safeguard their competitive edge. Furthermore, such information should be obtained from the time-pressured shipping managers or someone with enough knowledge about the firms’ logistic decisions. This will bring down the response rate in such voluntary surveys, which could even nullify the results and open serious doubts about validity and unbiassedness of the collected information. Widespread adoption of outsourcing, e-commerce, JIT delivery systems, etc., emerges new shipping behaviors (Meyburg and Mbwana 2002)<<not referenced in the references section>> and requires new type of data collection efforts. Therefore, as Bronzini (2001)<<not referenced in the references section>> emphasized, new ways of freight data collection should be considered that encourage higher participation rate. Different types of freight surveys are discussed by Southworth (2003), among which carrier activity surveys and commodity flow surveys have an extensive application in calibrating FAME. Shipper and carrier surveys are more manageable (NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008)) and may contain valuable information on the weight, value, and type of commodity, origin and destination, haul time, transportation modes, and other information on the entire shipping process. Due to the high cost of behavioral freight surveys, modelers try to utilize public data, and previous rates, coefficients, and relationships. For instance NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008) discussed several publications that can be used for truck trip generation and distribution. Some of the public freight data sources that can be freely used as a reliable database in many freight studies in the US are discussed in the following section. Some previous freight data collection efforts are also discussed along with a recent nationwide online freight survey in the US based at the University of Illinois at Chicago (Samimi, *et al*, 2010b).

**5.1 Public Freight Data Sources in the US**

There have been some studies in the literature that critically analyzed existing freight data sources in the US, including NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008). The Commodity Flow Survey (CFS) is the only nationwide mandatory survey that provides very useful information on commodity movements (US Census Bureau, 2007). Although CFS filled a critical data gap and provides necessary information for many freight studies, its aggregation level imposes some restrictions on its applicability for behavioral models. This level of aggregation, however, seems unavoidable for the government to respect and protect privacy of respondents. Shin and Aultman-Hall (2007) argued that a higher level of geographical resolution should be considered for CFS to better address regional and national freight planning needs. They also proposed a zoning system termed Freight Analysis Zone (FAZ) that better serves the planning needs and takes into account confidentiality issues. Freight Analysis Framework (FAF) by Federal Highway Administration (2006) produced a commodity flow dataset for the years 1998, 2010, and 2020. This is heavily drawn from other surveyed data including CFS and provides OD commodity flow matrixes by mode and commodity type in annual tonnage and annual dollar value. Since the commodity coverage is broader than CFS, we preferred to use FAF data as the input OD commodity flow to FAME.

Vehicle Inventory and Use Survey (VIU.S.) is another national level public data set with a focus on truck usage and a sample of approximately 150,000 (NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008)). VIU.S. had been conducting in America from 1963 to 2002 in five-year intervals. State-level truck activities could be utilized together with establishment surveys and provides an understanding of urban truck trip pattern, loading/unloading activity, etc. VIU.S. has a similar commodity classification to CFS and FAF that makes simultaneous use of these data sources easier. Carload Rail Waybill Sample also has some rail shipments data including origin, destination, commodity type, haul length, interchange locations, and other confidential information. This information is used primarily by Federal and state agencies (NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008)), but an aggregate version of the data is available for public use.

County Business Patterns (CBP) is provided by the US Census Bureau (2008) and provides basic information about business establishments across the US. This includes number of establishments, number of employees, and payroll data by industry classification. Some information is not disclosed at higher geographic resolutions due to confidentiality issue. This public information is very helpful in the first module of FAME, where aggregate information about business establishments is needed to synthesize firm-types. Another dataset that should be used in the second module of FAME concerns the amount of different commodity types that each industry sector uses and produces. Bureau of Economic Analysis (2008) has provided an input-output account that contains such information in the US.

**5.2 Private Freight Data Sources**

TRANSEARCH is proprietary dataset, developed initially by Reebie Associates and then purchased by Global Insight. Although TRANSEARCH is a commercial product, it has been extensively used in different states including four case studies that are reviewed in NCHRP Report 606 (Cambridge Systematics, Inc., *et al*, 2008). TRANSEARCH is updated annually from many commercial and public data sources and provides county-to-county freight movements (Yang, *et al*, 2009). While there has been a limited number of disaggregate freight data collection efforts in the US, Canada has experienced some large-scale freight surveys. Around 7,300 business establishments in Calgary and Edmonton regions in Canada were interviewed about their commercial movements on an assigned day (Hunt, *et al*, 2006). This survey provided information of roughly 37,000 tours and 185,000 trips only in the Calgary region. In another effort, some valuable behaviors of truck tour formation was obtained and adopted in Ohio for developing urban freight models (Hunt and Stefan, 2007). Patterson, *et al*, (2007) also performed a stated preference survey in Quebec City-Windsor corridor to test the difference between 3PLs and other shippers in mode choice behaviors. This is the only recent survey in Canada that did not focus on urban freight and also considered truck rail competition and its effect in an intercity corridor. Close to 400 shippers participated in this study. Roorda, *et al*, (2007) conducted the Region of Peel Commercial Travel Survey, focusing on urban goods and services. The survey had two major parts, namely shipper survey and driver survey and some information about the establishments’ shipping behavior together with truck tour formation was provided (Kwan, 2007; McCabe, 2007). Trucks were also equipped with a GPS unit in the driver survey component which was novel in freight surveys.

There have been other freight data collection efforts in the world, some of which are briefly discussed here. Wisetjindawat and Sano (2003) carried out a freight survey in the Tokyo Metropolitan Area to develop a truck logistics model. They did not take into account other modes of transportation and only focused on urban freight. Norojono and Young (2003) also performed a stated preference survey in Java, Indonesia to further explore truck and rail competition in goods movement. This shipper’s survey was later used in other studies as well (Arunotayanun and Polak, 2007). In India, Shinghal and Fowkes (2002) carried out a similar study in a limited scale and asked 32 firms in six industry sectors to fill out an adaptive stated preference survey about their freight modal selection behaviors. The very small sample size, however, could make any similar survey open to serious questions. Catalani (2001) also discussed freight data limitations in Italy and performed a similar survey to shed light on freight mode choice behaviors. Some other studies did not collect specific freight data, but discussed data needs for a specific freight study, analyzed available data sources, and proposed freight surveys to fill out data gaps (Ahanotu and Mani, 2008; Roorda, *et al*, 2010). There are many other freight data collection efforts, especially in the Europe that cannot be covered in this short review. Allen and Browne (2008) presented an inclusive discussion of more than 160 urban freight surveys in the world.

**5.3 UIC National Freight Survey**

FAME requires some data that cannot be found in the available data sources in the US. This mainly includes disaggregate data on the shipping process and supply chain formation to fulfill data gaps in the second and forth modules of the framework. UIC National Freight Survey was conducted during April and May 2009 to provide some disaggregate information for calibrating the FAME components (Samimi, *et al*, 2010b). As mentioned earlier, a major concern in many freight surveys that not only makes them costly but also could endanger the credibility of the results is the survey response rate. Since this survey was to cover every industry sector in the United States, in-person or telephone interview, and mail-in and mail-out survey methods could make the survey very expensive. Although these methods prove to have a better response rate compared to web-based surveys, more responses could be obtained by a given budget in the web-based methods. However, non-response selection bias is more serious in online surveys and appropriate methods to detect and resolve such potential issue should be considered (Heckman, 1990).

The survey was designed in three sections, containing questions on establishment, five recent shipments, and optional contact information. Invitation emails were sent to the shipping manager or a person with enough knowledge about the logistic decisions of a large number of randomly selected firms in the US. A marketing company also provided information about the recipients’ industry sector, size of the establishment, location, name and phone number. 4,544 recipients successfully opened the inviting email, among which around 9.3% clicked on the survey link, but not necessarily filled out the survey. This effort provided information on a total of 881 individual shipments. A non-response selection bias was also performed to test whether location, industry type, or size of the companies had a significant effect on participation chance. Only employment size showed a very slight association with response rate in a binary choice model that had a pseudo r-squared of around 4%. A detailed explanation of the survey design, development, recruitment, non-response bias analysis, descriptive analysis, and validation along with a discussion on lessons learned from this experience can be found elsewhere (Samimi, *et al*, 2010b).

1. **Conclusion**

Freight transportation has a tight relationship with the economical growth of a country. A behavioral model could provide reliable policy measures for evaluating different alternatives and to improve economic welfare. The major problem of the current freight models is that they are not actor-based and the responsible decision-makers do not play a significant role in them. Similar problems existed in passenger transportation models. However, recent advances in the area of emerging activity-based travel demand modeling have addressed this issue to an acceptable extent. The activity-based approach emphasizes on the role and behavior of the household or individual as a primary decision maker. One can argue that there is a similar need for an activity-based micro-model in the literature of freight demand forecasting. Such an approach should effectively incorporate business establishments, shippers, carriers, and other logistic service providers’ decision making process. There have been some valuable efforts in developing agent-based urban freight microsimulation models in Canada and Europe that only focus on truck trip behaviors. These achievements are considered as a first step toward a successful freight transport system; however, they do not provide a realistic picture of freight movements in a larger-scale, which is an absolutely necessary factor for a nationwide policy analysis and infrastructure investment program.

This study discussed a behavioral microsimulation framework, called FAME that aims at providing a more realistic picture of freight movement activities in the US. FAME has an open structure and different components can be included in the framework based on research needs. Some of these components could be developed based on previous studies. Therefore, several different freight modeling efforts inside and outside of the US were discussed based on nature of the data sources used for calibration and their geographical resolution. It was argued that a major barrier for developing the proposed activity-based freight microsimulation model is the lack of suitable disaggregated data. Freight surveys are costly and many studies cannot afford collecting behavioral data and should build the models upon available aggregate information. This study also discussed available public freight data sources in the US that can be easily utilized for developing the FAME. A supplementary establishment survey was also very briefly discussed as an alternative cost-effective approach to fulfill FAME’s data needs.

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<<Note: Please check the consistency of references. The references marked with ‘\*’ are not cited in the text and the citations in text followed by ‘<<’ have no/vague references.>>

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