A Behavioral Freight Transportation Modeling System

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1. Introduction

Freight movements have significant impacts on transportation system, regional wellbeing and economic growth. Because of the complexity of decision-making in freight system, sophisticated modeling tools are used for forecasting, policy assessment, and counteracting the impacts of freight movements. Unlike the passenger transportation subject, freight transportation is a relatively less-researched field in terms of advanced modeling applications. However, this has been recognized by researchers around the world and the field is rapidly developing in many directions, including data collection, modeling frameworks, and operational strategies. There are still significant gaps in terms of our understanding of the fundamentals and the nature of freight movement systems and their behavioral decision making process.

Review of the literature revealed that many available freight transportation models have aggregate nature. Moreover, many of the current models are short in term of logistics elements such as, use of intermediate handling facilities, determining optimum shipment size, mode choice, and multi-modal shipments. Many researchers have discussed the drawbacks of the aggregate models in capturing the complexity of freight policy systems (1 and 2). In particular, they cannot replicate the supply chains and logistics decisions made by individual actors in the freight system. Recently, there have been some advances in developing logistics models at the urban level with a primary focus on road transportation. The urban logistics models are effective analysis tools at the local level. However, a more comprehensive framework and detailed behavioral models are needed to assess policies at the national level and to examine the effects of changes to the system-level elements (e.g., expanding ports capacity, or widening the Panama Canal) on regional/national level freight movement.

This paper introduces a behavioral microsimulation framework for freight transportation modeling named FAME (Freight Activity Micro-simulation Estimator). FAME has a wide geographic coverage and to the best of the authors’ knowledge, it is the first comprehensive nationwide freight microsimulation model in the U.S. The FAME model uses a fresh approach in modeling freight demand by incorporating a modular structure and working at the disaggregate level of firm as the basic decision-making unit in the freight market. The large-scale model simulates commodity movements in the U.S. at the disaggregate level of firm-to-firm. Data
scarcity appears to be a crucial barrier in developing such a disaggregate logistics model. A set of publicly available datasets are utilized to develop the model. In addition, more detailed information concerning individual shipments is collected through an online nationwide establishment survey, conducted by the research team (3).

2. Freight Activity Micro-simulation Estimator (FAME)

FAME was introduced as a freight activity-based modeling framework with five basic modules (4). This paper provides very brief overview of this framework. Interested readers may refer to Samimi et al. (4) for further elaboration of the FAME framework. FIGURE 1 illustrates FAME framework. In the first module, all firms in the study area are synthesized and their basic characteristics, including industry type, employee size, and location are identified. Based on each firm's characteristics, types and amounts of incoming and outgoing goods are determined, and trade relationships are formed for each pair of supplier-buyer firms in the second module. Third and forth modules deal with logistics choices. In the third module, the shipment sizes are defined based on the acquired information on the firms’ characteristics, and shipping modes are determined in the fourth module. Finally, in the last module, the impact of the goods movements on transportation network is investigated.

Four categories of data are required for developing FAME: information on business establishments for the first module, aggregate freight flows (OD matrix) for the second module, detailed information on a sample of individual shipments and supply chains for the third and forth tasks, and specifications of the transportation networks for the last module.
FIGURE 1. FAME OPERATIONAL FRAMEWORK

Firm-types Generation
Identifying individual decision-makers

Supplier selection
Determining relationships between firm-types

Shipment size determining
Based on observed shipment size distribution

Mode choice
Select mode of transportation

Network analysis
Assigning commodity flows to the traffic network and assess the impacts

Firm-types Generation

As discussed earlier, FAME simulates freight flows at the disaggregate level of firm-to-firm. Thus, the decision-makers in this microsimulation are individual firms in the U.S. Since, there are more than 239,000 firms with six digit North American Industry Classification System (NAICS) industry type in the U.S. (5). Some form of aggregation is inevitable to keep the computational burden at a reasonable level and diminish the need for highly disaggregated data. We proposed to aggregate the firms based on firm-types. A firm-type is a collection of firms with similar location, industry type, and establishment size. It is assumed that firms with the same characteristics have the similar behavior in freight decision-making process. Number of firm-types can differ based on the number of industry types, establishment size, and geographic zones in the study area. Considering 123 domestic zones, 328 industry classes (NAICS), and
eight employee size groups in this simulation, a total of 45,206 firm-types were identified in the U.S.

**Supplier Selection**

Trade relationships were replicated based on a fuzzy expert system that was developed by the research team (6). This model scores the appropriateness of all the possible suppliers for a given firm-type. Having the likelihood of partnership for any pair of supplier and buyer, annual commodity flows is disaggregated from geographic zone level into firm-type level. For a given origin, destination, and commodity type, the value of total annual tonnage was obtained from Freight Analysis Framework data (FAF3.0) (7) and disaggregated between the top five percent of supplier and buyer pairs with the highest appropriateness score.

Two-digit Standard Classification of Transported Goods (SCTG) used in FAF is also utilized in this study to classify the commodities. All FAF industry sectors were considered in FAME, but some of them were not present in specific zones in the simulation. This is due to the limitations of business establishment data sources and also the crosswalks that were used in the second module to connect industries to commodities. As a result, not all of the FAF commodity flows between the zone pairs was allocated to firm-types. In total, freight flows for 40 classes of commodity types is simulated in FAME.

**Shipment Size Determination**

A shipment size model, developed by the research team (6), provides a categorical output variable with three clusters: small (less than 1,000 lb), medium (1,000-50,000 lb), and large (more than 50,000 lb). Establishment size of the supplier and buyer, shipping distance and commodity type, are the inputs of the model. This model was applied on the annual commodity flow between each pair of supplier and buyer from the former section and determined share of small, medium, and large shipments accordingly. However, knowing that a shipment is small is not enough to run the modal split in the next module and a crisp value should be assigned as well. In order to do so, a distribution of observed shipment sizes from the UIC National Freight
Survey (3) was obtained for each class of shipment size. Details of the shipment size model and the shipment size distributions are elaborated elsewhere (6).

**Modal Split**

A binary probit mode choice model was deployed in this simulation to determine the share of truck and rail (including truck-rail intermodal) for each shipment. This model has a proxy for distance, weight, relative impedance between truck and rail, a dummy for containerized shipments and commodity type as input variables all of which have to be determined for every simulated shipment. In this simulation the overall probability of having containerized shipments was assumed to be 11.8%, according to the UIC National Freight Survey (3). Although the binary mode choice has a satisfactory goodness of fit, it underestimates the total number of rail shipments. Therefore, the estimated probability of a rail shipment is increased by a 1.3 factor to cover this underestimation in general.

Modal split of domestic freight movements in the U.S. was performed by calibrating and simulating the first four modules of FAME. As mentioned, only truck and rail (including truck-rail intermodal) are covered as the primary modes of freight transportation, and the relative percentages of total tonnage, value, and ton-mile of commodities between the two modes are estimated. Due to the random nature of the microsimulation, the simulation was repeated several times. Although the tonnage of the shipments carried by each mode is obtained directly from the model, the dollar value of the shipment is approximated using FAF3.0 dataset.

### 3. Simulation Results

Some of the major results of this microsimulation are presented in this section. Since there is no disaggregate freight data available, the results are aggregated and validated with public aggregate datasets. TABLE 1 shows results of the modal split model in FAME. It presents the relative percentages of total tonnage, value, and ton-mile of commodities between two modes simulated in FAME and compares them with FAF3.0 and Commodity Flow Survey (CFS) estimates. It
should be noted, that modal split information of none of these datasets has been used in model calibration and thus can be an appropriate base line for validation.

**TABLE 1. MODAL SPLIT VALIDATION IN FAME**

<table>
<thead>
<tr>
<th>Item</th>
<th>CFS 2007</th>
<th>FAF3.0</th>
<th>FAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tonnage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>19%</td>
<td>16%</td>
<td>16%</td>
</tr>
<tr>
<td>Truck</td>
<td>81%</td>
<td>84%</td>
<td>84%</td>
</tr>
<tr>
<td>Value</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>7%</td>
<td>18%</td>
<td>18%</td>
</tr>
<tr>
<td>Truck</td>
<td>93%</td>
<td>82%</td>
<td>82%</td>
</tr>
<tr>
<td>Ton-mile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td>53%</td>
<td>48%</td>
<td>48%</td>
</tr>
<tr>
<td>Truck</td>
<td>47%</td>
<td>52%</td>
<td>52%</td>
</tr>
</tbody>
</table>

Moreover, FIGURE 2 compares simulated commodity flows in FAME with FAF estimates by commodity type. Based on FAF dataset, a total of 14,845 million tons of commodities valued at around 12,276 billion dollars is transported between the domestic origin and destinations on truck, rail, or truck-rail intermodal (7). In total, 14,202 million tons of commodities valued at around 10,916 billion dollars is simulated in FAME. Thus, more than 95% of FAF domestic tonnage and around 89% of commodity values is simulated in this study. FIGURE 2 shows the result of second module (supplier selection) where trade relationships are formed and commodity flows are simulated between firm-types.
FIGURE 2: COMMODITY FLOWS (KTon) (COMPARISON BETWEEN FAME AND FAF)
4. CONCLUSION

The primary motivation for this research was to develop a behavioral freight transportation model in the U.S. Therefore, a nationwide freight activity microsimulation was conducted. A major drawback of many previous studies of this kind is the aggregate nature which prevents the development of an actor-based microsimulation. A large-scale behavioral microsimulation framework, named FAME was developed in this study. This framework incorporates firms’ characteristics in replicating shipping behaviors, and aimed at paving the way for future behavioral freight microsimulation efforts. Final results of simulation showed a close match with CFS 2007, and FAF3.0 data. This study aimed at facilitating a sound microsimulation freight model as a valid forecast tool that eventually could contribute to more reliable policy assessments compared to currently available decision tools.

FAME is largely based on public freight data in the U.S. and therefore data collection costs are substantially mitigated. Furthermore, this study covered a wide range of industry classes and commodity types. FAME has a unique geographic coverage, as well, and to the best of the authors’ knowledge, it is the first comprehensive nationwide freight microsimulation in the U.S. This study presented the first steps toward a comprehensive activity-based freight microsimulation. There are still several components that need further exploration.

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