A Firm-Based Freight Demand Modeling Framework: Capturing Intra-firm Interaction and Joint Logistic Decision-Making

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1. INTRODUCTION

Effective freight transportation planning and programming requires the means to accurately forecast the response of freight pattern to infrastructure improvements, demand management strategies, and traffic control measures. The need for reliable freight demand forecasting procedures has received a major impetus also because of the legislative requirements on mobile-source emissions and the importance of freight mobility to the nation’s economic competitiveness.

Today, most ongoing statewide and urban area freight planning processes adapt the growth factor method or the trip-/commodity-based four-step modeling approach, originally developed for passenger transport. Yet, development in freight demand forecasting has clearly lagged behind that in the passenger demand forecasting, despite the critical role of freight transportation in the overall transportation planning process. In the passenger transportation arena, there has been a shift in demand modeling paradigm from the trip-based, four-step approach to the activity-based approach, which views travel as a derived demand from the need to pursue activities distributed in space (1). This shift in modeling approach is driven by the need to realistically represent and assess travelers’ response to new policy action and technology innovations.

Given the lessons learnt from the passenger travel arena, planners and modelers are beginning to recognize that, similar to passenger travel demand, freight transportation demand is also a derived demand (2). That is, commodities do not receive satisfaction from being transported. Rather, they are transported across the supply chain as a result of economic activities and business operation decisions. Despite the importance of recognizing supply chain concepts when considering freight movement, the conventional approaches to freight demand forecasting often do not account for such concepts. It is only very recently that disaggregate freight demand forecasting models capable of incorporating supply chain concepts began to emerge (3, 4, 5, 6). These models represent a promising approach for incorporating the needed behavioral realism and policy sensitivity into freight demand forecasting models. However, the supply chain based approach is at its infancy and requires further improvements and innovation.

This paper focuses on addressing one particular limitation of the existing supply-chain based freight demand models: business establishments are treated as separate and independent decision-making agents in these existing models and inter-establishment interactions are considered only between agents assuming different roles in the supply chain (e.g., between supplier and customer, between shipper and freight forwarder). In reality, however, establishments within a firm interact with each other in the making of logistics and other business decisions. This interaction is typically motivated by the desire of achieving maximum profit for the entire firm rather than for its individual establishments. Multi-establishment firms
may benefit from individual establishments’ proximity to suppliers and customers, flexibility in procurement and production, and specialization in activities (7). To realize these advantages associated with the multi-establishment structure, firms have to coordinate activities across establishments rather than manage each establishment independently (8). This interdependency means that the logistics management practices of multi-establishment firms may differ significantly from those of single-establishment firms. The implication of overlooking such intra-firm interaction in a freight demand model is nontrivial.

Table 1 shows that, as firm size increases, the establishment-to-firm ratio increases. While most small firms (with less than 20 employees) tend to consist of a single establishment, large firms that have over 500 employees have, on average, 63 establishments per firm. Even though nationwide there are a lot more of the small firms (89.4%) than large firms (0.3%), these large firms account for more than 60% of the total sale receipts (defined as the revenue for goods produced, distributed, or services provided), suggesting that large firms have great influence on commodity flows. Failure to represent their behavior in freight demand models is likely to impact forecasting accuracy very significantly.

Table 1. Number of Firms and Establishments by Employment Size in U. S. (9)

<table>
<thead>
<tr>
<th>Firm Size (No. of Employees)</th>
<th>1-19</th>
<th>20-99</th>
<th>100-499</th>
<th>500+</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Firms</td>
<td>5,410,367</td>
<td>532,391</td>
<td>88,586</td>
<td>18,311</td>
</tr>
<tr>
<td>No. of Establishments</td>
<td>5,466,985</td>
<td>723,385</td>
<td>355,853</td>
<td>1,158,795</td>
</tr>
<tr>
<td>Establishment-to-Firm Ratio</td>
<td>1.01</td>
<td>1.36</td>
<td>4.02</td>
<td>63.28</td>
</tr>
<tr>
<td>Sale Receipts ($000,000)</td>
<td>3,975,109</td>
<td>3,792,921</td>
<td>3,612,050</td>
<td>18,366,661</td>
</tr>
</tbody>
</table>

In this short paper, we first discuss the intra-firm dependency across member establishments in their logistic decision-making; we then present a firm-based freight demand modeling framework that incorporates supply chain concepts and accounts for the interdependency of establishments within a firm. If selected to present at the TRB SHRP 2 Symposium, we will include in the extended paper a more in-depth description of the conceptual premise and proposed modeling framework, as well as discussions on model estimation methods, data sources, and implementation.

2. LOGISTICS MANAGEMENT AND INTRA-FIRM INTERACTIONS

Following from the supply-chain based freight demand modeling approach, the premise of this paper is to consider freight transportation demand as being derived from the need for businesses to move materials and products from one location to another. In this section, we first outline the elements of logistics management that drive a firm’s freight transportation demand. Within this logistics management framework we then discuss the intra-firm interactions associated with multi-establishment firms.
2.1 Logistics Management Framework

Business logistics management involves making a variety of decisions that fall within different business planning areas (10). Figure 1 depicts those logistics planning areas that we consider as being more closely relevant to freight transportation, the key decisions being made in each area, and the common principles based on which these decisions are made.

![Figure 1. Typical Logistics Management Areas within a Firm](image)

The innermost circle in Figure 1 is *customer demand & service*, which is at the heart of a firm’s operation and drives almost every aspect of logistics management. The middle layer of the diagram includes three logistics areas: *inventories, purchasing* and *facility structure and location*. *Inventory* decisions are concerned with the transportation and storage of commodities throughout firm’s logistics channel, ranging from the stockpiles of extra raw materials for smooth production to the allocation of finished products at warehouses for delivery. *Purchasing* refers to buying commodities from sources outside a firm; typical questions in purchase management are how much to order, where and from whom to order and when to obtain products. *Facility*
structure and location establishes the capacity and location of facilities, as well as the spatial pattern of commodity flows and the lead time necessary to fulfill any order. The outermost layer of the diagram refers to the transportation aspect of logistics management. The internal and external, inbound and outbound transportation decisions of a firm are directly driven by the many decisions listed in the middle layer of the diagram.

2.2 Intra-firm Interaction

The logistics management considerations and approaches differ between single- and multi-establishment firms in many ways, some of which are discussed below.

With regard to inventory management, single-establishment firms are usually too small to separate the problem of inventory from production. Multi-establishment firms, on the other hand, typically comprise multiple echelons (e.g. warehouse-plant in the manufacturing industry, warehouse-retail outlets in the wholesale industry) and the inventory problem could often be handled independently at the warehouse level.

With regard to purchasing, multi-establishment firms have the opportunity to gain economies of scale in purchase by ordering large quantity for its establishments from a common supplier. This so-called centralized purchasing strategy is found in many large firms such as Whirlpool, General Motors, Dells, Wal-Mart and IBM (11, 12). An alternative approach is called “centralized pricing with decentralized purchasing”, in which suppliers are selected through firm-to-firm negotiation but each establishment makes its own orders by specifying order quantity, shipment frequency, etc.

With regard to facility structure and location, multi-establishment firms definitely face a more complex problem than single-establishment firms. This is because the multiple facilities involved in a multi-establishment firm cannot be considered as economically independent and their locations are driven by different forces depending on the type of facility (10). For example, in the wholesale/retail industry, consumer demand is the key determinant driving the location of retail outlets. The location decision is also affected by the effects of cannibalization and market expansion (13). Cannibalization refers to the situation where new facilities attract some of the demand from existing facilities and may result in diminished profits for the entire firm. However, this effect could be partially or fully offset by market expansion, which refers to the case that new facilities trigger new consumer demands and therefore make the market even bigger. In the manufacturing industry, facility structure and location decisions depend largely on the production scheme adopted by a firm. For example, a manufacturer with the market area plant strategy (in which all or most of the product lines are manufactured in each plant of a firm to serve a regional market) tends to have spatially scattered plants. On the other hand, a manufacturer operating under the process plant strategy (in which the output products of a plant serve as input materials or components for other plants within the same firm) are likely to locate its facilities closely to reduce lead time and transportation cost.

With regard to transportation decisions, large multi-establishment firms have the option of shipping products out of each establishment independently or consolidating shipments across facilities. Consolidation may result in bulk shipments that make a mode such as rail attractive. The added complexity due to the amount of shipment and the number of stops involved also
makes efficient vehicle routing a more difficult problem to solve. In this case, the pros and cons of using firm-owned or rented fleet versus outsourcing transportation to third party logistics service provider need to be carefully evaluated.

3. FIRM-BASED MODELING FRAMEWORK

Based on the concepts discussed in the preceding section, we have developed a firm-based framework for modeling freight demand. The overall structure of the framework is shown in Figure 2 and briefly described below.

As depicted on the left hand side of Figure 2, the modeling process begins with creating the firms and establishments that represent the underlying decision making agents in the study region. This entails using aggregate economic census data to synthesize the key attributes of firm headquarters (industry type, and firm size) and establishments (employment size, facility area, economic activity, and sales). Additional attributes, such as business history and production scheme, are then determined based on discrete choice models estimated using firm survey data. Once pools of headquarters and establishments are separately created, each firm is then matched to one of multiple establishments to determine the structure of the firm and the location of its constituting establishment(s). At the end of this Firm Creation module, each firm together with any member establishments is regarded as our analysis unit in the subsequent modeling process.

The next module, Commodity Sourcing and Distribution, focuses on determining the annual amount of goods flow between establishments. The demand for goods is first modeled at the firm level. For multi-establishment firms, internal sourcing of commodities is considered, resulting in commodity flows between establishments within the firm. Establishment level commodity demand and production capacity are then updated; and the remaining demand for goods are taken care of through purchasing from outside firms. The purchasing decisions include the selection of suppliers and purchase quantity. These decisions are modeled at the firm level to account for the economy of scale attainable by multi-establishments firms. If the chosen supplier also operates multiple establishments, the specific sourcing point is then determined by considering the characteristics of both the supplier and the receiving firm.

Next, the annual commodity flows are divided into a series of individual orders in the Purchase Ordering module. The optimal order quantity is determined based on the transportation cost, ordering cost, and inventory carrying cost. Order frequency is then calculated as the ratio between the annual purchase quantity and the optimal order quantity, yielding the number of orders per year. For multi-establishment firms, orders are then combined based on the compatibility of orders in their commodity properties, quantity and frequency. The last component of this module determines the day and time when an order is to be delivered. Depending on whether data is available to depict the daily, weekly, and/or seasonal variations and whether the freight demand model is intended to capture temporal dynamics or to represent an average day, the resulting order schedule could take the form of a multi-day schedule or represent the schedule of a randomly selected day.

Once the spatial and temporal flows of good are determined between firms and establishments on a daily basis, the Transportation module determines decisions such as carrier selection, shipment size, mode choice and routing and scheduling. Depending on whether the shipper decides to use
in-house fleet or a 3rd party logistic service provider, the shipment size, mode, routing, and scheduling decisions may be made by the shipper, the carrier, or both. Finally, depending on the mode chosen, the vehicles or containers are scheduled and routed through the appropriate transportation network to satisfy any delivery time windows assigned by receivers.

Figure 2. Overview of Proposed Firm-Based Freight Demand Modeling Framework
4. DISCUSSION AND CONCLUSION

The modeling effort reported herein is on-going. Our study area covers multiple counties (including three MPOs) in northeast Wisconsin. Currently, we are in the process of estimating some of the modeling components and conducting a firm/establishment survey for further model estimation. If selected for presentation at the Symposium, we will expand the current paper to include description of data sources, mathematical structure, estimation methods, and any estimation results associated with each model component. We will also discuss the merits and limitations of the current modeling framework and the steps for moving forward.

5. ACKNOWLEDGEMENT

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6. REFERENCE