Tour based and supply chain modeling for freight: integrated model demonstration in Chicago

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Despite recent advances in freight and commercial vehicle modeling, the current state of the practice methods are not adequate to address the increasingly complex issues related to freight demand. This project includes research that has combined tour based truck models and logistics supply chain models for urban commercial vehicle movements and that has demonstrated a functional model framework that addresses the limitations of current freight demand forecasting models. The research was performed by Resource Systems Group Inc., in partnership with the Chicago Metropolitan Agency for Planning and the University of Illinois at Chicago. The project introduced a model framework and focused on the estimation of each of the model components, described the approach to linking the models together in the model application, and presented initial results from applying the model in the Chicago region. The models were estimated for demonstration purposes from several sources, since there were no datasets that could support all aspects of the new framework. To make the demonstration more practical, two commodities were chosen to model from the data available (food products and manufactured products). The models developed for the project were applied using software developed in R, an open source platform. A data collection program to support the estimation, calibration, and forecasting of the framework for future use was recommended. Further efforts to improve this framework with new data, model improvements, and forecasts would be welcome.

Keywords: Freight forecasting, Supply chain models, Tour based freight models, Urban commercial goods movement

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Introduction

Resource Systems Group Inc. (RSG), in partnership with the Chicago Metropolitan Agency for Planning (CMAP) and the University of Illinois at Chicago (UIC) developed a tour based and logistics supply chain model for the Chicago metropolitan area as part of the Federal Highway Administration Broad Agency Announcement program. This work was a proof of concept study that was envisioned to be sensitive to critical global, regional, and facility based conditions. It was designed to test a new modeling framework and confirm its practicality and usefulness before conducting data collection activities to support the models. Once the models were tested, we developed recommendations for a new data collection program to support this system.

The overall goal of this research was to identify a framework that can be adopted by Metropolitan Planning Organizations (MPOs) in the USA for use in evaluating transportation investments and their impacts on freight mobility. The details of the framework are specifically designed to address current weaknesses identified in standard practice freight forecasting, as follows:

(i) The lack of detail at the traffic analysis zone level. The framework was designed to synthesize firms and microsimulate goods movements at the zone level rather than relying on available national data on commodity flow produced at a district level.

(ii) The lack of information about the local pickup and delivery trips. The framework was designed to specifically model the delivery system at the

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end of the supply chain. This delivery system in many industries is based on a series of deliveries by a truck before returning to home base for additional goods. This delivery system is represented by tours that each truck makes to pick up and dropoff goods.

(iii) The need to estimate shifts in long haul and short haul demand resulting from regional investments. Current practice in freight forecasting uses commodity flow tables derived from national sources to represent long haul goods movements and uses four-step planning models to represent short haul movements. Some freight models have estimated models that predict long haul commodity flows. The framework was designed to represent the full supply chain for a specific commodity shipped from the supplier to the customer, including both the long haul and short haul components of the goods movement in a single framework rather than modeling these separately.

(iv) The ability to capture trip chaining that occurs. Trip chaining is an important component of freight movement and commercial vehicle delivery of services. Trip chaining can occur along the supply chain (goods travel from the supplier through a distribution center or warehouse to the retailer) or can occur during delivery (goods travel from the retailer to each customer along a tour). Trip chaining is also expected for many service trips (service providers' travel from home base to each customer before returning to home base at the end of the day).

(v) The need to represent commodities produced and consumed by different industries. Commodities will travel differently based on their production and consumption characteristics. For example, the construction industry will consume many different commodities (forestry, mineral, metal, and chemical products). Forestry commodities are also consumed by material wholesalers. The supply chain for forestry products will be different if they are destined to a construction site as opposed to a material wholesaler. By identifying both the production and consumption industry for each commodity, we can more accurately predict the travel required to bring these products to market.

The framework described here is focused on two aspects of the approach: using disaggregate representations of goods movement, and representing the variety of supply chains that may apply to a specific commodity produced by a specific industry and consumed by a specific industry. Local pickup and delivery is explicitly represented by tour based methods for goods movement.

Literature and data review

Data review

While tour based and logistics supply chain methods have been researched in the USA and applied in other countries (Canada, Japan, and Europe), there are currently no known examples of an application of these types of freight models in the USA for a metropolitan region. This literature review summarizes survey data that were considered to use in developing tour based and supply chain models, and models that have been estimated and/or applied and that could be transferred. Several key sources, summarized in Table 1, were found to be the most applicable to the development of the framework. The first five sources are freight movement and truck surveys, the first four of which were obtained to support model estimation during this project. The fifth dataset, from Tokyo, was not available due to data confidentiality issues. The remaining key sources are tour based and supply chain models that have been estimated and/or applied.

Table 2 summarizes the commodity and industry type variables found in the datasets from the four surveys, identifies inherent limitations in the datasets, and notes their sample sizes. A calculation of average trips per vehicle from the commercial vehicle surveys illuminates some of the differences in the coverage of the various surveys. For example, Toronto has the lowest trips per vehicle rate (1·5) and reflects an oversampling of manufacturing and midsize firms in Toronto, leading

Table 1 Key sources for data and model elements

Source/location	Shipper survey	Driver survey	Supply chain model	Tour based model
Phoenix: MAG Survey (2007)	✓	✓		
Texas: CV Survey (2005–2006)		✓		✓
FAME National Establishment Survey and Model (2009–2011)	✓		✓	
Toronto: Peel Survey (2007)	✓	✓		
Tokyo: Metropolitan Goods Movement Survey (1972, 1982, 1994, and 2004)	✓		✓	
Denver: DRCOG Survey (1998)		✓		✓
Oregon: ODOT Model			✓	✓
Calgary: CV Model, Survey (2000)		✓		✓
Ohio: Statewide Model (2003–2004)		✓		✓
Netherlands: GoodTrip			✓	
Netherlands: SMILE			✓	
Norway/Sweden: National Freight Model System			✓	

one to conclude that these types of firms have lower trips per vehicle rates. Toronto also has the smallest sample size, so this conclusion may be limited by this fact. Phoenix had an average trips per vehicle rate (5·5) that reflects only specific industries (agriculture, mining, construction, retail trade, local pickup and delivery, mail/parcel, and for-hire sectors). The Texas dataset had the highest average trips per vehicle rate (8·1) and included all industries and all firm sizes within small to medium size urban areas in Texas. Given the size of this sample and the fact that it was not oversampled or limited, this value is likely the most robust average trips per vehicle result.

The three shipper surveys (Phoenix, FAME, and Toronto) had a range of shipments per firm of 1·4 for Phoenix, 2·0 for FAME, and 4·5 for Toronto. The FAME dataset is unique in that it reflects both short haul and long haul freight movements in both urban and rural areas in the USA while the Phoenix and Toronto datasets represent select industries and oversamples for firm sizes, which may explain the variation in these results.

Tour based models

The research on tour based models includes model components for tour generation, vehicle type models, trip purpose models, time of day models, stop location models, and stop duration models. These are activity based models that derive methods from the evolving world of activity based passenger models. They focus on the tour characteristics of truck trips and are less concerned about what is being carried in the vehicle. Thus far, the focus of these models has been on truck trips, so they are not truly multimodal.

Holguín-Veras and Patil (2005) describe a comprehensive analysis of the observed trip chain behavior of commercial vehicles in the Denver region using data collected by the Denver Regional Council of Governments in 1998 and 1999. Wang and Holguín-Veras (2009) describe models developed using these data that estimate tour flows of commercial vehicles.

A well documented example of a tour based model was developed in Calgary, Canada (Hunt *et al.*, 2003). The model applies tour based microsimulation modeling concepts to urban goods movement modeling. The primary source of the data used in development is an extensive set of interviews about own account commercial vehicle movements conducted at just over 3100 business enterprises in the Calgary region.

Gliebe *et al.* (2007) describe a disaggregate commercial vehicle model developed using establishment survey data collected by the Ohio Department of Transportation. The model generates entire daily patterns for workers who

Table 2 Survey data available for model estimation

Location/type	Commodity/industry type	Limitations	Sample size/coverage
Texas Commercial Vehicle Survey	SIC codes for the truck's base location	Base location of a tour may not be the supplier	1711 vehicles
	22 Cargo commodity types	Land use types for stops may not be coded consistently with other data sources that contain SIC/NAICS codes for industry types	3760 shipments
	15 land use types for stops (at all stops including the base and customer)		13 802 trips
			Covers five urban areas in Texas
Toronto Establishment Survey	Establishment survey has: commodity type, supplier address for inbound shipments, customer address for outbound shipments, establishment industry classification for surveyed establishment	Supplier/customer companies need to be matched with address database containing industry classification	597 firms 2699 shipments Oversampled manufacturing and midsized firms in Toronto
Toronto Vehicle Survey	Truck survey has commodity type and land use type for stops	Land use types for stops may not be coded consistently with other data sources that contain SIC/NAICS codes for industry types	86 vehicles 42 GPS vehicles 131 trips
FAME Establishment Survey	10 commodity types 6 supplier or buyer industry types	For each shipment record, the dataset only has either the supplier or buyer of the commodity	316 firms 881 shipments Covers all USA
Phoenix Establishment Survey	Commodity type and supplier or customer industry for surveyed establishment in operator survey	Focuses on manufacturing, wholesale trade facilities and warehouse/distribution centers	562 firms
		Does not include industry of the customer for outbound shipments/the supplier for inbound shipments	808 shipments
Phoenix Vehicle Survey	Has data on the industry of the truck operator and the addresses and land use type of the stops made but no commodity data	Focuses on agriculture, mining, construction, retail trade, local pickup and delivery, mail/parcel, and for-hire sectors	46 firms 236 vehicles 1304 trips

regularly travel as part of their jobs and creates tours through a dynamic choice process that incrementally builds tours.

There were three models, with data, that were particularly promising for this study: Phoenix, Texas, and Toronto:

(i) In 2007, Maricopa Association of Governments (MAG), the MPO for the metropolitan Phoenix area conducted a study to update their internal truck travel model, which included conducting internal truck travel surveys (Cambridge Systematics, Inc. with NuStats and Northwest Research Group, 2007). The study included two survey components: truck diary surveys and operator surveys. The truck trip diaries were used for sectors that generated multistop tours that were short haul in nature. There were a total of 236 completed truck diary surveys out of 3276 sampled businesses in the dataset. Operator surveys or establishment surveys were used for sectors that generated truck traffic that were long haul in nature. The survey received 562 completes out of 6143 businesses contacted.

(ii) The Texas Department of Transportation Travel Survey Program sponsored the external station surveys and the commercial vehicle surveys in a number of MPOs during 2001 and 2006 (Prozzi *et al.*, 2004, 2006; Nepal *et al.*, 2007a,b,c; Roorda *et al.*, 2007a, 2007b). External surveys aimed at capturing the inbound, outbound, and through traffic, while commercial vehicle surveys captured the internal activities in the region. The Texas data were suited for this project in understanding the tour structures by commodity and location. We focused on the data from a subset of cities, San Antonio, Amarillo, Valley, Lubbock, and Austin, during 2005 and 2006 (for more details see Nepal *et al.*, 2007a,b,c) as they are more recent, consisting of a total of 13 802 trips made by 1711 commercial vehicles.

(iii) The Region of Peel (Toronto, Canada) Commercial Vehicle Survey was a data collection effort that collected commodity, mode choice, and commercial vehicle movement data from a sample of approximately 600 shippers and their drivers. The survey was undertaken by the University of Toronto in the time period from October 2006 to May 2007. Peel is a suburban region, located to the west of the City of Toronto, which is a center of transportation, warehousing, and manufacturing activity in the Greater Toronto Area. The survey used a mail-out/mail-back survey questionnaire and part of the survey sample also completed a GPS supplement. The shipper survey data have been used to estimate models that are reported in Cavalcante and Roorda (2010). The paper presents a discrete/continuous model with shipment size as the continuous variable and vehicle type choice as the discrete variable.

Supply chain models

The literature review included papers discussing supply chain and logistics models, including some models developed for urban freight studies. Fischer *et al.* (2005) and Yang *et al.* (2009) provided summaries of recent developments in supply chain models.

A study by Tavasszy *et al.* (1998) is a prominent example of a supply chain and logistics modeling effort. They developed a series of disaggregate logistics models, called the Strategic Model for Integrated Logistics Evaluation (SMILE), together with an economic input–output model to provide a decision tool for policy evaluation in 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 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. This approach was used by Cambridge Systematics, Inc. in a freight forecasting study for CMAP (Cambridge Systematics, Inc., 2011) that was adopted for use in the mode and intermediate transfer model component of the framework introduced in this paper. Holguín-Veras (2005) also discussed an urban freight modeling framework capable of incorporating logistic information and trip chaining behaviors.

In addition to these studies, three other models and datasets were of particular interest to this study's goals:

(i) The University of Illinois at Chicago has developed and completed administering three waves of an establishment survey. The goal of the survey is to collect information on Individual Shipments that are not available from other aggregate sources of data. To date, three waves of the survey have been completed. Wave III, completed in 2011, targeted 100 000 firms by emails. In this wave, data were collected from 316 establishments and included 881 shipments. The survey provides a disaggregate dataset of a significant number of shipments and as such is a valuable source of information about the interrelationships between industry types, commodities, and the characteristics of the shipments that they make. The freight activity microsimulation estimator (FAME) is a freight activity based modeling framework with five basic modules (Samimi *et al.*, 2010). The FAME model has some characteristics that are similar to the proposed framework, although it is designed specifically as a national level model. These include the synthesis of firms, the supplier selection occurring in the supply chain module, and modeling shipment sizes directly.

(ii) The Tokyo Metropolitan Goods Movement Survey has been conducted four times, in 1972, 1982, 1994, and most recently in 2004. The 1982 survey obtained the largest sample, with information from approximately 46 000 firms. The data consists of records on commodity movement and truck movement of each firm. Each record provides information about firm characteristics, commodity movement, and truck movement. The more recent survey, from 2004, contained data from 12 000 firms. The survey included questions about the facility and business characteristics (size, site factors, functions, etc.), the origins of inbound shipments and the destinations of outbound shipments, in addition to the weight, mode, truck load, truck load factor, commodity, time window utilization, and vehicle type for each shipment. Wisetjindawat and Sano (2003) developed a microsimulation model for the modeling of urban freight transportation in the Tokyo Metropolitan Area using the 1982 survey data and validated it using the 1994 survey data. The proposed model considers the behavior of each freight decision maker individually. The model structure consists of three stages: commodity production and consumption, commodity distribution, and conversion of commodity flow to vehicle movement.

(iii) Donnelly *et al.* (2010) describe the development of the MOSAIC model system that is implemented in a metropolitan context in Portland, Oregon. The model is a microsimulation model that models (separately) each of the important decisions that characterize the demand for freight transport. Canadian National Roadside Survey was used to estimate transshipments by commodity; the observed distributions of shipment size by commodity and mode were derived from surveys in Michigan and Oregon for trucks and from the Surface Transportation Board Carload Waybill Sample for rail; and data from the Commodity Flow Survey and the Vehicle Inventory and Use Survey were used to determine carrier types.

Tour based and supply chain freight forecasting framework

We developed a framework that would address the goals of the project and then constructed a demonstration of this framework for the Chicago metropolitan region to ensure that the concept is practical, useful, and improves upon the existing methods of modeling freight in an urban area. The focus of the project was on the structure of the modeling system and the ability to overcome previous limitations in freight forecasting models and not on the calibration and validation of the system for local conditions. The freight forecasting framework we developed has two main parts: a national part which focuses on applying supply chain methods and a regional part which focuses on tour based methods. Shipments developed in the national part of the framework are tracked through the regional part of the framework. This framework is presented in Fig. 1, with the step numbers for the 11 main steps in the model denoted in parentheses. These steps are also described in the following sections.

The tour based and supply chain freight modeling framework is comprised of a series of model components which together identify the primary decisions for moving freight in a metropolitan region:

(i) Which firms are involved in moving freight?
(ii) What is the demand of production and consumption of goods?
(iii) How are these goods distributed in the region?
(iv) How are the goods moved (i.e. what modes and intermediate handling locations are used)?
(v) How many and what size trucks are needed to move the goods that are transported by truck?
(vi) What time of day do these trucks travel?

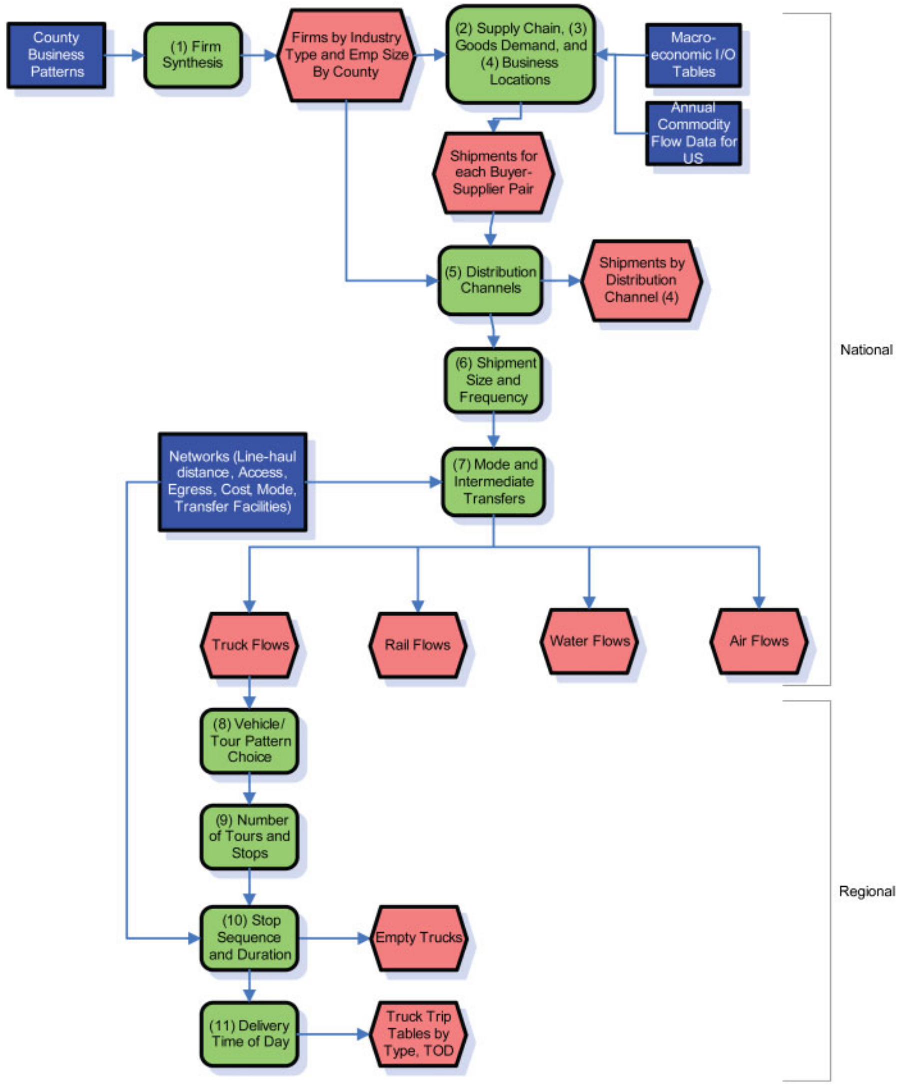
There is a final decision regarding the route choice for trucks that completes the framework, but, once the individual truck movements (trips) are simulated in the model system, this can be completed using existing aggregate assignment methods in use by MPOs around the country and so it is not a focus of this framework. Each of the primary decisions is further subdivided into specific choices that are represented by individual model components. There are currently two primary types of freight or goods movement models that have included these model components: supply chain and tour based models.

Supply chain methods at national scale

The national scale portion of the freight forecasting framework focuses on how firms who buy goods select suppliers and how suppliers ship goods to their buyers. These model components were adapted from research conducted by UIC for the FAME (Samimi *et al.*, 2009).

Firm synthesis (step 1) is the initial element of the framework, which synthesizes all firms in the USA for purposes of capturing long haul freight movements. The geographic detail within the region of interest is based on jurisdictional boundaries such as cities (although the allocation down from counties to individual cities takes place in step 4, business location), and the geographic detail outside of the region of interest is defined by freight analysis framework zones. This model synthesizes firms by industry category and by size category to capture the primary drivers of commercial vehicle travel. Firm synthesis can be controlled by regional, county, and state control totals obtained from State, MPO, or national sources.

The supply chain model (step 2) is the next element of the framework, which predicts the demand in tonnage for shipments of each commodity type between each firm in the synthetic population. The demand represents the goods produced by each firm and the goods consumed by each firm in the USA. The model is applied in two steps. In the first step, buyers who have a demand for goods are paired with suppliers who sell those goods using a probabilistic model. The connections between industry types for each commodity are based on input–output tables. Once the buyer–supplier relationships are established, the amount of commodity shipped on an annual basis between each pair of firms is apportioned based on the number of employees at the buyer and their industry so that observed commodity flows are matched nationwide (step 3). The business location within the region is identified using a smaller zone system within the counties used in the firm synthesis model (step 4). The allocation is based on employment by industry category.



1 Freight forecasting framework

The next step of the process is to determine the complexity of the distribution channel used in the supply chain (step 5). This concept was pioneered by Wisetjindawat, Sano, Matsumoto, and Raothanachonkum (2003) where eight distribution channels comprised of combinations of raw material suppliers, producers, wholesalers, retailers, and end users were used to determine supply chains. Multinomial logit choice models were used to determine the supply chain based on buyer–supplier pair characteristics and characteristics of the industry. The models were based on large surveys conducted in Tokyo over several decades, but these data were not available for testing in this research. Data collected for a national survey as part of the FAME project were used to identify four distribution channels comprised of combinations of intermodal terminals, warehouses, consolidation centers, and distribution centers (direct shipments, 1 type of intermediate stop, 2 types of intermediate stops, or 3+ types of intermediate stops). This is not an ideal representation of distribution channels since it does not identify all aspects of the supply chain or include all combinations of the types of intermediate stops individually, but the FAME data were a small sample and this was the best representation possible with these data. The four distribution channels chosen represent a complexity of supply chains rather than a specific type of supply chain. Since this model is before mode choice, the distribution channels are multimodal rather than mode specific.

Table 3 shows the multinomial logit (MNL) model estimated for food products from the FAME survey. As it can be seen from the constants, the direct distribution channel is the most preferred everything else remaining constant. The other variables that affect the choice of distribution channel in a significant manner are firm size and the industry type of the firms involved. It is acknowledged that the estimated model does not have a very rich specification but it is reasonable given the data constraints.

Shipment size is estimated using an MNL model based on a variety of firm, commodity, and travel characteristics (step 6). It is as this point in the model that the units of analysis change from annual commodity flows between pairs of firms to discrete shipments that are individually

Table 3 Distribution channel model specification for food products

Choices	Utility equations				
Direct	ASC_V1 * one+EMP49_1 * emple49				
1 type used	ASC_V2 * one+MFGIND2 * mfgind				
2 types used	ASC_V3 * one+TRWIND3 * trwind				
3 types used	ASC_V4 * one+TRWIND4 * trwind+DIST1 * Distance				
Choices	Variable description	Variable name	Coefficient	*t*-stat	*p* value
Direct	Alternative specific Cconstant	ASC_V1	0 (fixed)		
1-type used	Alternative specific constant	ASC_V2	−0·932	−2·47	0·02
2-types used	Alternative specific constant	ASC_V3	−3·32	−3·20	0·00
3-types used	Alternative specific constant	ASC_V4	−52·5	−3·11	0·00
Direct	49 or less employees firm involved	EMP49_1	0·907	2·03	0·04
1-type used	Manufacturing industry firm involved	MFGIND2	1·94	3·48	0·00
2-types used	Transportation\warehousing or wholesale trade firm involved	TRWIND3	3·49	3·23	0·00
3-types used	Transportation\warehousing or wholesale trade firm involved	TRWIND4	51·4	3·05	1·00
3-types used	Great circle distance between buyer and supplier zones	DIST1	0·000559	1·14	0·24
Number of observations	Final log likelihood	Rho-squared			
106	−85·326	0·419			

accounted for and delivered from the supplier to the buyer. Separate models were estimated for food and manufactured products. The Texas commercial vehicle survey dataset was used for estimating the MNL model due to its relatively high sample size. Table 4 shows the shipment size choice model results for food products. The shipment size between 1000 and 9999 lbs is the most preferred for food products everything else being equal. The service industry tends to transport smaller shipments; the construction industry tends to primarily transport larger shipments but also transports some smaller shipments. An indirect distribution channel in which the shipment stops at three types of facilities positively influences the highest shipment size category (≥10 000 lbs). Midsize shipments (1000–9999 lbs) are less likely to include a single transfer facility, possibly because these tend to be direct shipments. The other explanatory variables in the model specification are trip length until current shipment stop from the base location and industry types at the stop location. Longer trip lengths are associated with shipments greater than 10 000 lbs.

The last part of the national scale models identifies the mode and path based on travel time, cost, characteristics of the shipments, and characteristics of the distribution channel (step 7). This model was adapted from research conducted by de Jong and Ben-Akiva (2007) to predict the mode and path of long haul movements of freight in Norway and Sweden based on a comprehensive accounting of transport and logistics costs. These include transport and intermediate handling costs, inventory costs, deterioration and damage costs, pipeline costs, and ordering and stock-out costs. This model was applied separately for each type of distribution channel, allowing for different parameters for complex supply chains and direct movements. The output of the national models is freight shipments by mode and path for origins and destinations across the USA.

There are four primary modes (road, rail, air, and water) modeled. Detailed networks of road and rail for the USA are used, with simpler functions of distance and the value of goods being transported to represent the air and water modes. The modes and transfer locations on the shipment paths are determined based on the travel time, cost, characteristics of the shipment (perishable, expedited, and containerized), and characteristics of the distribution channel (whether the shipment is routes via a warehouse, consolidation or distribution center, and whether the shipment includes an intermodal transfer, e.g. truck–rail–truck). Once the modes and intermodal transfers have been

Table 4 Shipment size model specifications for food products

Choices	Utility equations				
≤999 lbs	ASC_V1 * one+SIC11 * SIC1+SIC21 * SIC2				
1000–9999 lbs.	ASC_V2 * one+DISTCHAN12 * DISTCHAN				
≥10 000 lbs	ASC_V3 * one+SIC23 * SIC2+DISTCHAN32 * DISTCHAN_2+Cost2 * cost				
Choices	Variable description	Variable name	Coefficient	*t*-stat	*p* value
≤999 lbs	Alternative specific constant	ASC_V1	0 (fixed)		0·00
1000–9999 lbs	Alternative specific constant	ASC_V2	0·546	3·85	0·00
≥10 000 lbs	Alternative specific constant	ASC_V3	−1·71	−5·98	0·00
≥10 000 lbs	Trip length (cost)	Cost2	0·245	2·48	0·01
1000–9999 lbs	Distribution channel with 1-type used (DISTCHAN)	DISTCHAN12	−0·788	−3·58	0·00
≥10 000 lbs	Distribution channel with 3-types used (DISTCHAN_2)	DISTCHAN32	0·759	3·05	0·00
≤999 lbs	Service industry (SIC1)	SIC11	5·84	5·77	0·00
≤999 lbs	Transportation/construction industry (SIC2)	SIC21	0·975	3·57	0·00
≥10 000 lbs	Transportation/construction industry (SIC2)	SIC23	2·88	9·9	0·00
Number of observations	Final log likelihood	Rho-squared			
738	−554·922	0·316			

assigned, the shipment list is converted from all annual shipments to a daily sample to represent the day being modeled. This process can be calibrated to allow for seasonal variations in commodity flows where that information is available. This step also assigns shipments to specific warehouse, distribution, and consolidation centers if the shipment passes through one of those locations.

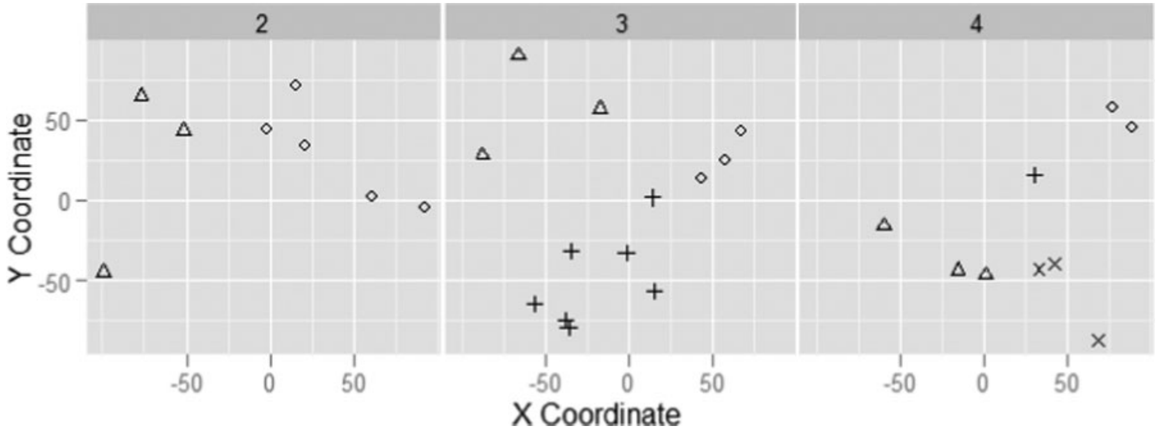
Tour based methods at regional scale

The tour based models are implemented at a regional scale for truck modes only to determine individual vehicle movements needed to distribute the goods within the region. The regional scale models take shipments from their final transfer point (i.e. the last point at which the shipment is handled before delivery, which is at the supplier for a direct shipment, or at a warehouse, distribution center, or consolidation center for shipments with a more complex supply chain) to their final delivery point. It does the same in reverse for shipments at the pickup end, where shipments are taken from the supplier and taken as far the first transfer point. For shipments that include transfers, the tour based truck model accounts for the arrangement of delivery and pickup activity of shipments into truck tours. Initially, the origins and destinations of the national freight shipments are identified as internal or external movements to the Chicago region for input to the regional scale models. Shipments involving an intermodal handling facility, warehouse or distribution center were allocated to a specific facility within the Chicago region and this represented a home base for vehicle tours. The tour based models were estimated using commercial vehicle surveys conducted in five urban areas in Texas and processed for tour-based analysis at UIC (Ruan *et al.*, 2011).

There were four modeling components in the tour based models and several are joint estimated models of two key decisions. The vehicle and tour pattern choice model (step 8) is an MNL model that predicts the joint choice of whether a shipment will be delivered on a direct tour from transfer to delivery (i.e. where a truck departs the transfer location, delivers the shipment, and returns to the transfer location) or a multistop tour where the truck makes multiple deliveries or pickups, and the size of the vehicle that will make the delivery. The size of the vehicle (small, medium, and large) is determined jointly with tour pattern (direct or multistop) because certain vehicles support different types of tours. The model was estimated with six alternatives which are combinations of two tour patterns (direct and multistop) and three vehicle types (two-, three- or four-axle, and semi/trailer). The two-axle trucks here refer to two-axle six-tire, single unit trucks, and three or four-axle trucks are single unit trucks. Semi/trailers are any truck combination with a truck tractor or single unit truck pulling a semi or full trailer. The results are shown in Table 5. Just from the constants, it appears that two-axle trucks are more likely to be chosen when compared to the heavier trucks and multistop tours are more likely than direct tour. The type of commodity (food/manufactured), pickup/dropoff weights (shipment sizes), and the type of industry at the stop location (delivery/buyer location) of the shipment along with county total employment (at the dropoff or pickup location) are some of the other

Table 5 Vehicle choice and tour pattern model specifications

Choices	Variable description	Variable name	Coefficient	*t*-stat
Direct, two-axle six tires	Alternative specific constant	ASC_V01	0	
Direct, 3–4 axles	Alternative specific constant	ASC_V02	−4·5	−7·25
Direct, semi/trailer	Alternative specific constant	ASC_V03	−4·41	−7·55
Multistop, two-axle six tires	Alternative specific constant	ASC_V04	3·89	11·32
Multistop, 3–4 axles	Alternative specific constant	ASC_V05	−1·29	−3·07
Multistop, semi/trailer	Alternative specific constant	ASC_V06	−2·94	−6·91
Multistop, two-axle six tires	Cargo is food products	CARGO_FOOD_V04	1·21	9·95
Multistop, 3–4 axles	Cargo is manufactured products	CARGO_MANU_V05	−1·21	−8·86
Multistop, semi/trailer	Cargo is manufactured products	CARGO_MANU_V06	−0·294	−2·71
Direct, 3–4 axles	Cargo weight at dropoff (lbs)	Cargo_Weight_DO_V02	0·412	6·16
Direct, semi/trailer	Cargo weight at dropoff (lbs)	Cargo_Weight_DO_V03	0·371	5·91
MultiStop, two-axle six tires	Cargo weight at dropoff (lbs)	Cargo_Weight_DO_V04	−0·209	−4·89
Multistop, 3–4 axles	Cargo weight at dropoff (lbs)	Cargo_Weight_DO_V05	0·283	6·45
Multistop, semi/trailer	Cargo weight at dropoff (lbs)	Cargo_Weight_DO_V06	0·263	6·03
Direct, 3–4 axles	Cargo weight at pickup (lbs)	Cargo_Weight_PU_V02	0·355	5·59
Direct, semi/trailer	Cargo weight at pickup (lbs)	Cargo_Weight_PU_V03	0·401	6·64
Multistop, two-axle six tires	Cargo weight at pickup (lbs)	Cargo_Weight_PU_V04	−0·156	−3·7
Multistop, 3–4 axles	Cargo weight at pickup (lbs)	Cargo_Weight_PU_V05	0·282	6·53
Multistop, semi/trailer	Cargo weight at pickup (lbs)	Cargo_Weight_PU_V06	0·263	6·1
Direct, semi/trailer	Destination industry is manufact	MANUFAC_V03	1·19	3·53
Multis, 3–4 axles	Destination industry is manufact	MANUFAC_V05	1·41	11·97
Multistop, semi/trailer	Destination industry is manufact	MANUFAC_V06	1·34	11·24
Multistop, 3–4 axles	Destination industry is office	OFFICE_V05	−0·834	−2·66
Multistop, semi/trailer	Destination industry is retail	RETAIL_V06	0·928	9·1
Multistop, 3–4 axles	County total employment	cbp98EMP_V05	0·137	7·47
Multistop, semi/trailer	County total employment	cbp98EMP_V06	0·309	16·55
Number of observations	Final log likelihood	Rho-squared		
5314	−5765·731	0·392		



2 Clustered stops for two, three, and four tour trucks

explanatory variables in the specification. Food shipments tend to be on two-axle trucks and multistop tours. Manufactured goods are less likely to use multistop tours and larger trucks (three to four-axle trucks and semi/trailers). An intuitive result is that the trucks get larger with heavier shipments (look at the coefficient of pickup and dropoff weights). Also, heavier shipments are more likely to be put on direct tours than multistop tours. Delivery to an office location is less likely to be on multistop tours and three to four-axle trucks. Delivery to a retail location is more likely to be on multistop tours and semi/trailer trucks.

The number of tours and stops choice (step 9) model is composed of two elements. The first is an MNL model that predicts the complexity of the multistop tour that a shipment is contained in; for example a truck might return to the transfer point after one large loop or might break their delivery schedule into two, three, or more tours. The second element uses hierarchical clustering to divide the shipments into spatially collocated groups that can be reasonably delivered by the same truck during a tour. The model specifications for this and the remaining models are not shown due to space limitations. Figure 2 shows an example of how shipment stops from a warehouse are clustered. The stop which are in two tours category are clustered into two groups or tours, those in three tours category are clustered into three tours, and those in four tours category are clustered into four tours.

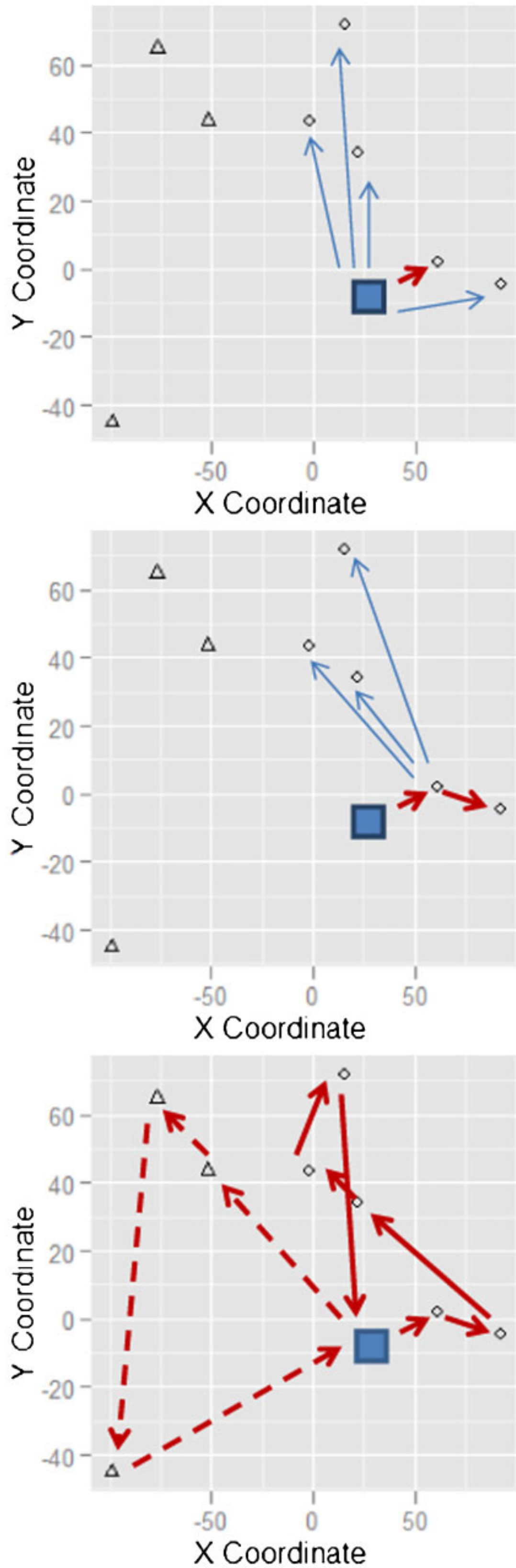
The stop sequence and stop duration (step 10) model uses a greedy algorithm to sequence the stops in a reasonably efficient sequence but not necessarily a shortest path (our research shows that touring trucks only sometimes deliver in a sequence that is efficient in shortest path terms). Then an MNL model predicts the amount of time taken at each stop based on the size and commodity of the shipment. Once the stops have been sequenced, it is possible to identify the trips on which trucks are traveling empty, which is shown as an output from this step in the framework flow chart. The greedy algorithm for sequencing shipment stops is only applied for multistop shipments whereas the stop duration model is used to simulate the stop durations of both direct and multistop shipments. Figure 3 shows an example of how stop sequencing algorithm sequences the stops in two separate tours from a warehouse.

The delivery time of day (step 11) model is an MNL choice that predicts the departure time of the truck at the beginning of the tours. Based on this, the travel time of each trip, and the stop duration of each delivery, all of the trips on the tour can be associated with a time period for assignment purposes. At this point, an iterative process is used to identify and then split tours that are too long into tours that meet time constraints. In the last step, the vehicle tours are converted to an aggregate zone to zone trip table that can be assigned.

Demonstration in Chicago

The demonstration project was a proof of concept to test that the framework can be applied using local Chicago economic, socioeconomic, and network data. The estimation of the model components for the framework was based on available freight survey datasets that contain the desired variables. The model estimations were based on several different datasets (one for each model component) and so the resulting models do not necessarily represent local Chicago behavior, but they do contain many of the desired sensitivities and have reasonable coefficients.

The models developed in this project were estimated for demonstration purposes from several sources, since there were no datasets that could support all aspects of the new framework. To make the demonstration more practical, two commodities were chosen to model from the data available (food products and manufactured products). These were chosen to represent different aspects of goods movement and because they were the largest samples in the datasets. While the model estimation and application development work focused on these two commodity groups, the final version of the demonstration application does include all commodity classes. It does this in model components that have commodity specific models or variables by applying the manufactured products models to all other commodities for which commodity specific models were not developed. The demonstration application is designed so that, if other commodity specific models are developed in the future, these can be inserted into the model and (with minor code changes) used instead of the manufactured products models.



3 Stop sequencing algorithm

The models developed for the project were applied using software developed in R, an open source platform which is freely available from the Comprehensive R Archive Network (http://cran.r-project.org/index.html). Some of the national model components were implemented by CMAP as part of another project (firm synthesis, supplier selection and demand, mode and path choice) in SAS (Cambridge Systematics, Inc., 2011) and converted for use in this demonstration. The other model components were developed for this project and integrated with the Chicago datasets for demonstration.

The models were not calibrated or validated for the Chicago region as it was only designed to show how these models would function in the broader regional context. Data collected in the future could support models estimated for all commodities. As this was a demonstration project, there is no way to know how future data sources will influence the findings. This framework is focused on commercial vehicle movements of urban freight and do not represent commercial service vehicles or commercial vehicles moving people (like taxis, rental cars, paratransit vehicles, shuttles, or school buses). The demonstration project was completed in April 2012 and the software and final report are available.

Data collection recommendations

A data collection plan was developed to identify the data required to develop and apply the tour based and supply chain freight forecasting models. The national and international freight transport data should be collected by the federal government, while the responsibility for collecting the regional data should fall to regional agencies.

The key missing data for the proposed freight forecasting framework is disaggregate shipment data, which would come from a national level integrated shipment survey. However, major barriers stand in the way of the development of such data, as described in TRB Special Reports 276 and 304 (TRB, 2003, 2011), and it is unlikely that these barriers will be overcome in the short term.

Nevertheless, further steps can be taken in the short term toward a full implementation of the regional components, and enhancing the national components. The first recommendation is to conduct a regional freight survey for a selected region, and implement regional components of the model framework for that region. The objective would be to demonstrate a full implementation of the regional components of the model framework. The second recommendation is to find practical ways of obtaining the needed national data by carrying out pilot data collection efforts. The data collection methods would include interviews, Delphi panels, stated preference surveys, and shipment surveys. The in-depth interviews and Delphi exercises would target supply chain architects and shipment decisionmakers representing shippers, carriers, and third party logistics firms.

Summary

The challenge of freight forecasting is that changes in freight traffic are often related to economic, political, geographic, and business operation factors. In addition, data sources are often proprietary and difficult to obtain.

This research is designed to test a new modeling framework and confirm its practicality and usefulness before conducting data collection activities to support the models. Current forecasting methods have tried to work within existing data sources and this has limited the usefulness of the models for planning purposes. This project has produced a freight forecasting framework that incorporates supply chain methods at a national scale with tour based methods at a regional scale to predict changes in freight movements for an urban area. The tour based and supply chain freight forecasting framework has added capabilities to existing freight forecasting models, by integrating these methods into a single framework and applying them on a disaggregate basis. This integration provides a linkage between short haul and long haul shipments. The addition of a model to determine the distribution channel has segmented downstream models by the type of distribution channel.

Planners have and will continue to face a difficult question: how to accommodate the growing demands of freight movement on a transportation infrastructure that is shared by the traveling public who are likewise placing more demands on the system? The freight forecasting framework described herein provides a model that is more sensitive, to policies, regulations, and transportation investments than is possible with a four step freight model, a supply chain model or a tour based model. The integration, combined with a disaggregate modeling system, allows for a more consistent and comprehensive representation of goods movement in a region. This research is designed to improve the current freight forecasting models for CMAP and other MPOs around the country so they will be able to evaluate current and proposed freight alternatives and policies. As a demonstration project, the major result of this study is the proof of the concept, the identification of data recommendations to support a model of this type in the future, and an implementation of the concept that integrates the modeling concepts with data from the Chicago region.

One result of the research was the development of data collection recommendations to support the estimation, calibration, validation, and forecasting of the framework for future use. Many of the data needed are readily available, but estimation data are still needed for both the national and regional aspects of the framework. The national data collection should be considered by the US Department of Transportation to support this type of forecasting across the country. If in the short term, these national surveys are not available, extensive sensitivity testing on the models can be used to assess reasonableness of the models. The regional data collection should be considered by any region interested in applying the freight forecasting framework. This regional data collection may be considered at the state level, similar to the Texas data collection program, to provide more robust sample sizes and consistency for several regions in a state.

The model components in the freight forecasting framework should be reestimated when new data are available, especially the mode and intermediate transfer model, which was not reestimated as part of this research, and the distribution channel model, which was limited in scope by the available data in the USA. In addition, other model components could consider model forms other than MNL; for example, the shipment size model could be estimated as an ordered response model. Ideally, each model component would be calibrated to local conditions and validated as a system for a region. Forecasts using a calibrated and validated modeling system could be reviewed for reasonableness and sensitivity tests would provide insight on the details of modeling system and may contribute to some adjustments. Forecasts of individual projects or future alternatives would also provide useful information on any aspects of the system that could be improved.

The freight forecasting framework described herein is a start to implementing advanced modeling techniques to forecast goods movement and commercial vehicles for regional planning purposes. Further efforts to improve this framework with new data, model improvements, and forecasts would be welcome. The open source aspect of the software allows any transportation agency to use and contribute to this framework.

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