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Examining carrier categorization in freight models

Maura Rowell [a,*], Andrea Gagliano [a], Anne Goodchild [b]

[a] University of Washington, 201 More Hall Box 352700, Seattle, WA 98195, United States
[b] University of Washington, 121E More Hall Box 352700, Seattle, WA 98195, United States

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ABSTRACT

Travel demand models are used to aid infrastructure investment and transportation policy decisions. Unfortunately, these models were built primarily to reflect passenger travel and most models in use by public agencies have poorly developed freight components. Freight transportation is an important piece of regional planning, so regional models should be improved to more accurately capture freight traffic. Freight research has yet to fully identify the relationships between truck movements and company characteristics in a manner sufficient to model freight travel behavior. Through analyzing the results of a survey, this paper sheds light on the important transportation characteristics that should be included in freight travel demand models and classifies carriers based on their role in the supply chain. The survey of licensed motor carriers included 33 questions and was conducted in Oregon and Washington. Respondents were asked about their vehicle fleets, locations served, times traveled, time windows, types of deliveries, and commodities. An assessment of how the relationships found can be integrated into existing models is offered.

1. Introduction

State economies are served by the distribution of goods and services, i.e., freight, via the transportation network. For freight transportation planning to be efficient, state Departments of Transportation (DOTs) need informative freight models, and incorporating the relationships between transportation activity and characteristics such as commodity, shipment size, time windows, and origin and destination into these models can improve their ability to estimate the impact and policies on transportation activity.

Fig. 1 shows the Quick Response Freight Manual's simplified freight forecasting procedure (Cambridge Systematics, COMSIS Corporation, & University of Wisconsin-Milwaukee, 1996). This approach represents the state of the practice in freight demand modeling. At different steps of the procedure, simple categories of motor carriers are used to capture varying transportation characteristics. Different trip generation rates are often determined for different truck types such as four-tire and single unit trucks (Fischer & Han, 2001). Trip generation rates can also be categorized based on distance using long haul, short haul, local traffic, and through trips. Each distance category has different transportation characteristics; for example, long haul trips are made primarily by for-hire carriers and often originate from the manufacturing sector (Fischer & Han, 2001). Freight flows can be separated into truck trips that are classified as either private or for-hire. Depending on this classification, these trips take on different characteristics, such as the proportion that go to intermodal facilities and the allocation of trips into various truck sizes (Brinkerhoff, HBA Specto Incorporated, & EcoNorthwest, 2010). In the trip assignment step, analysts can do separate assignments for different categories of time, namely peak and off-peak times (Fischer & Han, 2001). One of the most common categories used in all steps of the freight forecasting procedure is commodity.

Commodity data is the basis of commodity flow models and provides a method of trip generation by translating tonnage flows into truck trips using commodity-specific truck payload factors (Fischer & Han, 2001). After trip generation, commodity-specific parameters continue to be used in models. Commodity can determine the percentage of shipments that are allocated to transshipment facilities, the percentage of trips that are long haul versus short haul, and whether the carrier operates on a for-hire or private basis (Çetinkaya & Bookbinder, 2003; Fernández, J. E., de Cea Ch & O, A. S., 2003; Fischer & Han, 2001; Picard & Gaudry, 1998; Samimi, Mohammadian, & Kawamura, 2010; Southworth & Peterson, 2000).

Garrido and Regan found that the choice between private and for-hire carriers is a critical shipper decision. The choice determines several factors: door-to-door transportation costs, time definitive delivery/pick-up services, freight loss/damage liability, geographical coverage, distribution patterns, shipment size, and driver availability (Regan & Garrido, 2001).

Carlos Bastida and Jose Holguin-Veras found relationships between carrier and receiver establishment characteristics and freight generation, documented in their Freight Generation Models report. In Brooklyn and Manhattan, industry segment, commodity type, facility type, total

* Corresponding author. Tel.: +1 206 685 6817.
E-mail addresses: mkrowell@uw.edu (M. Rowell), gagliano@uw.edu (A. Gagliano), annegood@uw.edu (A. Goodchild).

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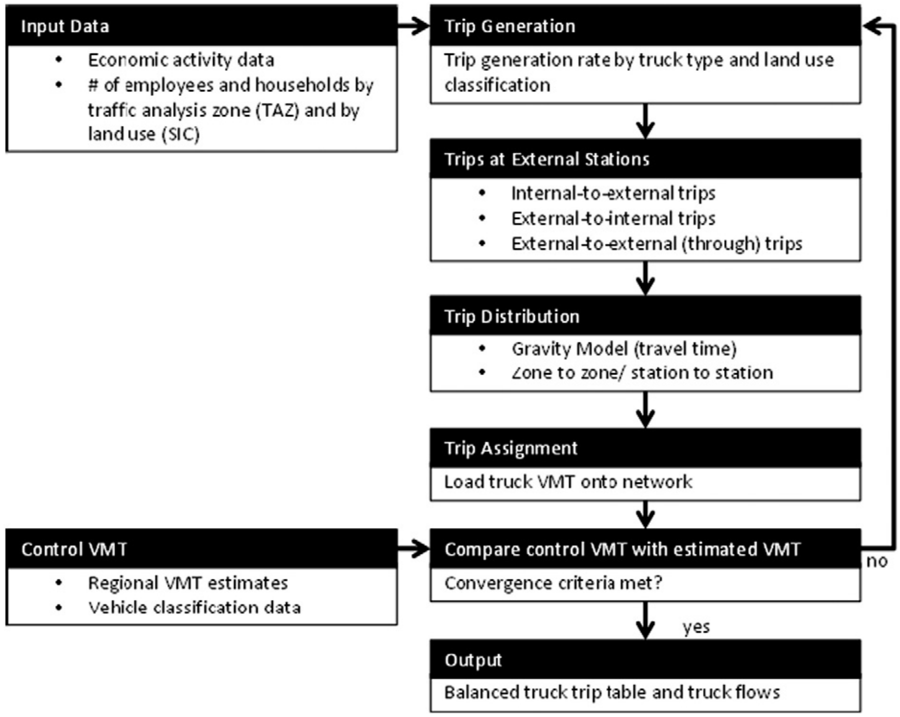

Fig. 1. Freight forecasting procedure. The procedure found in the Quick Response Freight Manual (1996) shows the main steps in freight modeling (Cambridge Systematics et al., 1996).

sales, and numbers of employees were statistically significant indicators of the number of deliveries generated per establishment. Because of insufficiently detailed data, Bastida and Holguin-Veras collected their own data from carriers and receivers (Bastida & Holguin-Veras, 2009).

Recently, a wave of second-generation models has begun to include some of the characteristics that researchers have found to be factors in freight movement. In Calgary, Canada, Hunt and Stefan developed a commercial vehicle movement model that, as it builds truck tours, distinguishes among vehicle types, trip purposes, establishment categories, and commodity NAICS codes (Hunt & Stefan, 2007). In Tokyo, Wisetjindawat et al. developed a model that considers each individual firm by taking into account location, number of employees, and floor area. By using these firm characteristics and delivery size, vehicle choice, and vehicle routing, the model converts commodity flows into truck trips (Wisetjindawat et al., n.d.). The GoodTrip model, used in The Netherlands, considers factors consistent with the aforementioned models, but takes an additional step by considering the roles of producer, carrier, and retailer as goods travel through transportation links (Boerkamps, van Binsbergen, & Bovy, 2000).

More recent research has hypothesized that incorporating supply chain thinking into freight modeling would better capture the complexity of freight transportation (Hunt & Stefan, 2007; Wisetjindawat et al., n.d.; Hensher & Puckett, 2005; Fischer, Outwater, Cheng, Ahanotu, & Calix, 2005; de Jong & Ben-Akiva, 2007; Boerkamps & van B., 1999). Supply chain thinking can aid commodity-based freight modeling when determining the percentage of trips that visit facilities such as manufacturing plants and retail stores. Knowledge of which supply chain nodes the goods are being moved between can provide more information about the shipment's transportation characteristics. For example, wood products (SCTG 26) moving between a raw production facility and a distribution center when compared to wood products moving between a distribution center and a retail facility may be moved in larger shipment sizes by a larger full-truckload vehicle making fewer stops.

When faced with the discrepancy between the number of factors affecting freight and the amount of data used in modeling, the initial reaction is to gather more data, create more categories, and add complexity to the models. The goal of this research is to determine whether categories of carriers (e.g., private/for-hire) used in freight models today are supported by industry data and whether informative novel categories exist that could replace or be used in addition to current categories. Should relationships be observed in the data analysis, this initial effort can provide support for specific model improvements; however, if these relationships are not observed, this work can help avoid developing more complex models. This article first describes the specific research questions and methods, including data collection via survey and statistical analysis in Section 2. The evaluation of current and novel categories is presented in Section 3. Lastly, the contribution to scholarly knowledge is discussed in Section 4.

2. Research questions and methods

The research question investigated in this article is whether empirical data supports the categorization of motor carriers into clear categories that have different transportation characteristics. First, the private/for-hire and commodity categories are studied to check if the data supports such a distinction. Then exploratory analysis is used to discover new categories that are data-driven. These new categories provide a potential new path forward in modeling research.

The first step in testing which categories provide statistically significant results is data collection. In order to collect relevant data, a targeted survey was designed and distributed specifically for this research. The data was then divided based on the current categories used today and tested on a variety of transportation characteristics.

2.1. Survey

The Commodity Flow Survey (CFS) and the Freight Analysis Framework (built on the CFS) are the primary national-scale publicly available datasets regarding freight transportation in the United States. They provide sub-state level tonnage by commodity and by mode, but they do not provide significant insight into carrier travel behavior. While there are numerous other sources of data, none is widely available that can provide detailed behavioral observations.

The lack of data required the research team to design and distribute a survey to collect detailed carrier data. The Social and Economic Science Research Center (SESRC) at Washington State University distributed via phone the survey designed by the authors. The survey was designed to be a 15 min interview and was tested for both content and clarity by SESRC and six professionals in the freight industry. Current freight data, state of practice models, and frameworks of second generation models were all taken into account when constructing the survey.

The survey asks general business demographic questions and freight-related questions aimed at capturing how the respondent moves freight. Screening questions were asked to ensure that the respondent held the information necessary to answer the survey. This was followed by questions concerning number of vehicles, travel locations, travel distances, delivery/pickup types, vehicle types, time windows, travel times, delivery/pickup locations, facility locations, facility size, and company revenue.

2.2. Population and sample

The survey was distributed to 8238 Oregon and Washington State motor carriers of which 522 responded. The list of licensed motor carriers was obtained from the Washington State Department of Transportation (WSDOT) and the Oregon Department of Transportation (ODOT). The population of carriers is dominated by carriers with fewer than 50 vehicles. To ensure that enough surveys were obtained from minority carriers (those with more than 50 vehicles) to make conclusions regarding their behavior, a stratified sample with proportionate allocation was used. The sample population was constructed to include 100% of the total population carriers with 50 to 1803 vehicles and 9.61% of the total population carriers with fewer than 50 vehicles.

A majority of carriers in Washington and Oregon have 10 or fewer vehicles in their fleet; many of the carriers were extremely small with only one truck as seen in Fig. 2.

The survey respondents were asked to report if they transport a primary commodity and, if so, which commodity. The self-reported text commodities were categorized into SCTG commodities. Fig. 3 shows that the most common commodities are gravel, mixed freight, raw wood, and wood products. The prominence of raw wood and wood products is expected since Oregon and Washington are two of the nation's largest lumber producers. If a company reported that they did carry a primary commodity but failed to state which commodity, then they were categorized under mixed freight.

Survey respondents were asked to report whether they operate solely as a private or for-hire company, and if they operate as both, what percentage of shipments is on a for-hire basis (Fig. 4). There is an equal number of solely private and solely for-hire carriers observed in the survey. Of the carriers that reported that they operate as both types, about half of the shipments are on a for-hire basis.

Another question asked if the respondent owns or operates a facility that produces raw materials, a facility that manufactures goods, a storage center, a distribution center, and/or a retail store. Respondents that responded "no" to all the facility types were classified as link carriers. Those that responded "yes" to at least one of the facility types were classified as node carriers. This paper addresses the hypothesis that link and node carriers demonstrate substantially different transportation characteristics. The carrier classification data is analyzed to determine whether any significant differences between the two types can be identified. Conclusive differences are drawn among factors that are statistically significant (p-value less than or equal to 0.05), as determine by a Welsh two sample t-test for continuous data or the Fisher comparison of proportions test for categorical data.

3. Findings and discussion

3.1. Private versus for-hire and commodity categories

Many current truck freight models use a private versus for-hire classification. This carrier distinction is thought to effect transportation characteristics in several ways. For example, private carriers need to coordinate inbound and outbound shipments in order to reduce empty backhauling. For-hire carriers may require trips to distribution and storage centers (Min, 1998). The distinction between private and for-hire carriers is easily found from the Commodity Flow Survey data.

The survey data showed that this distinction is not significant for certain characteristics. Of the numerical survey questions, number of vehicles, delivery value, and number of stops were tested to determine if there was a significant difference between the mean values for each carrier classification. Table 1 shows that only the number of vehicles is significantly different between private carriers and for-hire carriers. Fig. 5 shows the histogram of the number of stops for all carriers excluding observations over 50 only in order to show the variation in the lower range more clearly.

Many current models assign truck size and carrier type (private or for-hire) to trips based on commodity. Using the survey data, the relationships between carrier type (i.e., private, for-hire, both) and commodity and truck size were tested. Truck size is determined from the survey by asking respondents what vehicle they use most commonly. Using the chi-squared test for contingency tables, carrier type is found to be independent of commodity (p-value = 0.6935) and dependent on truck size (p-value = 1.614e-07). Commodity and truck size are independent (p-value = 0.5652).

These results suggest that a commodity-specific private versus for-hire split is not needed since carrier type is independent of commodity. Rather, the models can apply a single private versus for-hire split to the entire population. Since the private versus for-hire data is easily obtained and generates significant carrier groups, it is appropriate to continue using it in models. However, the carrier type distinction does not provide useful information about more complex characteristics such as number of stops.

Using exploratory data analysis several categories of carriers were investigated. The categorization scheme that leads to the strongest results is the link versus node carrier categorization. Section 3.2 explains how link and node carriers were determined and the results found using this categorization scheme.

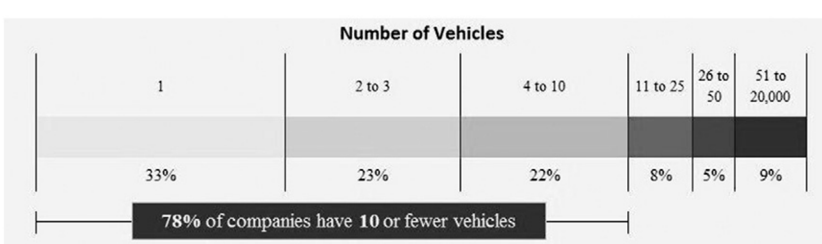

Fig. 2. Number of vehicles. The number of vehicles in any given fleet range from one to 20,000 with the largest percentage of carrier fleets consisting of only one truck.

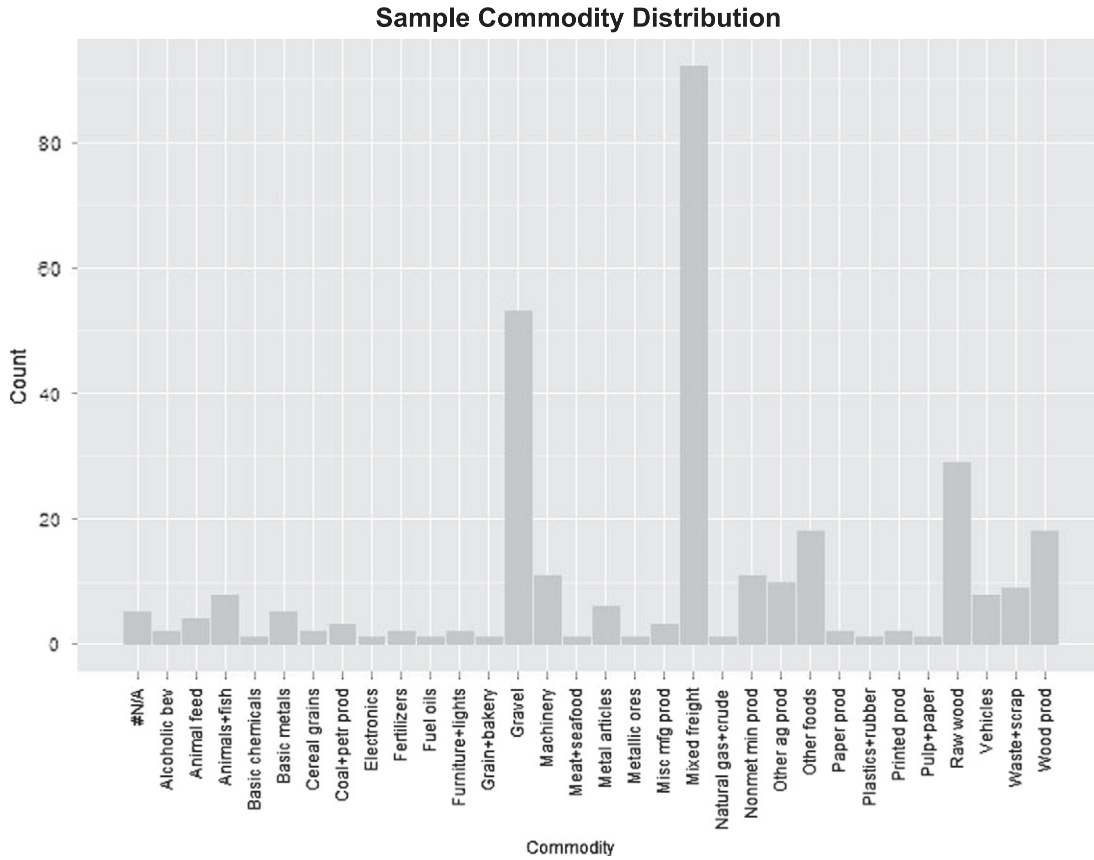

Fig. 3. Commodity. The most prominent commodities are gravel, mixed freight, raw wood, and wood products.

3.2. Link versus node categories

The transportation differences between link and node carriers investigated include: delivery/pickup type, frequency, location, style, time of day, and time windows. All the results provided in this section were weighted by number of vehicles. The number of carriers and vehicles are (1) link: 422 carriers and 15,664 vehicles and (2) node: 116 carriers and 1882 vehicles. The number of observations (vehicles) used in the statistical tests varies as respondents did not answer all questions. Using the number of vehicles rather than carriers has advantages and disadvantages. The survey asked the carrier to respond to questions with regard to their typical activity (e.g., typical size of truck, number of stops in typical trip); therefore, duplicating results based on the reported number of vehicles applies average characteristics to all vehicles in the fleet. It also assumes that all vehicles are used and observed on the network. Observations are duplicated based on the number of vehicles owned; the survey does not ask what proportion of vehicles owned are used on average. Commodity flow models use shipments as the basis of analysis rather than carriers, and weighting by number of vehicles gets the survey data one step closer to shipments. Many models, however, are trip-based and most are intended to model transportation activity rather than carrier choices.

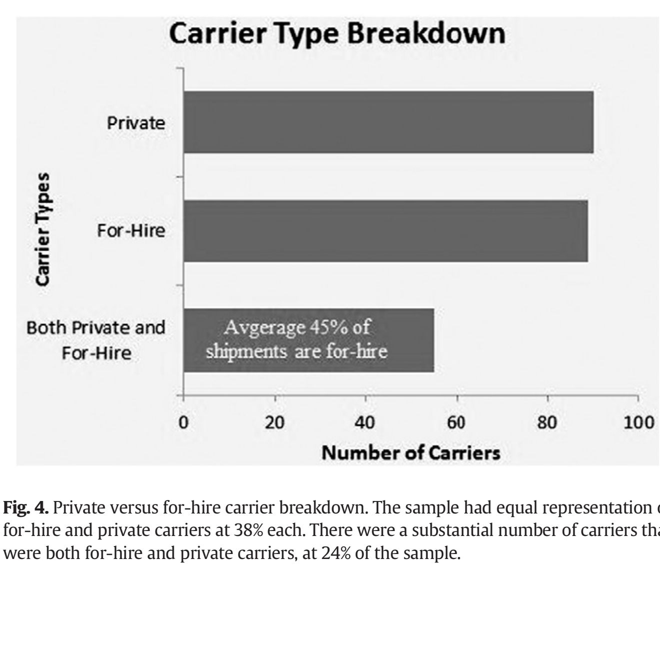

Fig. 4. Private versus for-hire carrier breakdown. The sample had equal representation of for-hire and private carriers at 38% each. There were a substantial number of carriers that were both for-hire and private carriers, at 24% of the sample.

One transportation characteristic regards delivery type with the options of letters, packages, less than truckload, and full truckload for the carriers' typical delivery or pickup. Zero carriers offered letter delivery/pickup, and less than 1% of trucks performed package delivery/pickup. Less than truckload (LTL) and full truckload (TL) deliveries/pickups had a significant difference between link and node carriers. Link carriers have a higher percentage of LTL trips compared to node carriers (22.2% versus 18.4%); node carriers have a higher percentage of TL trips compared to link carriers (81.5% versus 70%). An example of how this could impact models can be illustrated by using Oregon's Statewide Integrated Model (SWIM2) which fills private carrier trucks to the commodity-specific average payload until all shipments are accommodated. The model will hold under-capacity for-hire trucks at the origin and allocate shipments from nearby establishments to the truck before generating a new for-hire truck (Brinkerhoff et al., 2010). Using the LTL and TL percentages observed in the data can inform the for-hire truck assignment so that the model produces a similar LTL/TL split.

The survey asked: Which of the following delivery or pickup frequencies do you provide for your customers? (a) Do you stop multiple times a day? (b) Do you stop daily? (c) Do you stop weekly? (d) Do

Table 1
Two sample *T*-test results.

	Mean private carriers (127 carriers)	*Mean for-hire carriers (268 carriers)*	*P-value*
Number of vehicles	8.5	25.7	0.0055
Delivery value	11,409	9091	0.7401
Number of stops	7.7	2.3	0.1604

you stop monthly? (e) Do you stop less than monthly? Each subquestion was asked independently and the carrier could respond "yes" or "no" to each one separately. Link carriers and node carriers had significantly different results for the range of delivery frequencies to a single facility (Table 2). Both link and node carriers have a similar shape of the delivery frequency distribution but link carriers have a higher magnitude in all cases. This survey question aims to determine how often a carrier serves a single establishment. This information manifests in modeling when for a given origin and destination pair, if more than one truck is needed to move all shipments, the model should distribute those truck trips according to the delivery frequency distribution rather than simultaneously. In Tables 2, 3, and 4 the very small *p*-values are a result of the large sample sizes.

To address the location of freight activity, the survey asked if the carrier delivers to or pickups at urban, suburban, and rural locations. There were significant differences with regards to all delivery locations between link and node carriers. The survey also asked if the delivery/pickup locations were residences or businesses. Of those that deliver/pickup at businesses, the survey asked if the location was a manufacturing facility, distribution center, or intermodal facility. The majority of all deliveries/pickups were to businesses regardless of carrier type. For node carriers, manufacturing facilities were the most visited and intermodal facilities the least. Link carriers most often visited distribution centers. This result is similar to the description of trip generation rates based on distance described in the introduction (Section 1). The distance-based categories include long haul trips which were generally private trucks which most often visited manufacturing facilities. Link carriers behave similar to for-hire carriers with regards to this characteristic in that they often visit distribution centers. The results for these characteristics are shown in Table 3.

The survey also inquired about delivery style: either scheduled appointment times or a first-come-first-serve basis. On average, link carriers make more scheduled deliveries/pickups and node carriers make more first-come-first-serve deliveries/pickups. The *p*-values for these

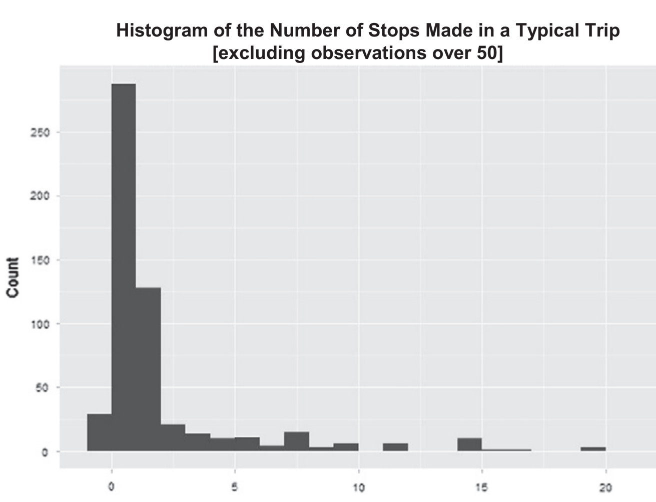

Fig. 5. Number of stops in a typical trip histogram. The histogram shows that there is variance in the reported number of stops made in a typical trip for all carriers. Observations excluded from the histogram are (50, 50, 200, 300, 300, 600, 800). This explains why the difference in the mean number of stops for private and for-hire carriers appears large but is not significant.

results indicate that both delivery styles differentiate link and node carriers. This characteristic affects when a freight model sends a truck to a destination. Under the first-come-first-serve scenario, a truck may leave the origin once it has reached capacity. On the other hand, under the scheduled appointment scenario, a full truck may be delayed at the origin or a truck may be forced to depart before reaching capacity.

The survey divided the day into (a) morning 06:00 to 10:00, (b) daytime 10:00 to 15:00, (c) evening 15:00 to 19:00 PM, and (d) overnight 19:00 to 06:00. Between link and node carriers all times of day were significantly different except the daytime period. Link carriers have more morning activity, equal activity during the daytime, and less activity during than evening and overnight compared to node carriers (Fig. 6). The results are shown in Table 4. This information can aid an analyst when deciding the proportion of shipments that correspond to time-of-day dependent trip generation rates. Not only does the overall amount of activity change throughout the day, it changes differently for link and node carriers. The survey also asked: During a typical day do your drivers have time windows for deliveries or pickups that are (a) less than 30 min? (b) 1 to 2 h? (c) half day? (d) all day? All time windows were significantly different between link and node carriers (Table 4). This information can aid the analyst when modeling scheduled appointment deliveries that have varying time windows.

The survey data has generated a category of carriers that provides information on more complex transportation characteristics. This link carrier versus node carrier category is not currently used in models and would not be directly implementable in models. These results are data-driven and are not meant to fit neatly into today's models. They are, however, meant to direct future research and model development.

4. Conclusions

The results found in this research suggest changes that can be made to the state of the practice freight models. There are three ways that the analysis can impact the freight models. First, the data found can be used to update inputs currently used in the model. Second, the results can be integrated into the model as new input parameters. Third, an entirely new framework can be developed for future model generations.

4.1. Contribution to management practice

In this section, management is defined as Metropolitan Planning Organizations (MPOS) and DOTs. This paper critiques the elements of the existing models, provides suggestions for improvement to the state of practice models, and provides data on carrier behavior.

In some models, each commodity has a proportion of truck trips that is classified as private and a proportion that is for-hire. This distinction determines on average how many stops are made on a typical tour, the allocation of shipments into various truck sizes, and whether the carriers backhaul. The outcome of this research cannot confirm that the private versus for-hire split has any impact on the number of stops, but does confirm that truck size distribution is dependent on carrier type. The survey did not ask about backhauling.

Commodity flow models break commodities into industry classifications, and then shipments are allocated to terminals, distribution centers/warehouses, manufacturers/producers, and others. The survey in this research asks for similar information, specifically the proportion of residential and business deliveries/pickups made and what proportion of business locations were intermodal, distribution centers, and/

Table 2
Delivery frequency results.

Delivery frequency	*Sample size*	*Link (%)*	*Node (%)*	*Test*	*P value*
Multiple times a day	12,920;1795	63.1	51.6	Pairwise comparisons using Pairwise comparison of proportions (Fisher)	2.00E-16
Daily	12,920;1795	89.7	71.8		2.00E-16
Weekly	12,920;1795	85.1	55.7		2.00E-16
Monthly	12,920;1795	71.7	43.3		2.00E-16
Less than monthly	12,920;1795	52.3	31.9		2.00E-16

Table 3
Location results.

Location type	*Sample size*	*Link (%)*	*Node (%)*	*Test*	*P value*
Urban	13,395;1859	89.6	85.1	Pairwise comparisons using Pairwise comparison of proportions (Fisher)	2.70E-08
Suburban	13,395;1859	74.0	79.0		2.00E-06
Rural	13,395;1859	96.7	93.4		2.00E-10
Business type	*Sample size*	*Link (%)*	*Node (%)*	*Test*	*P value*
Residential	15,186;416	8.1	22.6	Welch two sample *t*-test	2.20E-16
Business	15,186;416	86.2	57.3		2.20E-16
Business type	*Sample size*	*Link (%)*	*Node (%)*	*Test*	*P value*
Manufacturing facility	15,024;1668	78.4	78.9	Pairwise comparisons using Pairwise comparison of proportions (Fisher)	0.66
Distribution center	15,024;1668	88.8	62.3		2.00E-16
Intermodal facility	15,024;1668	67.5	30.5		2.00E-16

or manufacturers. The data suggests that using the link and node carrier classification results in significantly different percentages of pickups/deliveries at businesses including distribution centers and intermodal facilities.

The survey gathers information about carriers' delivery frequency to a given destination. This information can aid modeling when for a given origin and destination pair, if more than one truck is needed to move all shipments, the model should distribute those truck trips according to the delivery frequency distribution rather than simultaneously.

Another relevant characteristic is delivery style. Under the first-come-first-serve scenario, a truck may leave the origin once it has reached capacity. On the other hand, under the scheduled appointment scenario, a full truck may be delayed at the origin or a truck may be forced to depart before reaching capacity.

Time of day is currently addressed in models as far as distinguishing the average time of day that shipments leave for various truck sizes. This data can be gathered from the Quick Response Freight Manual. The survey data provides more relevant regional data for US models. This information can aid an analyst when deciding the proportion of shipments that corresponds to time-of-day dependent trip generation rates. Not only does the overall amount of activity change throughout the day, it changes differently for link and node carriers.

4.2. Contribution to scholarly knowledge

Most of the input parameters suggested above require modifications to the model structure, but this section discusses entirely different model frameworks that may be more appropriate for freight modeling based on the results from the survey. A discussion of two proposed new frameworks of a time based model and supply chain based model is presented below.

4.2.1. Time based model

Time considerations can be increased in freight models. For example, time is currently considered in Oregon's SWIM2 Commercial Transport module to the extent that the model keeps track of the time it takes to travel the shipment distance and dwell time at each stop (Brinkerhoff et al., 2010). The model does not optimize based on time considerations but does maximize the duration of a total trip based on driver availability. There are additional time considerations that can be integrated into the model to lay the ground work for potential time-based optimization.

Delivery style and time windows can be integrated into the model. When carriers design their routes, some have scheduled delivery times with their customers and some operate on a first-come-first-

Table 4
More results.

Delivery style	*Sample size*	*Link (%)*	*Node (%)*	*Test*	*P value*
First come first serve	12,963;1731	15.4	37.0	Welch two sample *t*-test	2.20E-16
Scheduled	12,963;1731	75.1	54.5		2.20E-16
Time of day activity	*Sample size*	*Link (%)*	*Node (%)*	*Test*	*P value*
Morning	9777;1504	49.2	32.5	Welch Two Sample *t*-test	2.20E-16
Daytime	9777;1504	29.6	29.5		0.833
Evening	9777;1504	15.5	20.1		2.20E-16
Overnight	9777;1504	5.3	15.8		2.20E-16
Time windows	*Sample size*	*Link (%)*	*Node (%)*	*Test*	*P value*
Less than 30 min	11,927;1078	55.8	69.8	Pairwise comparisons using Pairwise comparison of proportions (Fisher)	2.00E-16
1 to 2 h	11,927;1078	59.0	69.5		8.40E-12
Half day	11,927;1078	31.8	41.1		9.20E-10
All day	11,927;1078	40.8	26.6		2.00E-16

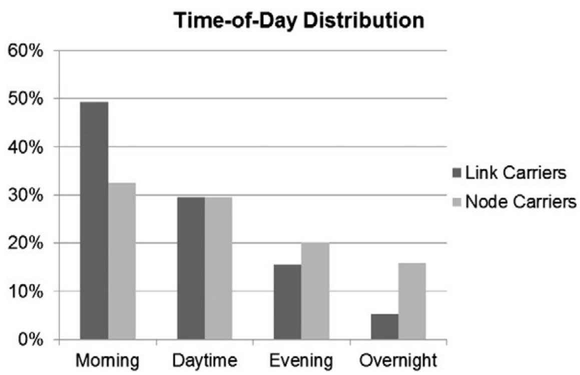

Fig. 6. Time-of-day distribution. The histogram shows that node carriers' activity is more uniformly distributed throughout the day when compared to link carriers which show a more severe monotonic trend.

served (FCFS) basis. The survey gathered data on both delivery styles and time windows. The survey also asks who determines delivery times, the carrier company or the customer. This input could be included in the model to determine flexibilities of route creation. If the carrier has control of delivery times, they can design a more efficient route. If customers determine delivery times, oftentimes this forces carriers to choose less efficient routes to cater to customer requirements.

A new modeling framework could acknowledge the inherent variability in travel times in coordination with the time windows typically given for shipment arrival times. Introducing congestion factors into the model (which can be introduced through time of day allocations) in combination with the uncertainty of travel time allows for models to be optimized not only on distance but on time. Priorities can be determined between optimizing time and optimizing distance for each trip based on arrival time constraints which would vary depending on the type of destination.

4.2.2. Supply chain based model

Through the analysis of the survey data, noticeable differences were found between supply chain node carriers and link carriers. An entirely new model could be developed that instead of building truck itineraries based on for-hire and private distinctions, would generate trips based on specific steps within a supply chain. In this paper, some carriers are classified as link carriers which travel across any link of the supply chain and are not attached to any specific nodes. The remaining carriers are classified as node carriers and are attached to nodes along the supply chain, such as raw or manufacturing facilities, distribution centers or warehouses, and retail establishments. Node carriers can be further classified according to which nodes they are associated with; there were not enough observations in the survey to conduct this analysis.

This style of model would take into consideration unique supply chains for each industry. Shipments would have unique characteristics dependent on which supply chain they are traveling in and which step along the supply chain the shipments are contributing to. A necessity for this type of model to work is to have a deep understanding of specific establishments that make up the supply chain nodes.

Models use zones as origins and destinations for shipments (Cambridge Systematics et al., 1996; Fischer & Han, 2001; Brinkerhoff et al., 2010). If specific establishments are used, unique facility characteristics can be attached to these establishments such as node type along the supply chain, commodity, types of vehicles, and number of vehicles. Number of vehicles and types of vehicles available are valuable inputs as they can provide constraints on the number of shipments and types of goods that can depart from specific locations. Constraining truck creation would allow for more accurate optimizations. Understanding origins and destinations in further detail would reveal truck creation limitations. In order to get a deeper understanding of specific establishment features, further surveys or investigations into supply chains are suggested.

These two frameworks of time based models and supply chain based models could be created separately or could be combined together. Establishing supply chain information and more detailed time information in models lays the foundation for optimizing factors other than distance.

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