State-of-the-Art in Freight Modeling

Undergraduate Paper
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INTRODUCTION

Early travel demand models neglected freight components, as they were assumed to comprise a small percentage of the overall traffic stream. Due to this fact, travel demand forecasts frequently modeled freight traffic using the same four-step models as those used for passenger vehicles. America’s freight transportation system affects the nation’s economy, security, and quality of life. 6.4 percent of the U.S. Gross Domestic Product is spent annually to move freight. Domestic freight is estimated to grow 50 percent in the next 20 years, making freight modeling an increasingly important part of the nation’s future. (1)

Due to the complex nature of freight flows, many different approaches have been made in an attempt to model them. These approaches often vary in terms of scope and data use, depending upon the needs of the user. Understanding the various methods that have been attempted is essential in building a freight model that is both user-friendly and comprehensive. It is the purpose of this paper to try to organize some of the most important variables, data sources, and model applications as a framework for creating a comprehensive freight model.

There are several key differences that make freight modeling more difficult than passenger vehicle modeling. These differences are outlined by de Jong et al. (2) as:

- The diversity of decision makers in freight.
- The diversity of items being transported.
- The limited availability of data.

Several other factors that separate freight models from passenger vehicle models are trip purpose, vehicle type, and time of day. Although these factors are found in both types of models, they play different roles in freight modeling than they do in passenger vehicle models.

Donnelly (3) highlights several important criteria in freight modeling:

- Linkage to economic forecasts.
- Placing the study in a global context.
- Capturing important dynamics.
- Including multi-modal options.
- Including commodity flows and converting those flows to modal vehicle flows.
- Sensitivity to policy options and the ability to evaluate those policy options.
- Minimizing data requirements.

These criteria will be used to evaluate the modeling platforms that are presented in the next section of this paper.

MODELING PLATFORMS

Holguín-Veras and Thorson (4) divide freight modeling into two essential platforms; commodity-based models and trip-based models. Another basic modeling platform that has recently been used for urban and regional areas is the micro-simulation model. The following section reviews these three approaches to freight modeling, as well as hybrid and economic activity models.
Commodity-based Models

Commodity-based models focus on measuring freight amounts by weight, thus capturing the fundamental economic mechanisms that drive freight movements. Commodity-based models are broken into five steps, shown in Figure 1.

![Commodity-based Approach Diagram](https://example.com/commodity-diagram)

**FIGURE 1 Commodity-based Approach.**
Source: Holguín-Veras and Thorson (4)

The first step in a commodity-based model is commodity generation. Commodity generation consists of dividing the study area into traffic analysis zones (TAZs) and estimating the weight of the commodities produced and attracted by each TAZ. The second step is commodity distribution, where the weight of the commodities moving between each origin-destination (O-D) pair are estimated using a spatial interaction model. The third step is commodity mode split. In this step, an estimation of the weight of each commodity moved by each mode available to move it is made. This estimation is usually achieved using discrete choice models or logit models that are based on mode split data. The fourth step is assigning vehicle loading. This step estimates loading rates based on previously conducted surveys. The final step is traffic assignment, which is the process of assigning the vehicle trips to the network.

Table 1 shows an evaluation of the commodity-based modeling technique based on Donnelly’s (3) criteria.

**TABLE 1 Evaluation of the Commodity-based Approach**

<table>
<thead>
<tr>
<th>Does the model include…</th>
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<tr>
<td>Economic linkage</td>
<td>Yes</td>
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<tr>
<td>Global context</td>
<td>Yes</td>
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<tr>
<td>Behavioral dynamics</td>
<td>No</td>
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<td>Multi-modal traffic</td>
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<td>Commodity flows</td>
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<td>Policy evaluation</td>
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Commodity-based approaches capture the relationship between the economy and freight flows by basing them upon economically sensitive data. These models can be put into a global context by
including import and export data for each of the commodities. Holguín-Veras and Thorson (4) include multi-modal generators as one of the five steps of basic commodity-based models. However, many commodity-based models lack a multi-modal component. According to Stefan et al. (5), O-D matrices often are not able to respond to policy changes. Conversely, de Jung et al. (2) claim that policy responses can be modeled if the coefficients in the mathematical functions are elastic.

Two weaknesses are associated with commodity-based models. First, they lack the ability to model the behavioral content of freight flows. Specifically, they have difficulty modeling less-than-truckload and empty truck trips. Stefan et al. (5) also note that they often model trips rather than tours and overlook many of the trips performed by light commercial vehicles. Second, commodity-based freight models often need detailed input-output (I-O) data, which can be difficult to obtain for regional and urban models.

### Trip-based Models

Figure 2 shows an outline for trip-based models:

![Diagram](image)

**FIGURE 2 Trip-based Approach.**
Source: Holguín-Veras and Thorson (4)

The model shown in Figure 2 is known as a three-step model. Another common trip-based model is the four-step model. This model follows the same process as the three-step model, with an additional mode assignment step inserted between trip distribution and traffic assignment steps.

The trip-based model begins with trip generation. In this step the number of vehicle trips produced and attracted in each TAZ is estimated, usually with regression models. The next step is trip distribution, which is accomplished through the use of spatial interaction models. A third step, included in four-step models, is mode assignment. Mode assignment is typically accomplished using a discrete choice logit model. The final step is assigning the traffic to the network.

Table 2 shows an evaluation of the trip-based modeling technique based on Donnelly’s (3) criteria.
TABLE 2 Evaluation of the Trip-based Approach

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The main advantage offered by trip-based models is that they require a minimal amount of data. The data they do require is readily available through traffic counts and freight surveys. Gliebe et al. (6) also cite the comparative ease of application and a consistency with the four-step passenger vehicle model as additional strengths.

There are several disadvantages associated with the use of trip-based models. They do not offer a link to the economy because vehicles are the unit of demand rather than commodities and services. This lack of connection to the economy makes it difficult to put trip-based models in a global context. The behavioral characteristics of freight flows tend to be overlooked by trip-based models. Such characteristics as vehicle touring are often ignored by these types of models, leading to poor results in urban and regional models. Gliebe et al. (6) note that trip-based models have a limited scope for evaluating policy changes.

**Micro-simulation**

Micro-simulation models are typically used in urban or regional settings, due to their focus on capturing behavioral characteristics associated with freight tours. In micro-simulation models, tours are typically assigned a vehicle, trip purpose, and start time. These assignments are typically computed with a discrete choice model. An iterative process is then assigned to the tour, in which the previous and current stops as well as the overall length and duration of the tour are considered. Figure 3 shows the general outline of a micro-simulation model.
Table 3 gives a general evaluation of the micro-simulation technique based upon Donnelly’s criteria.

**TABLE 3 Evaluation of the Micro-simulation Approach**

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The main advantage associated with using micro-simulation models is the provision of a detailed account of vehicle tours and the reasoning behind them. Micro-simulations are also effective at reflecting changes in policy. A change made in any step of the micro-simulation process will result in changes in each of the other steps.

Micro-simulation models have several weaknesses. They are usually urban in scope, making the models difficult to link to the economy or set in a global context. Micro-simulation models also require gathering extensive sets of data. Tavasszy (7) states that many of the estimations in micro-simulation models are based upon data gathered in truck counts and establishment surveys, making them difficult to calibrate and validate.
Hybrid Models

Hybrid models are a combination of trip-based and commodity-based models. Specific case studies include the Southern California Association of Governments (SCAG) heavy-duty truck model in Los Angeles, the FASTruck model in Seattle, and the San Joaquin Valley truck model in central California. The SCAG heavy-duty truck model is described in detail later in this paper.

There are several deficiencies associated with hybrid models. The first is the conversion of commodity flows to truck trips, typically done by using national databases such as the Vehicle Inventory Use Survey (VIUS). This is problematic because the payload factors obtained through the VIUS are an average of all trucks in a state rather than specific averages for each of the TAZ’s in the model area. Another issue is that commodity flows are usually given as county-to-county, making it hard for hybrid models to capture trips that occur entirely within a county. Hybrid models also tend to overestimate truck trips due to the combination of separate models.

Due to the many combinations that can occur with hybrid models, it is hard to evaluate them except on a case-by-case basis. Despite the drawbacks associated with these models, they can often combine the strengths of different models in an attempt to make a more comprehensive freight model.

Economic Activity Models

Economic activity models combine an economic/land use model with a freight demand model to create a model that will be sensitive to changes in a region’s economic activity. This is done by creating a spatial I-O model that is built from socioeconomic data, economic activity data, land use data, and transportation network information. This data is broken down into TAZs. The Oregon Statewide Passenger and Freight Forecasting Model and the Cross-Cascades Model are cited as examples of this type of freight model and are reviewed by the Quick Response Freight Manual (QRFM) (8).

DATA SOURCES

There are a variety of data sources available for constructing freight models. The purpose of this section is to review a few of the current data sources and their applications in freight modeling.

Freight Analysis Framework 2 (FAF2)

The FAF2 is an O-D database that is maintained by the U.S. Department of Transportation’s Federal Highway Administration (FHWA). The FAF2 is a nation-wide commodity framework based upon data from the 2002 Commodity Flow Survey. According to the FHWA (9), the FAF2 estimates the tonnage and value of goods shipped by commodity type and mode. The FAF2 network consists of 114 zones, as well as 7 international trading regions. The FAF2 is often used as a data source for commodity-based freight models.

Land Use Scenario DevelopeR (LUSDR)

Gregor (10) states that LUSDR was developed for a study to accommodate future growth in the Rogue Valley of Oregon. The objectives of LUSDR are as follows:
• To develop a large set of land use patterns.
• To test the effects of alternative land use patterns on transportation systems.
• To identify the features of land use patterns that most effect transportation systems.
• To identify future needs of transportation networks.

LUSDR uses a stochastic micro-simulation approach to simulate future land use by households, employment establishments, and developments, all of which are broken down to the TAZ level to coordinate with transportation models. Nearly all of the models used for estimation in LUSDR involve the Monte Carlo process. LUSDR can be run simultaneously with transportation models to note how changes in land use and population affect the transportation system or how changes in the transportation system can affect future growth and land use.

Production, Exchange and Consumption Allocation System (PECAS)

The PECAS system has two component modules, as described by Hunt and Abraham. (11) The first module is the space development module, which represents the actions of developers in the provision of space. The area covered by PECAS should be organized into a set of land use zones that match those of the prospective model. Logit allocation models are used to determine the future changes in space. The model considers:

- Existing floor space and developed land
- Serviced vacant land
- Unserviced vacant land
- Derelict land

Logit models are used to determine the proportion of the space that will remain the same, become derelict, or transform into one of the other floor space/developed land categories. The model has a large amount of inertia built into space remaining the same so as to prevent an excessive amount of change from occurring.

The activity allocation module produces a production and attraction I-O table with variable technical coefficients included. Certain categories of activity produce commodities in the production table while consuming other commodities in the attraction table. The commodities considered by PECAS include goods, services, labor, and space (land use/floor space). A buying utility and a selling utility are influenced by prices at exchange locations within the zones, which produce the ultimate production/attraction data. Imports and exports are also considered in PECAS, which connects it to the world economy.

PECAS is currently being used in several modeling applications, including the statewide models for Ohio and Oregon and Sacramento’s regional model. One challenge associated with PECAS is model calibration. Model calibration is difficult due to the many coefficients whose values need to be determined. Adding to the difficulty is the fact that the interactions between the coefficients are complex and a large amount of data is required for the calibration and operation of the subsequent model.
Quick Response Freight Manual II (QRFM)

The QRFM (8) is designed to provide easy access to information for transportation planners. The QRFM begins with an overview of the controlling factors that add complexity to freight modeling. It reviews many of the simple growth factor methods that can be used to project freight models into the future. The QRFM also discusses modeling platforms, including four-step trip-based models, commodity-based models, hybrid approaches, and economic activity models. The trip- and commodity-based models were discussed previously in this paper. The hybrid and economic activity sections of the QRFM will be reviewed in this section.

The QRFM also provides a review of data sources and model validation methods. The data sources include commodity O-D tables, mode specific data, employment/industry data, and performance data.

FREIGHT MODEL APPLICATIONS

Boile et al. (12) provide a review of freight model applications prior to 2004, as well as a review of the methods used to estimate freight flow in those models. The subsequent section presents a brief description of some of the model applications that have followed.

Atlanta Regional Commission (ARC) Model

The ARC model (13) is a trip-based adaptable assignment model. An adaptable assignment model is designed to work backwards from truck count data to create a zone-to-zone matrix of trips, placing a great deal of importance on the accuracy of truck counts. Three vehicle classifications were used in the ARC model; commercial (2-axle, 4-wheel), medium (single-unit, 6+ tires), and heavy (truck + trailer). The model also identified truck zones, which were areas where truck activity was higher than standard rates would indicate. These areas included truck stops, warehouses, distribution centers, etc. The purpose of identifying truck zones was to capture the higher truck trip per employee rates likely to occur in those areas.

The ARC model factored trip generation for medium and heavy trucks according to area employment and type. External trips were factored using vehicle type and distance from nearest cordon. Roadway and vehicle type were used to decide the estimated percentage of through trips that would occur. Trip distribution coefficients were estimated by averaging trip length per vehicle type. Coefficient values were tested until the estimated trip lengths closely resembled observed counts.

Several factors were used to determine trip assignment, including:

- Separate assignments by time period.
- Accounting for truck-prohibited links.
- A time-penalty value for commercial vehicles.
- Assigning trucks to their own path and maintaining the volumes separately on the output network.
- Separate loading of through trips.

The ARC model also placed a special truck penalty on a particular link and used a special trip assignment technique for trucks whose path did not go within a specific perimeter.

The adaptable assignment approach was used to match the estimated truck volumes with observed volumes. The adaptable assignment approach created a new I-O table and subtracted it from the
original I-O table, producing a delta table. The delta values were added to the original table, and the process was repeated until the results closely matched the observed counts.

The strengths and weaknesses of the ARC model are given in the NCHRP Synthesis 384. (14) Accurate representation of current freight patterns, a model sensitive to changes in land use, and providing a framework for more sophisticated future models are listed as strengths. The weaknesses stated are an inability to forecast future activity due to its basis on past truck counts and a lack of connection to the world outside the metropolitan area.

**Calgary Commercial Vehicle Movement (CVM) Model**

The Calgary CVM model is a disaggregate hybrid approach that includes a tour-based micro-simulation. Stefan et al. (5) used external cordon surveys to note that 6% of all freight flows were made by heavy and medium vehicles passing through the region. The internal trip ends were assigned using a singly-constrained gravity model. Stefan et al. (5) also noted that roughly one-quarter of all freight trips were made by fleet allocators, such as taxis, garbage pickup, mail/courier service, police, etc. The fleet allocator model used an aggregate generation and a gravity distribution framework to distribute freight flows to the network.

The remaining trips were modeled using the tour-based micro-simulation. Several characteristics were considered in the micro-simulation. First, vehicles were separated into light, medium, and heavy categories. Light vehicles were single-unit commercial vehicles with 4 tires, medium vehicles were single-unit commercial vehicles with 6 tires, and heavy vehicles were multiple-unit commercial vehicles with more than 6 tires. Next, truck routes were modeled so that medium and heavy truck movements were restricted to arterials. Shortest paths were used when it was necessary to model medium and heavy trucks on secondary roads. Purposes were assigned to each trip, which included goods, services, other (all non-business), and return to establishment. Finally, companies were divided into five categories: private services, retail, industrial, wholesaling, and transportation.

The Calgary CVM model used several mathematical models to develop their micro-simulation. Each industry had a separate tour generation rate which was determined using a regression model with zonal attributes (land use, accessibility, etc.) included as independent variables. A Monte Carlo process was used to assign each tour a purpose and vehicle type. Another Monte Carlo process with sampling distributions based on observed start times was used to assign tour start times. The next step was using a next-stop-purpose model. In this model, the purpose and the travel time were considered to decide how many stops would be made and at what locations. Once the next-stop-purpose was determined, a Monte Carlo process with selection probabilities (determined using a logit model) was used to find the next-stop-location. Stop durations were then modeled with a separate logit-based Monte Carlo process.

According to Stefan et al. (5), the Calgary CVM model was calibrated to match the following sets of targets:

- Tour generation by industry and geography
- Tour length
- Vehicle type and tour purpose proportions
- Total trip destinations
- Number of trips within the morning, afternoon, and off-peak periods
Stefan et al. (5) credit the model’s responsiveness to policy changes and behavioral patterns as strengths. The stop duration and fleet allocator models were noted as areas with potential for improvement.

**Los Angeles**

The metropolitan area of Los Angeles has developed two separate freight models. Both models approach freight modeling differently. A brief review of each model is given in this section.

*Southern California Association of Governments (SCAG) Heavy-duty Truck Model*

The first Los Angeles freight model is a trip-based heavy-duty truck model maintained by SCAG. (15) The SCAG heavy-duty truck model was designed to forecast truck movements for the purpose of air quality conformity. The model considered three truck classes based on gross vehicle weight (GVW):

1. Light-Heavy Trucks: 8,500-14,000 pounds GVW
2. Medium-Heavy Trucks: 14,000-33,000 pounds GVW
3. Heavy-Heavy Trucks: 33,000+ pounds GVW

The North American Industry Classification System codes were used to divide the SCAG heavy-duty truck model’s socioeconomic data into TAZs.

Incoming and outgoing commodity flows were used to estimate external truck trips. Internal truck trips were estimated using daily shipping and receiving truck trip generation rates. The trip generation rates corresponded to the number of employees in each TAZ. Special truck trip generators, such as ports and airports, had separate truck trip tables designed to account for the increased truck traffic in those areas. Through truck trips were estimated using the observed traffic counts at external stations and commodity flow data.

*Los Angeles County Metropolitan Transportation Authority (LACMTA) Cube Cargo Model*

LACMTA is in the process of developing a commodity-based I-O model. This model is based on the Cube Cargo model software developed by Citilabs. (16) According to *NCHRP Synthesis 384* (14) the LACMTA Cube Cargo model requires the following input data:

- Zone-level socioeconomic and employment data
- Zone-to-zone modal travel times and costs
- Matrices of existing commodity flows

Once the required data is entered, the LACMTA Cube Cargo model trip generation step used regression models to estimate annual tons of commodities produced and consumed by TAZ. Each regression model had locally adjusted parameters. The LACMTA Cube Cargo model has special generators to represent externally generated commodities. The next step is trip distribution. Here the LACMTA Cube Cargo model allocated goods produced by commodity class to O-D matrices. The model then assumed that a percentage of goods (according to commodity class) would be short-haul and forego the mode choice model, which is used exclusively for long-haul goods. Gravity model parameters were calibrated by commodity class for both long- and short-haul flows, with the impedance being a linear
combination of time, distance, and cost by mode. The parameters were then weighted by mode choice coefficients.

The LACMTA Cube Cargo model then used a mode choice model to split the long-haul flows into modes. The mode choice models are multinomial logit choice models that were stratified by commodity and distance. The models use travel time and cost as coefficients and were calibrated using observed data.

The LACMTA Cube Cargo model separates flows into direct flows and transport chain flows through the use of a transportation logistics nodes (TLN) model. The TLNs are defined and located by the user, as are the areas served by the TLNs. The TLN model created an O-D matrix that separates long-haul direct, long-haul to and from TLNs, and short-haul to and from TLNs by mode and commodity class. A socioeconomic-derived nesting and weighting process then redistributed commodity flows from larger areas to TAZs via gravity models. A service model was used to represent truck trips characterized as urban service trips. Regression models based on zone type or socioeconomic data perform trip generation. Gravity models then distributed those trips to the network.

The LACMTA Cube Cargo model has two vehicle trip models, a standard model representing direct shipments to and from O-Ds and a touring model estimating delivery tours. Due to the mathematical intensity of the touring models, these are typically only used in TAZs selected by the user.

**North Carolina Statewide Truck Model**

The North Carolina statewide truck model created by Stone et al. (17) for the North Carolina Department of Transportation is a commodity-based model that was developed using TransCAD software. Data for the model was taken from the FAF2. The Fratar method was used to estimate growth from the 2002 base year of the FAF2 to the 2006 base year of the model.

The model was broken into a total of 357 TAZs covering the entire United States, with most of the TAZs concentrated in and around the state of North Carolina. In rural areas in North Carolina, counties were used as TAZs. In metropolitan areas of North Carolina, the TAZs were broken down into sub-county regions. Stone et al. (17) gave several rules for developing metropolitan TAZs.

- Use major routes as boundaries.
- Use census tracts in urban areas as TAZs.
- Natural features are often used as TAZ boundaries.
- Downtown areas comprise separate TAZs, except larger cities, where downtowns can comprise several TAZs.

A buffer area of county TAZs in neighboring states was used to disperse external truck traffic to the rest of the United States. The rest of the nation was divided into 176 TAZs, which coincided with Bureau of Economic Analysis (BEA) districts.

The roadway network was based upon the 2005 version of the National Highway Planning Network (NHPN). The NHPN consists of Interstates, U.S. Highways, and some roads. All outside traffic was restricted to the interstates, with the buffer TAZs acting as connectors between the highways and roads within North Carolina and the Interstate system. Average speeds inside North Carolina were assigned to the roads using the typical travel speed factors based on functional class of roadway, speed limit, number of lanes, and terrain type within the state. All travel speeds outside of North Carolina were assumed to be 70 mph on the Interstate and 55 mph on U.S. Highways.
The data for areas outside North Carolina had to be aggregated from the county-level data given by the FAF2 to the BEA-level data needed for the model. For metropolitan areas within the state, the FAF2 data had to be disaggregated into TAZ levels by using employment data taken from TransCAD. Due to the commodity-based nature of the model, it was necessary to calculate empty truck trips separately. This was done by adding an additional 30% of trips to the original FAF2 matrix and using the Fratar method to balance the O-D pairs. Another issue addressed by this model was short haul trips. Short-haul trips were estimated by obtaining employment records from the North Carolina Employment and Security Commission and using that data for the trip assignment and distribution steps. Stone et al. (17) note that the data suffered from the “headquarters problem”, which centralized employees from where their paychecks are issued rather than from where they work.

The three-step model approach was used to assign trips to the network. Trips were generated by assigning productions and attractions. Gravity models were then used to distribute those trips within the TAZs. Finally, network assignment was accomplished using a stochastic assignment method. Each O-D pair had multiple routes on which trips could occur. The routes were assigned probabilities through a logit choice model based upon the travel times of each path.

The North Carolina model was calibrated on the system-wide, regional, and link levels. At the system level, the model volumes and trip lengths were checked for accuracy against observations. Regional level calibration occurred through the matching of observed volumes with model volumes at cordon and screen lines. The link level calibration was done by matching the model volumes on certain arterial roads with observed volumes at the same locations.

**SUMMARY AND CONCLUSION**

Tavasszy (7) states that the general trends in freight modeling are increasingly integrative treatment of various decisions made by firms and increasing detail in the behavioral content of models. Yang et al. (18) also predict that the future in freight modeling will see more hybrid models that combine the positive attributes of different model types, depending upon resource constraints and data modeling needs. Regardless of the approach, it is essential that more importance be placed on the development of freight models with the rapid growth of freight transport occurring worldwide. The complexity of freight movements requires more detailed data collection and in-depth models in order to provide more accurate representation of freight movements. This paper has attempted to gather some of the current resources available to freight modelers so that they can build the increasingly complex freight models of the future.
REFERENCES


