Effectively Using the QRFM to Model Truck Trips in Medium-Sized Urban Communities

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University Transportation Center for Alabama
The University of Alabama, The University of Alabama in Birmingham,
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16. Abstract

This report analyzes the effectiveness of applying the Quick Response Freight Manual (QRFM) to model freight transportation. Typically freight transportation is modeled indirectly or as an after-thought. Increasing freight volumes, coupled with cost-saving strategies such as just-in-time delivery systems, require that transportation policymakers analyze infrastructure needs and make investment decisions that explicitly include freight volumes as a component. This paper contains a case study using a travel model for a medium-sized urban area and the QRFM trip-generation and distribution methodology to provide a framework for freight planning that can be used to improve resource-allocation decisions.

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Contents

Contents iv
List of Tables v
List of Figures v
Executive Summary vi

1.0 Introduction 1

2.0 Transportation Planning Background and Freight Specifics 2

3.0 Case Study: Huntsville, Alabama 4

4.0 Statistical Analysis 6

5.0 Implementation, Conclusion, and Recommendations 10

6.0 References 11

List of Tables

Number Page

2-1 Trip-generation rates from the QRFM 3

4-1 Freight locations for Mobile, AL 7

List of Figures

Number Page

2-1 Friction factors from the original QRFM 3

3-1 Huntsville, AL planning model 4

3-2 Freight trips versus non-retail employment 5

4-1 Scatter plot of truck traffic 6

4-2 Scatter plot of truck traffic with distribution modification 8

Executive Summary

Freight is a critical component in the transformation and growth of the economy, and knowledge of the freight volumes on the existing transportation infrastructure is vital to maintain growth. Planning models are used for forecasting traffic volumes to evaluate changes in roadway infrastructure in response to growth. In small- and medium-sized urban communities, proper roadway infrastructure resource allocation decisions based on traffic-volume projections obtained from the community's planning model could be the determining factor between continued community growth and stagnation. Unfortunately, freight transportation is often not included in planning models maintained in smaller communities. An option for smaller communities is to use the Quick Response Freight Manual (QRFM) trip-generation equations to ensure freight data are included.

This report demonstrated that the trip-generation equations from the QRFM can accurately replicate freight volumes if correctly applied. The application depends on the use of an appropriate trip distribution method that accounts for freight movements entering and leaving the study area. The ability to successfully model freight in an urban area can be used to overcome the limitation of neglecting freight in travel-demand modeling.

Section 1
Introduction

The efficient and effective movement of freight is a critical component in the transformation and growth of the economy. Often transportation planners use urban transportation planning models, which are representations of the existing transportation infrastructure, to determine the impact of future changes. These planning models are developed and validated to reflect existing traffic volumes and patterns. After validation, the models are used to forecast daily traffic volumes on primary arterials and freeways and to evaluate the effect of changes in roadway infrastructure and socioeconomic characteristics. In small- and medium-sized urban communities, proper roadway infrastructure resource allocation decisions based on traffic volumes projections obtained from the community's travel-demand model and long-range transportation planning process could be the determining factor between continued community growth and stagnation.

Since the modeling process is important, it is critical that the models used provide the best forecasts. Unfortunately, freight-transportation requirements often are either ignored by the travel-demand models used in small communities or are included through simplified methodologies.

This report examines the potential to use available freight trip generation factors and a distribution scheme to determine freight transportation demand appropriate for incorporation into a community travel-demand model. First, the report presents background into travel-demand forecasting and the Quick Response Freight Manual (QRFM) trip-generation equations (Cambridge 1996, Cambridge 2007). Next, the report applies the model through a case study of Huntsville, AL, a medium-sized community in the north-central portion of the state. A statistical analysis of the QRFM technique is applied to the network using a variety of distribution schemes to improve its forecasting ability. The report concludes that the proper incorporation of freight-transportation needs into travel-demand modeling can improve results and should lead to improved investment decisions for the community.

Section 2
Transportation Planning Background and Freight Specifics

The background for this report is the traditional four-step modeling process used in most small- and medium-sized urban areas and the specifics of that process that deal with freight. The traditional transportation-planning process follows a sequential four-step methodology: trip generation, trip distribution, mode split, and traffic assignment. The first step in the process, trip generation, uses socioeconomic data aggregated by traffic-analysis zones to determine the number of trips produced by and attracted to each zone in the study area (Ortuzar and Willumsen 1994). For passenger transportation, the factors that can influence trips produced from or attracted to a zone are household income and size, automobile ownership, type of businesses, and trip purpose (Ortuzar and Willumsen 1994). Trip generation then converts these zone data values into trip purposes. However, in most small- and medium-sized urban communities, there is no model developed for freight productions or attractions since it is time consuming and costly to survey businesses and manufacturers on their freight requirements. The lack of a model for including freight trips into the trip-generation process leads to a loss of potential trips, essentially leading to a traffic model that is producing incorrect assignments and possibly leading to infrastructure-investment decisions that do not take freight needs into account.

Trip distribution connects trip origins and destinations for the development of a trip-interchange matrix. The two main factors considered are trip length and travel direction (or orientation). The most common method used for trip distribution is a gravity model, which is based on Newton's law (Ortuzar and Willumsen 1994). The gravity model predicts that trip interchanges between zones are directly proportional to the productions and attractions in the zones and inversely proportional to the spatial separation between zones (Ortuzar and Willumsen 1994). In other words, zones with more activities or businesses are more likely to exchange more trips, and zones with longer distances between them are likely to exchange fewer trips. For freight, it is expected that the trip distribution would be similarly performed.

Modal split is used to estimate how many trips will use public transit and how many trips will use private vehicles, typically using a logit model (Ortuzar and Willumsen 1994). This step of the process is generally ignored in small- and medium-sized communities, as transit ridership is not significant. For freight, this step would contrast truck versus alternative modes of shipment (rail, water, and air) and therefore it is not included as there is limited availability for alternate freight shipping modes within medium-sized communities, most freight is shipped by truck.

Traffic from the modal split analysis is then assigned to available roadways or transit routes using Waldrop's equilibrium theorem, or some approximation of equilibrium. By this theory, under equilibrium conditions traffic arranges itself in congested networks in such a way that no

individual trip maker can reduce his path costs by switching routes (Ortuzar and Willumsen 1994). Regarding freight, it is not necessarily logical to assume freight shipments will likely change their route due to congestion effects, at least not off the major roadways within the communities.

To overcome the absence of freight in transportation models, and as limited studies have been performed attempting to incorporate freight into the modeling process, the original Quick Response Freight Manual (QRFM) and its updated version QRFM II were prepared for the Federal Highway Administration (Cambridge Systematics Inc. 1996, Cambridge Systematics Inc. 2007). The objective of the reports was to provide background information on the freight-transportation system and factors affecting freight demand to planners who may be relatively new to the inclusion of freight planning and to provide simple techniques and transferable parameters that can be used to develop commercial-vehicle trip tables that can then be merged with passenger-vehicle trip tables developed through the conventional four-step planning process. The QRFM report identifies trip-generation factors that define production and attraction values manageable within a small community. To support trip distribution, the QRFM provides a series of friction factors that can be incorporated into the gravity model to specify the expected length of freight movements. Table 2-1 provides the trip-generation rates and Figure 2-1 the friction-factor equations.

Table 2-1. Trip-generation rates from the QRFM

Generator	Commercial Vehicle Trip Destinations (or Origins) per unit per Day			
	Four-Tire Vehicles	Single Unit Trucks (6+ Tires)	Combinations	TOTAL
Employment				
• Agriculture, Mining and Construction	1.110	0.289	0.174	1.573
• Manufacturing, Transportation, Communications, Utilities and Wholesale Trade	0.938	0.242	0.104	1.284
• Retail Trade	0.888	0.253	0.085	1.206
• Office and Services	0.437	0.068	0.009	0.514
Households	0.251	0.099	0.028	0.388

Source: Cambridge Systematics, Inc. (2007)

Four-tire commercial vehicles:

$$F_{ij} = e^{-0.08 * t_{ij}}$$

Single unit trucks (6+tires):

$$F_{ij} = e^{-0.1 * t_{ij}}$$

Combinations:

$$F_{ij} = e^{-0.03 * t_{ij}}$$

(Source: Cambridge Systematics, Inc. 2007)

Figure 2-1. Friction factors from the original QRFM

Section 3
Case Study: Huntsville, Alabama

Huntsville, Alabama, with a population of approximately 300,000, was selected as a case study to analyze the incorporation of freight into the modeling process. For this research, the data on the transportation network for the City of Huntsville was acquired from the Huntsville Metropolitan Planning Organization (MPO); see Figure 3-1 (Huntsville MPO 2007).

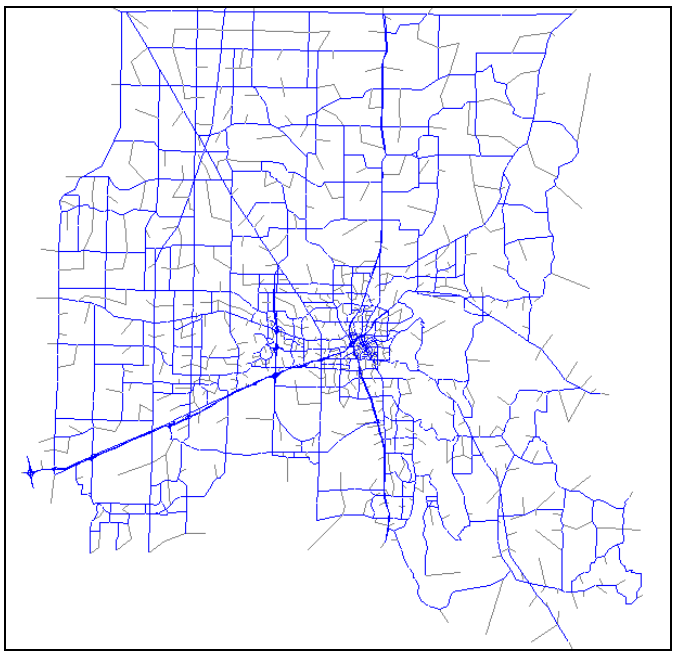

Figure 3-1. Huntsville, AL planning model

The research was performed by applying the trip-generation rates obtained from the QRFM to the socioeconomic data collected by the Huntsville MPO. The data collected by the Huntsville MPO were aggregated to one of the 508 traffic-analysis zones for the area and included household, average income for the households, school enrollment, and employment. The employment was classified as either retail employment or other employment, where retail employment is defined as the number of employees where the business is expected to operate in similar fashion to a retail establishment, essentially those with high turn-over throughout the day. Due to the nature of the employment data available, the distribution of employees for each category as defined by the QRFM was used in the analysis. For each zone, the socioeconomic data previously identified were converted into freight trips using the rates provided by the QRFM. A visual validation of the results from the trip-generation model as they relate to the total non-retail employment in the study city was performed by developing a thematic map

showing the amount of non-retail employment within each traffic-analysis zone overlaid with a dot density plot of the freight trips (see Figure 3-2). The figure indicated that the QRFM freight trips were located in areas of higher non-retail employment, as these employers represent the manufacturing industry are likely to have a greater number of freight shipments comprised of raw materials and finished goods. This result was expected and validated the use of the QRFM model in the planning process.

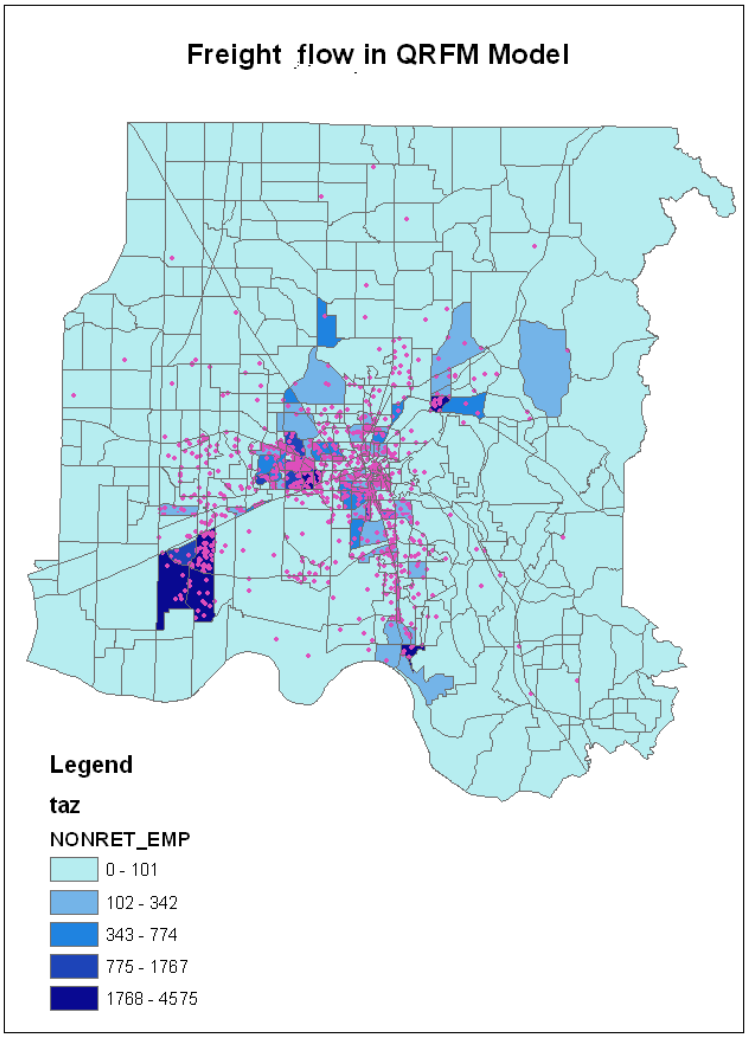

Figure 3-2. Freight trips versus non-retail employment

The Huntsville model was based on trip generation, distribution, and assignment. As is common in planning studies, this model uses the static traffic assignment technique. The rationale is that it mirrors the modeling system used in the community and approved by the state for transportation-forecasting processes. This ensured that the model would be accepted upon development of a successful application. Though not used, the analysis could have benefitted by employing dynamic traffic assignment techniques—such as those available in PARAMICS, VISSUM, or VISTA—that have the capability to move vehicles through the network using car-following and lane-changing models (Jeihani 2007).

Section 4
Statistical Analysis

An analysis of the model for calculating truck trips was performed by developing freight-trip purposes and designing a series of travel modules to perform trip distribution and to assign freight trips to roadways in the network. Initially, the trips produced and attracted were distributed using a gravity model that treated truck trips similarly to passenger trips by distributing freight trips to zones within the study area. Truck counts at external stations in the model were included as a separate trip purpose and distributed between these stations. For traffic assignment, the freight trips were assigned to the network without the presence of passenger cars using the shortest-path algorithm, where all trucks were assumed to take the shortest travel time path through a network. This algorithm limits the number of trucks assigned to local roadways due to the slow travel speeds on these roadways, a result that could also have been obtained with an impedance function. Though the possibility exists for some trucks to be assigned to local roadways, the number of such trucks is assumed to be minimal.

The accuracy of the assignment of truck volumes was determined by comparing the assignment results to the actual truck volumes reported by the Alabama Department of Transportation (ALDOT). The first comparison used a scatterplot of actual truck traffic volume versus traffic volumes from the QRFM. Figure 4-1 shows that there is no clear relationship between the QRFM results and the actual freight counts in Huntsville using the 100% internal distribution.

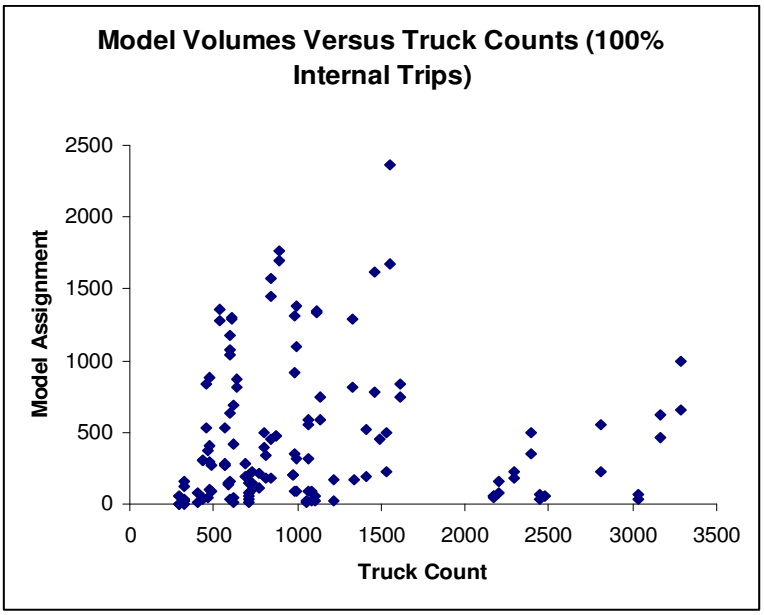

Figure 4-1. Scatter plot of truck traffic

To statistically measure the difference between the assigned truck traffic and actual truck counts, the Nash-Sutcliffe (NS) coefficient was calculated (Nash and Sutcliffe 1970). The value of this coefficient ranges from -∞ to 1, with a coefficient of one ($E = 1$) showing a perfect match of forecasted counts to the ground counts. A coefficient of zero ($E = 0$) shows that the forecasted values are as accurate as the mean of the ground counts, whereas a coefficient less than zero ($-\infty < E < 0$) occurs when the forecasted mean is less than the ground counts. In other words, this coefficient gives a measure of scatter variation from the 1:1 slope line of modeled truck counts versus the ground counts. The more the points deviate from the 1:1 slope line, the lower the coefficient is. The greater the NS-value, the better the forecast is. This coefficient can be calculated using the formula:

$$\text{NS-Coefficient} = 1 - \frac{\sum_1^n (ModeledCounts - GroundCounts)^2}{\sum_1^n (GroundCounts - MeanGoundCounts)^2}$$

The application of the Nash-Sutcliffe test to the data gave an efficiency coefficient of -1.45, showing that taking the average value of the truck counts from ALDOT would better predict truck flows than the travel-demand model.

Further statistical tests were performed to determine whether the data obtained from the travel-demand model were similar to actual truck counts. The MINITAB™ statistical software was used to conduct the analysis of variance (ANOVA) test. The results provide statistical evidence to suggest that actual truck volumes are different from the volumes assigned by the model.
To improve the results, an alternate trip distribution method was employed. This method was developed from the results of a study being done in Mobile, Alabama (Thompson, *et al.* 2010). The flow patterns collected from the Mobile area in Table 4-1 show that external-internal (E-I) truck trips and internal-external (I-E) truck trips represent over 80% of the total truck volumes, while the internal–internal (I-I) truck trips account for less than 20%. This implies that approximately 80% of the raw materials for manufacturing are generated outside the area and that approximately 80% of the finished products are exported to points outside the area.

Table 4-1. Freight locations for Mobile area

Freight Origin/Destination Location	Origins	Destinations
Within Mobile County	14.5%	16.4%
Outside Mobile County	84.5%	80.7%
Local Port	1.0%	2.8%

To account for changes in truck distribution in the model, the modules used to run the Huntsville MPO travel-demand model were adjusted to account for freight trips distributed into the community from outside (E-I) and out of the community to points beyond the study area (I-E). An experiment was designed to include four trip-distribution levels:

- 90% (E-I and I-E) and 10% (I-I),
- 80% (E-I and I-E) and 20% (I-I),
- 70% (E-I and I-E) and 30% (I-I), and

- 60% (E-I and I-E) and 40% (I-I).

The reason for not simply using the 80% E-I and I-E found in the Mobile project is the uncertainty that Huntsville would perform similarly as Mobile, due to socioeconomic differences between the two communities and the influence of the Port of Mobile.

The E-I and I-E truck trip distributions were developed using the total number of trucks crossing the study area boundary. The total number of trucks at the boundaries was split by percentage into the number of trucks expected to enter and leave the community (E-I and I-E) and the number of trucks passing through the community. Parameters in the gravity model were set to constrain the E-I and I-E truck numbers such that the total number of trucks at the external stations did not exceed boundary conditions. A separate gravity model, which used the modeling details for the City of Huntsville, was used for the internal truck trips that included a reduction factor to limit the number of trips. As before, mode split was not included in the model, and truck trips were assigned to the Huntsville network without passenger cars to allow truck access to the major roadways.

A scatter plot was drawn to compare actual truck count and the trucks assigned from the model for each percentage split. A scatter plot for the 80% E-I and I-E with 20% internal trips is shown in Figure 4-2. The results appear to align much closer to the 1:1 slope with the trip-distribution adjustment.

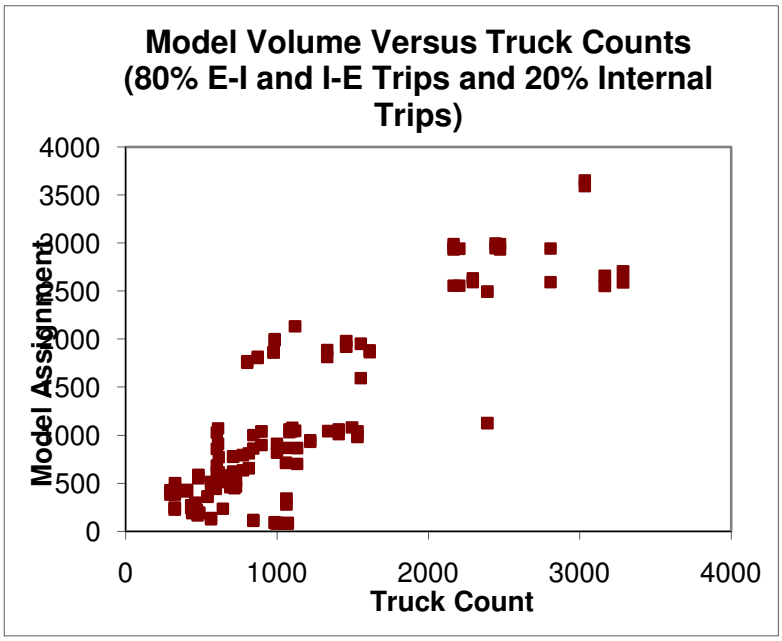

Figure 4-2. Scatter plot of truck traffic with distribution modification

For comparison, the Nash-Sutcliffe efficiency coefficient was calculated for each trip distribution split. The results follow:

- NS Coefficient=0.59 for the 90% (E-I and I-E) and 10% (I-I),
- NS Coefficient=0.61 for the 80% (E-I and I-E) and 20% (I-I),

- NS Coefficient=0.62 for the 70% (E-I and I-E) and 30% (I-I), and
- NS Coefficient=0.61 for the 60% percent (E-I and I-E) and 40% (I-I).

As these results show, there is little difference between the models. However, all the models show significant improvements over the 100% internal distribution.

Further statistical tests were performed to determine if the data obtained from the travel-demand model were similar to actual truck counts. MINITAB™ Statistical Software was used to analyze the data and to perform analysis of variance (ANOVA). The results showed no statistical evidence that actual truck volumes are different from the volumes assigned by the model. Further, using the non-parametric Mann-Whitney test, it was found that that the QRFM data likely come from the same population as the actual data.

The implementation of the methodology would require that smaller communities develop a truck trip purpose using the QRFM equations. However, the resulting truck values need to be converted into internal truck trips and internal-external and external-internal truck trips based on the percentage of trips expected to leave the study area. Then the two purposes need to be included into the modeling process.

Section 5
Implementation, Conclusion, and Recommendations

The implementation of the methodology would require that smaller communities develop a truck-trip purpose where the number of trucks expected to be produced or attracted to a traffic-analysis zone was calculated using the QRFM equations and the employment and household data associated with each zone. The data to perform this generation of truck trips should be available, as almost all smaller community planners collect these basic data for modeling passenger trips in their study areas.

After collecting the data, the percent split between internal truck trips and internal-external and external-internal truck trips need to be determined. It is recommended that transportation professionals start with a value that approximates between 70 percent and 80 percent of the trips having one end of the trip outside the study area, with the higher value being used for communities with a greater percentage of distribution activities in the area. Then, the two truck-trip purposes—internal-internal and internal-external—need to be included in a basic distribution step similar to the gravity model used in this paper. It is recommended that the user evaluate the percent-split decision based on actual truck assignment to determine adjustments to the percent for calibration to actual conditions. Once calibrated, the forecast model that is to be used to evaluate investments in transportation infrastructure can be modified in a similar fashion, with socioeconomic data representing the horizon year of the model. This will allow for the explicit modeling of truck traffic in the community for the forecast year, thus potentially improving output from the model and allowing for more accurate decisions.

This report demonstrated that trip-generation equations from the QRFM, when calculated using socioeconomic data from a medium sized travel-demand model, can accurately reflect the locations where truck trips are likely to originate or terminate inside a community. Secondarily, this report showed that the use of an appropriate trip-distribution method that accounts for freight movements entering and leaving the study area produces an accurate forecast of trucks on existing roadway infrastructure, where the percentages to use will be based on varying the data and determining the best fit or using the recommended values presented in this report. This ability to successfully model freight in an urban area can be used to overcome the limitation of neglecting freight in travel-demand modeling processes.

Section 6
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