

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

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ABSTRACT

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

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 in order to determine the impacts of future changes. These planning models are developed and validated to reflect existing traffic volumes and patterns. After validation, the models are used for forecasting daily traffic volumes on primary arterials and freeways and evaluate changes in roadway infrastructure and socio-economic characteristics. In small and medium sized urban communities, proper roadway infrastructure resource allocation decisions based on data obtained from the community's travel demand model and long-range transportation planning process could potentially be the determining factor between the continued community growth or stagnation.

With the level of importance of the modeling process, it is critical that models provide the best forecasts of future conditions. Unfortunately, freight transportation requirements are often not included in travel demand models developed and maintained in small communities, or else, freight trips are included in these models through very simplified methodologies.

This paper 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 paper presents background into travel demand forecasting and the Quick Response Freight Manual (QRFM) trip generation equations (Cambridge 1996, Cambridge 2007). Next, the paper 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 applied to the network using a variety of distribution schemes improves the forecasting ability. The paper concludes that the proper application of freight transportation needs into the travel demand modeling process can produce improved model results, which should lead to improved investment decisions for the community.

TRANSPORTATION PLANNING BACKGROUND AND FREIGHT SPECIFICS

The background for this paper focuses on the traditional four step modeling process used in most small and medium sized urban areas and specifics of the process that deal with freight. The traditional transportation planning process follows the sequential four-step methodology: trip generation, trip distribution, mode split, and traffic assignment. The first step in the process, trip generation, uses socio-economic data,

aggregated to 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, 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). The trip generation step then converts these zonal 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 specific freight requirements.

Trip distribution connects the trip origins and destinations for the development of a trip interchange matrix. The two main factors considered are trip length and the 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 activity or businesses are more likely to exchange more trips, and zones with greater 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). However, this step of the process is generally ignored in small and medium sized communities, as transit ridership is not significant. With freight however,

this step would contrast truck versus alternative mode of shipment (rail, water, and air) and therefore is significant. As limited availability for alternate freight shipping models often exists in medium sized communities, this step is still not included.

Traffic is then assigned to available roadways or transit routes, following Waldrop's equilibrium theorem, or some approximation of equilibrium, determining the amount of traffic to allocate to each route. 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, the original Quick Response Freight Manual (QRFM) and updated version QRFM II, were prepared for the Federal Highway Administration (Cambridge 1996, Cambridge 2007). The objective of the reports were 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 which 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. Figure 1 provides the trip generation equations and Figure 2 presents the friction factor equations.

CASE STUDY: HUNTSVILLE, ALABAMA

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

The research was performed by applying the trip generation rates obtained from the QRFM to the socio-economic data collected by the Huntsville MPO. For each zone, the socio-economic data were converted into freight trips using the rates provided from the QRFM. A visual validation of the trip generation model results as they related 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 4).

The operation of the Huntsville model is as described previously and the model followed the traditional generation, distribution, and assignment pattern. It is important to note that the Huntsville model used a static assignment technique, often used in planning studies. The analysis may have benefitted by the use of 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).

STATISTICAL ANALYSIS

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 plus assigning the freight trips to roadways in the model network. Initially, the trips produced and attracted were distributed using a gravity model approach that treats the trips similar to other passenger related trip purposes in the model. Essentially, the freight trips produced in the study area are distributed to zones within the study area. Truck counts at external stations in the model were included as a separate trip purpose and distributed between themselves. For assignment, the freight trips were assigned to the network without the presence of passenger cars using a shortest path assignment technique where all truck were assumed to take the shortest travel time path through the network. This assignment technique was used to limit the number of trucks that would be assigned to local roadways. Ideally, an impedance function would have been placed on these roadways to restrict truck movement, however, the shortest path assignment technique provided an alternative that effectively restricted trucks on the local roads as the slow travel speed for these roadways, versus the higher functionally classified roadways in the community, effectively eliminated them from being on shortest path between origin/destination locations. The possibility exists for some trucks to be assigned to local roadways, however, the number of these trucks is assumed to be minimal.

Accuracy of the assignment of truck volumes was established by analyzing the model assignment versus actual truck volumes as reported by the Alabama Department of Transportation (ALDOT). The first examination included the development of scatter plot

with actual volume of trucks versus the QRFM assigned model volumes. The scatter plot is shown in Figure 5.

To statistically measure the difference between the model assignments using the QRFM trip generation methodology and the actual truck counts, the Nash-Sutcliffe (NS) coefficient was employed (Nash and Sutcliffe 1970). The Nash-Sutcliffe value can range from $-\infty$ to 1. A coefficient of one ($E=1$) corresponds to a perfect match of forecasted counts to the ground counts. A coefficient of zero ($E=0$) indicates 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 values. In other words, this coefficient gives us a measure of scatter variation from the 1:1 slope line of modeled truck counts versus the ground counts. The more deviation of points from the 1:1 slope line, the lower the coefficient. The greater the NS-value is the better the forecast. It can be calculated using the formula:

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

The result of applying the Nash-Sutcliffe test to the data from the Huntsville, Alabama case study generated an efficiency coefficient of -1.45. The negative value indicates that taking an average value of the truck counts from ALDOT would actually be a better prediction of the 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 the actual truck counts. The MINITAB™ statistical software was used to analyze the data employing the analysis of variance

(ANOVA) test and resulted in the conclusion that there is statistical evidence to suggest that actual truck volumes are different from the model assigned volumes.

In an effort to improve the results, an alternate trip distribution scheme was employed. This scheme was developed from the results of a study being performed in the Mobile, Alabama community (add Reference). The flow patterns collected from the Mobile area are shown in Table 1.

From Table 1, it can be seen that the External-Internal (E-I) truck trips and Internal-External (I-E) truck trips represent over 80 percent of the total truck volume in Mobile, while the Internal-Internal (I-I) truck trips accounted for less than 20 percent. This implies that approximately 80 percent of the raw materials for the manufacturing of the finished goods are generated outside the area and approximately 80 percent of the finished products are exported outside the area.

To account for the distribution changes 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, and outward from the community to points beyond the study area. An experiment was designed to include the adjustments made at four different distribution levels:

- 90 percent (E-I and I-E) and 10 percent (I-I),
- 80 percent (E-I and I-E) and 20 percent (I-I),
- 70 percent (E-I and I-E) and 30 percent (I-I), and
- 60 percent (E-I and I-E) and 40 percent (I-I).

The reason for not simply applying the 80 percent (E-I and I-E) found in the Mobile project was the uncertainty that Huntsville would perform similarly as Mobile due to socio-economic differences in the communities and the influence of the Port of Mobile. Therefore, other distributions were included in the experiment.

The E-I and I-E truck trip implementation was 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 derived 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 was performed for the internal truck trips, but with a reduction factor used to limit the number of trips. As before, mode split was not included in the model and the truck trips were assigned to the Huntsville network without passenger cars to allow truck access to the major roadways.

A scatter plot was developed to compare actual truck count versus the trucks assigned from the model for each percentage split. A scatter plot for the 80 percent E-I and I-E with 20 percent internal trips is shown in Figure 6. As can be seen, the results appear to align much closer to the 1:1 slope with the trip distribution adjustment.

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

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

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

As these results show, there is little difference between the models, however all model demonstrate significance improvement versus the 100 percent 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™ was used to analyze the new data using analysis of variance (ANOVA) test. The results show that there is no statistical evidence to suggest that actual truck volumes are different from the model's assigned volumes. Further, performing a Mann-Whitney non-parametric test shows that it is likely that the QRFM data comes from the same population as the actual data.

CONCLUSION AND RECOMMENDATIONS

This paper demonstrated that trip generation equations from the QRFM, when calculated using socio-economic data from a medium sized travel demand model, can accurately reflect the locations where truck trips are likely to originate/terminate inside a community. Secondly, this paper demonstrated that the use of an appropriate trip distribution scheme that accounts for freight movements entering and leaving the study area can be used to produce an accurate forecast of truck onto existing roadway infrastructure. This ability to successfully model freight in an urban area can be used to over-come the limitation of neglecting freight in travel demand modeling processes, or of only including freight in an implied methodology.

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Table 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%

Figure 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

(Daniel Beagan, Michael Fischer, Arun Kuppam, Quick Response Freight Manual II, FHWA-HOP-08-010 EDL No. 14396, September 2007.)

Figure 2. Friction factors from the original QRFM

Four-tire commercial vehicles: $F_{ij} = e^{-0.08 * t_{ij}}$ Single unit trucks (6+tires): $F_{ij} = e^{-0.1 * t_{ij}}$ Combinations: $F_{ij} = e^{-0.03 * t_{ij}}$

(Daniel Beagan, Michael Fischer, Arun Kuppam, Quick Response Freight Manual II, FHWA-HOP-08-010 EDL No. 14396, September 2007.)

Figure 3. Huntsville, AL planning model.

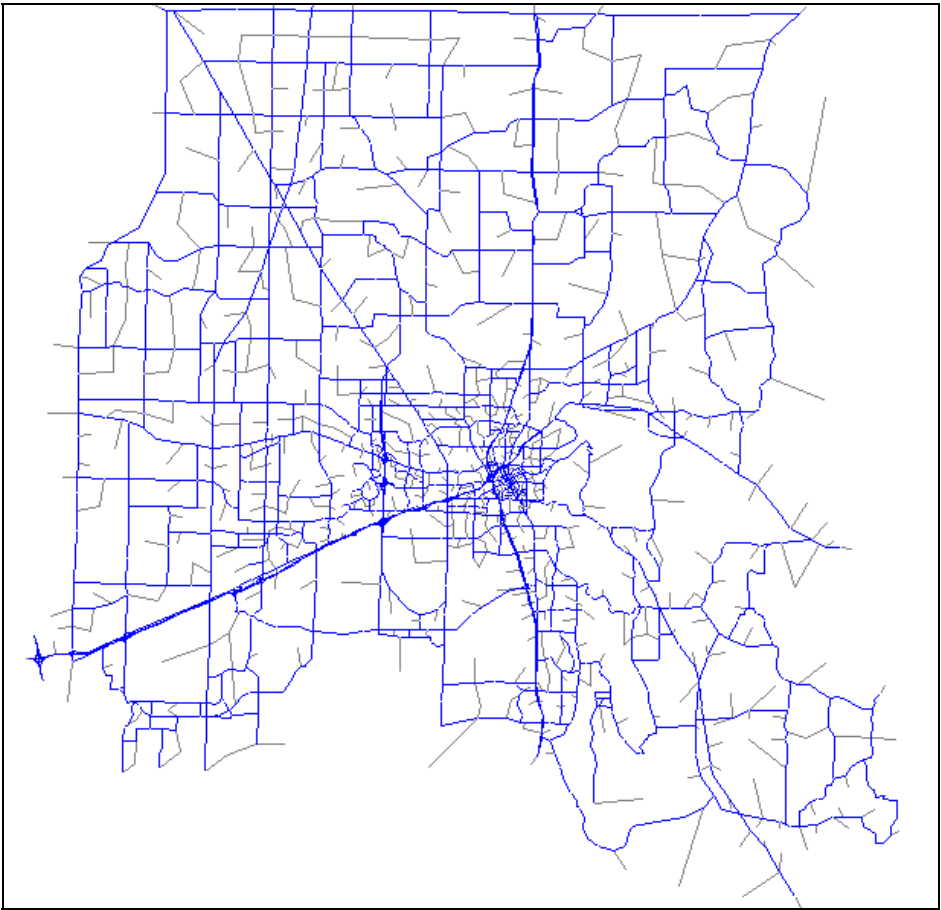


Figure 4. Freight trips versus non-retail employment.

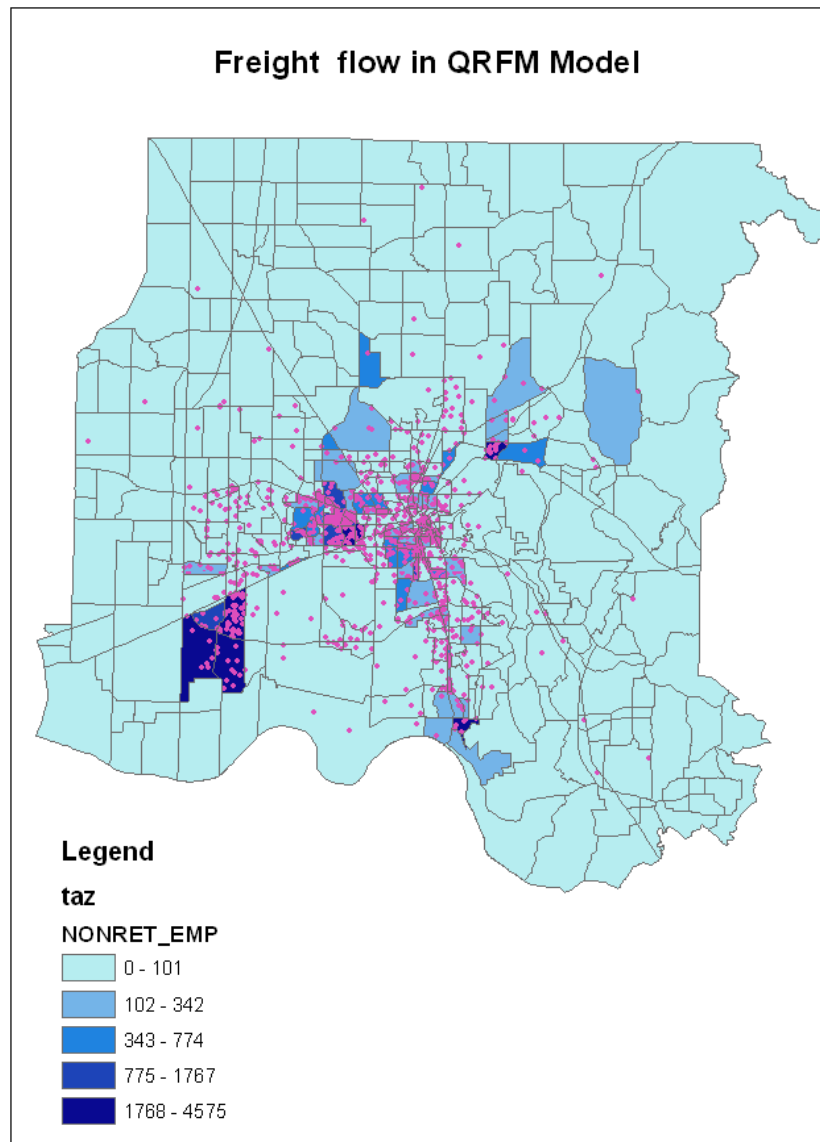


Figure 5. Scatter plot of truck traffic.

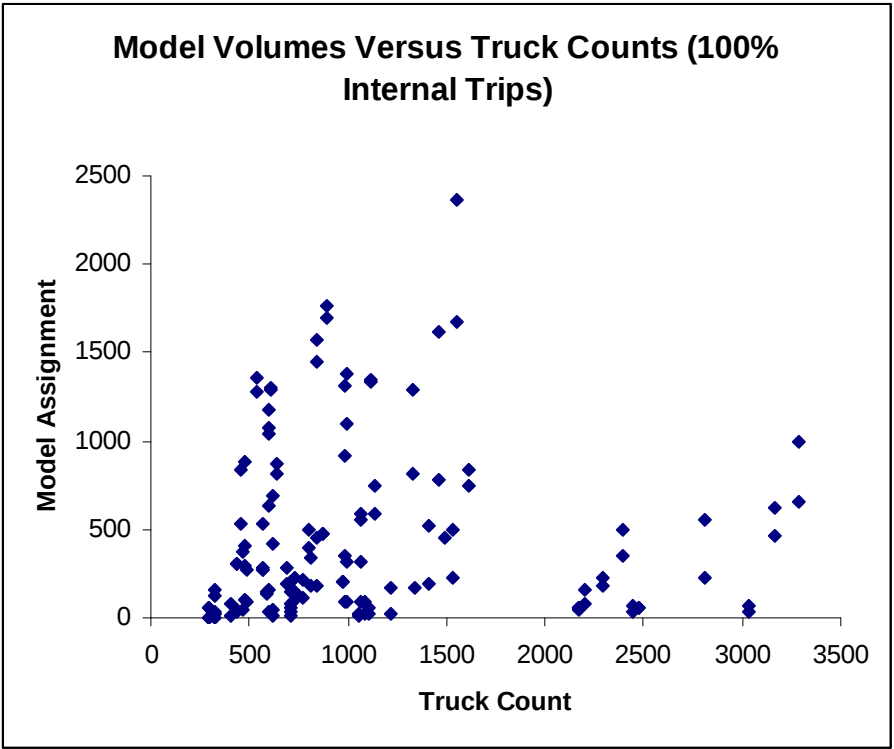


Figure 6. Scatter plot of truck traffic with distribution modification.

