International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 5 Issue 11|| November 2016 || PP. 45-51

Modeling Truck Movements: A Comparison between the Quick Response Freight Manual (QRFM) and Tour-Based Approaches

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Abstract: *In recent years, with a growing realization of the important impacts of truck traffic on the economy as well as urban congestion and pollution levels, there is a keen interest in modeling truck movements with greater accuracy, robustness, and detail. This paper examines two different approaches for explicitly including truck trips into travel demand forecasting models. The approaches considered are (a) the truck modeling methodology published in the Quick Response Freight Manual (QRFM) and (b) an emerging truck tour-based approach. In this paper, the two approaches are demonstrated and compared using the Birmingham, AL region as a case study and statistical analyses are conducted to evaluate the level of accuracy of both approaches. The results demonstrate that the model using tour-based approach performs better than the one based on the QRFM approach with respect to model accuracy, when compared to field data from the study area. However, the tour-based approach requires a comprehensive data collection and processing effort, whereas the QRFM approach uses the publicly available data such as household and employment data. The decision on the best approach for adoption should be made on a case-by-case basis after considering the tradeoffs between accuracy and data availability and processing requirements. Overall, the findings from this study can be used to support the development of efficient freight truck modeling applications for the Birmingham region. Moreover, lessons learned from the Birmingham case study provide valuable insights that can guide freight modeling efforts of planning agencies in other medium sized communities in the future.*
Keywords: *Freight Truck Modeling, QRFM Approach, Tour-based Approach.*

I. Introduction

Freight transportation supports essential services in a region and contributes to its economic vitality. Therefore, the ability to accurately model freight transportation in an urban area is critical toward making wise roadway infrastructure investment decisions. Transportation planners use travel demand forecasting models to estimate future travel demand on transportation facilities. Knowledge of future travel demand on the transportation network is used for several key decision making purposes in transportation planning, policy, and engineering.

Within the traditional planning framework, transportation forecasts follow the sequential four-step model that involves trip generation, trip distribution, modal split, and traffic assignment. In the trip generation step, the four-step model considers land use, household demographics, employment and other socio-economic data to determine trip production and attraction values within the community on the basis of transportation analysis zones (TAZ). These production and attraction values are then distributed between zones based on the attractiveness of each TAZ (trip distribution step), allocated by mode type (namely, private vehicle, transit, or carpool) in the modal split step, and assigned to optimal routes after considering the available roadway capacity, users preferences, and facility restrictions (traffic assignment step). The outcome of the process is the traffic volume forecast on each roadway.

While the sequential four-step travel demand forecasting process has been used broadly, it has come under criticism in the recent years as it does not capture realistically trip making behavior. One of its shortcomings is its inability of modeling truck trips explicitly. The use of household and employment data as inputs to the trip generation step is appropriate for generating passenger car trips, but overlooks truck trips. In some models, truck trips are considered implicitly as a portion of trips that are classified as non-home based [1]. Moreover, conventional travel demand forecasting models measure travel demand in terms of independent trips between pairs of zones and are unable to capture trip chaining behavior which is often prevalent in truck trips [2]. The lack of attention to truck movements in the conventional travel demand modeling methodologies may lead to an underestimation of infrastructure needs in areas where truck trips are significant and hinders the ability of transportation agencies and officials to make informed transportation planning decisions based on solid travel demand forecasts. Since resources for capacity and operations improvements are scarce, having robust and realistic travel demand models to support the decision making process is critical.

This paper examined the use of two distinct truck trip generation techniques which can allow for the inclusion of truck trips in travel demand forecasting models. The alternatives considered were: (a) the traditional truck modeling methodology published in the Quick Response Freight Manual (QRFM) and (b) the truck tour-based approach. Both techniques were showcased using data from the Birmingham, AL region and the Cube Voyager platform employed by the Regional Planning Commission of Greater Birmingham (RPCGB) for travel demand forecasting in the region. The study validated the results from both modeling approaches by comparing generated truck volumes against field counted truck volumes. First, the paper offers a brief description of the two options considered for generating truck trips for inclusion into the Birmingham travel demand forecasting model. The outputs from both models applied to the Birmingham transportation network were compared and contrasted to field data to determine the level of accuracy of each modeling approach. Furthermore, comparison of performance measures by different times of day took place and the main conclusions and recommendations were summarized.

II. QRFM Approach

The first approach considered in this study for modeling truck movements explicitly is the use of trip generation factors as outlined in the Quick Response Freight Manual (QRFM) [3]. The objective of the report was to provide simple techniques that can be utilized to develop truck trip tables which can then be incorporated into the conventional four-step planning process [3, 4]. In the QRFM report, trip generation factors were estimated using regression models developed from a trip diary in Phoenix, AZ region [3, 5]. Table 1 provides the trip generation rates for different trip generation variables.

Table 1. Truck Trip Generation Rate

Model Category No.	Generation Variable (Number of Employments/Households)	Four-Tire Trucks	Single Unit Trucks (6+ Tires)	Combination Trucks
1	Agriculture, Mining, and Construction	1.110	0.289	0.174
2	Utilities, Manufacturing, Transportation/ Communications/, and Wholesale	0.938	0.242	0.104
3	Retail	0.888	0.253	0.065
4	Office and Services	0.437	0.068	0.009
5	Households	0.251	0.099	0.038

As presented in Table 1, the QRFM approach requires employment/households data at the traffic analysis zone (TAZ). However, most data sources conform to U.S. Census Bureau geographic boundaries, such as the census tract, rather than TAZs. The Census Bureau has a program called Longitudinal Employer-Household Dynamics (LEHD) which provides a breakdown of existing employment by The North American Industry Classification System (NAICS) groups at the census block level. In this study, in order to convert the 2010 census tract data into the TAZ system, spatial analysis in ArcGIS was applied. The different categories of employment were then aggregated to produce truck trip generation variables breakdowns. Table 2 shows the employment category equivalency. The number of households by traffic analysis zone (TAZ) for the study area were obtained from Regional Planning Commission of Greater Birmingham (RPCGB).

Table 2: Employment Category Equivalency

Model Category No.	NAICS Code	NAICS Category
1	11	Agriculture
	21	Mining
	23	Construction
2	22	Utilities
	31-33	Manufacturing
	42	Wholesale
	48-49	Transportation, warehousing
3	44	Retail
4	51	Information
	52	Finance/insurance
	53	Real estate
	54	Professional/technical/scientific
	55	Management
	56	Administrative
	92	Government
	61	Educational
	62	Health care
	71	Entertainment/recreation
	72	Hotel/food
	81	Other services

The QRFM provides a series of friction factors that can be incorporated into the gravity model incorporated in the four-step travel demand forecasting process. In urban freight modeling, an exponential form of friction factor is utilized [3]. Equations (1)-(3) illustrate friction factor formulations based on average trip times from Phoenix, AZ region, recommended in the QRFM manual [3].

Four-tired commercial vehicles: $F_{ij}= e^{-0.08*t_{ij}}$ (1)

Single unit trucks (6+ tires): $F_{ij}= e^{-0.10*t_{ij}}$ (2)

Combinations: $F_{ij}= e^{-0.03*t_{ij}}$ (3)

A recent case study in Huntsville, AL used available freight trip generation factors and a distribution scheme to determine freight transportation demand appropriate for incorporation into a medium-sized community travel demand model [4]. Based on the case study and analyses performed, it was shown that proper application of the QRFM has the ability to effectively replicate actual truck traffic [4]. Given the findings from the Huntsville, AL study and in order to simplify the model development in the present study, it was assumed that the same friction factors can be considered for the Birmingham region.

For the Birmingham case study, household and employment data by traffic analysis zone (TAZ) for the study area were obtained from RPCGB and the truck trip generation rates were used to produce the truck trip table. The truck trips were distributed using friction factors, and ultimately truck traffic assignment was performed to assign truck trips to the roadway system on the network. The validation effort of QRFM approach is discussed in Section IV.

III. Truck Tour-Based Approach

The second approach considered for generating truck trips in this study is the use of a tour-based methodology. The main difference between the traditional approach outlined by the QRFM and the tour-based approach is that the trips in the QRFM approach are independent trips between origin and destination while in the tour-based approach, truck trips are assumed to be part of a longer route in which the truck makes several stops prior to returning its destination [2, 3]. As such, the tour-based approach is well suited for modeling truck travel, since many truck trips do make one or more stops between origin and destination [2, 6, 7]. It should be noted that the difficulty in obtaining the detailed truck movement data can be an obstacle toward developing the tours. However, due to the relatively recent availability of GPS truck data, planning organizations are now able to tackle this challenge. Still, there have not been any practical applications of this new approach in the study area.

In the Birmingham case study, four months of truck GPS data were obtained from the American Transportation Research Institute (ATRI) in 2011 and used to model truck movements as individual truck tours. The data provided origin, destination, and stop locations information for truck movements in the study region. Key variables were defined for each TAZ and used in estimating the aggregate number of tour origins per zone. These variables included accessibility, distance to the nearest cordon station, distance to the CBD, zonal density, and employment shares for the industrial and retail sectors. The model included components for tour generation, tour main destination choice, intermediate stop model, stop location, the time period of tour start, trip accumulator and traffic assignment. More details are available in [2].

IV. Models Validation

To compare the two study approaches and assess their accuracy, actual 2012 truck count data in the form of Annual Average Daily Traffic (AADT) and truck percentages along traffic count stations were obtained from the Alabama Department of Transportation (ALDOT) and utilized as a basis for comparison.

Based on the ALDOT truck traffic counts, the heaviest truck volumes within the study area were encountered along the I-65, I-20, I-459, and I-20/I-59 corridors. In this study, the models validation was performed using truck link-based volumes from 54 out of a total of 176 links along major Interstates in the study area. Table 3 presents the characteristics of roadway links used in the validation process.

Table 3: Study Links Characteristics

Interstate	Facility Type	Number of Links	Number of Lanes	Speed limit
I-65	1	24	6	60
I-20	1	10	6	60
I-20/I-59	1	14	4	60
I-459	1	6	6	60

First, actual daily truck traffic volumes were compared to truck volumes generated by the QRFM and tour-based models (Fig. 1 and 2 respectively). As shown in Fig. 1, there is no clear correlation between the truck counts generated by the QRFM approach and actual truck traffic counts. On the contrary, Fig. 2 illustrates a good agreement between actual truck counts and truck volumes resulting from the implementation of the tour-based approach.

To evaluate the quality of the approaches and statistically measure the difference between the assigned truck trips from the two approaches and the actual traffic counts, the percent root-mean square error (RMSE) was computed using Equation (4) [8].

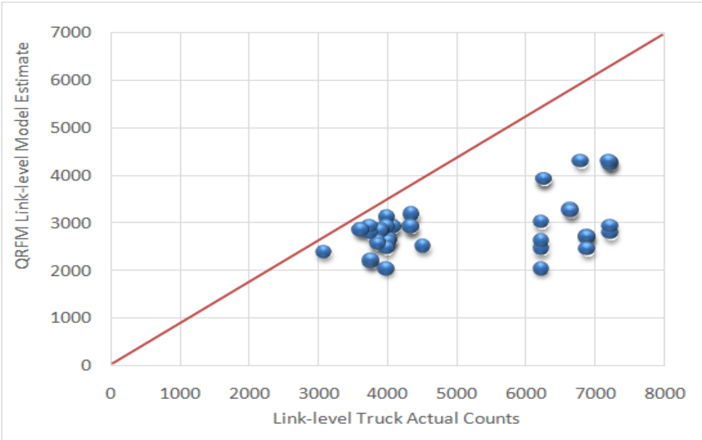

Figure 1. Truck Counts versus Truck Trips Assignment in QRFM Approach

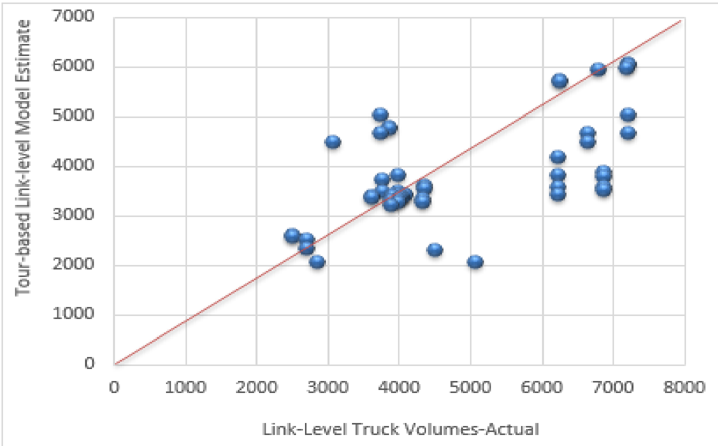

Figure 2. Truck Counts versus Truck Trips Assignment in Tour Based Approach

$$\%RMSE = \frac{(\Sigma_j (Model_j - Count_j)^2 / (Number\ of\ Counts - 1))^{0.5} * 100}{(\Sigma_j Count_j\ /\ Number\ of\ Counts)} \qquad (4)$$

An overall RMSE value of 47.96 percent was calculated for the model using QRFM approach while the RMSE value of 31.8 percent was computed for the model using tour-based approach. Both values are better that the RMSE value of 100 percent that resulted by the conventional trip-based planning model used by RPCGB as reported in [2]. It is worth noting that an appropriate percent RMSE recommended by the Montana Department of Transportation (MDOT) is less than 30 percent [8]. However, the overall RMSE values about 60% - 80% were found in most truck models in the literature. Thus the results from the validation tests demonstrate that the model using tour-based approach performs better than the one based on the QRFM approach when compared to actual truck counts within the study area.

V. Models Performance By Time Of Day

The two study approaches were also compared and evaluated by time of day. In the Birmingham truck tour-based approach, the time of day sub-model uses four time periods, namely AM peak, Midday, PM peak, and Night [2]. In the Birmingham QRFM approach, the time of day factors were applied to the truck trips so that the outputs could be directly compared with the truck tour-based approach. The time of day factors were obtained from NCHRP report 365 which provides the percent of trips by time of day and by trip purpose for the different population groups. For this purpose, the trip percentage table for an urban population of 500,000 to 999,999 in size and non-home-based trip purpose (a proxy for freight movements) were utilized to split daily truck trips into the same four time periods used in truck tour-based approach [9]. Ultimately, the two study models were run and the performance measures by time of day were compared to investigate the truck movement's patterns at different times of day.

The first performance measure considered is the truck volumes generated by models using each approach. As shown in Fig. 3, the tour-based approach generates higher truck volumes than the QRFM approach during AM, MD, and the NT periods. However, the QRFM approach generates slightly higher truck volumes during PM peak period. The largest difference between the truck daily volume forecasts from the two methods is observed during night hours.

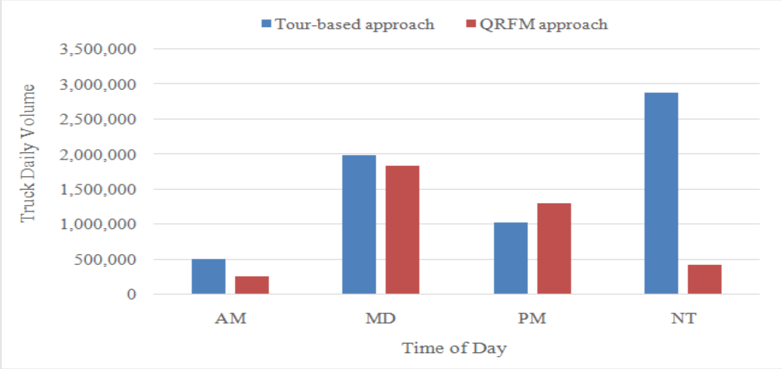

Figure 3. Truck Link-based Volumes by Time of Day; Tour-based Approach vs QRFM Approach

The second performance measure considered is the vehicle miles of travel (VMT) which refers to the number of miles traveled by trucks within the study area. VMT is calculated by multiplying truck daily volume on a segment by the length of the segment [3]. The aggregated Truck VMT by different time periods only for selected links in validation effort are presented in Table 3.

Table 3. Truck VMT by Time Period; Tour-based Approach and QRFM Approach

Vehicle Miles Traveled by Time Period	Tour-based Approach	QRFM Approach	Percent Difference	NS Coefficient
AM Truck VMT	25,895	14,842	42.68%	0.73
MD Truck VMT	103,316	100,349	2.87%	0.97
PM Truck VMT	33,185	43,072	-29.79%	0.56
NT Truck VMT	118,493	18,294	84.56%	-0.85

The comparison of the outputs from the two models considered (Fig. 4) shows a good agreement during MD period, however, the tour-based model tends to significantly overestimate truck VMT during AM and nighttime periods, in comparison to the QRFM model.

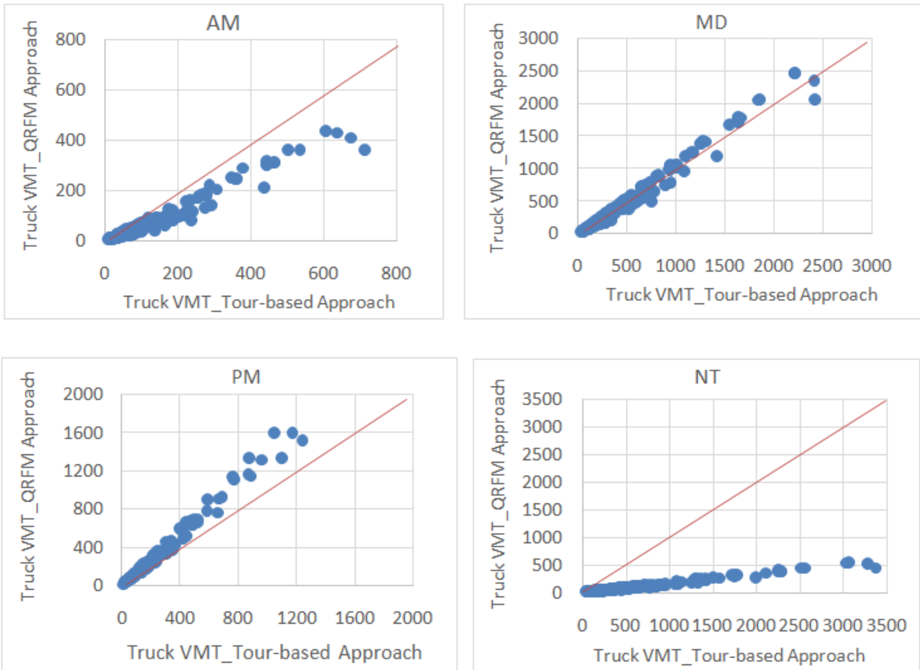

Figure 4. Truck VMT by Time of Day; Tour-based Approach vs QRFM Approach

To further assess the differences between two models outputs by time of day, a Nash-Sutcliffe (NS) efficiency coefficient was utilized and calculated using Equation (5) [10]. The value of this coefficient ranges from $-\infty$ to 1, with a coefficient of one (NS = 1) showing a perfect match of two models results [10]. It is:

$$E = 1 - \frac{\sum(y_2 - y_1)^2}{\sum(y_2 - \overline{y_2})^2} \qquad (5)$$

where y_2 is the link-based VMT of tour-based approach, $\overline{y_2}$ is an average of all VMT of tour-based approach, and y_1 is the link-based VMT of QRFM approach. The NS statistics during daytime (MD period) are close to each other during daytime particularly midday period, as shown in Table 3. However, truck trips generated by the two study approaches during all other periods illustrate large percent differences. To further understand the value of the findings, additional field truck data are needed by time of day that will enable comparisons between the outputs from the QRFM and tour-based models and actual truck counts. Such data were not available at the time of the analysis but can be valuable in future research. Still, the comparison is valuable as it shows that the selection of truck modeling approach can have significant impacts to the planning process in the study area.

VI. Conclusion

This paper examined two unique methodologies that can be applied in order to explicitly incorporate truck movements in a travel demand model for Birmingham, AL region. The methodologies studied were a. the QRFM approach that uses socio-economic data, households, and employment to develop truck trips and b. the tour-based approach that was developed using truck GPS data.

Both models were validated against actual truck count data provided by the ALDOT. The tour-based model validation process yielded an overall RMSE value of 31.8%. This is good value for a truck model and is superior to the value of 47.9% resulting from the QRFM approach. The findings from the validation process illustrate that the model using tour-based approach provides better results than the QRFM approach, when compared to the actual truck traffic counts.

Further analysis investigated the truck counts generated by the two approaches by different time of day. A comparison of outputs from the two approaches by time of day revealed a close agreement during midday periods. However, the model using the QRFM approach showed significant differences in truck trips assigned to the roadway system during all other periods and especially during nighttime, when compared to the tour-based approach. A limitation of the study is that the available data in the Birmingham case study do not permit for a direct comparison of the two models' outputs against actual traffic counts by time of day as such data are not readily available. Thus, while the differences between the two modeling approaches are noted, a clear conclusion about which method produces results that are closer to the reality in each time period is not possible. To provide better resolution in the validation process, it is recommended that detailed field data are obtained by different times of day and further validation takes place.

Overall, the study results demonstrate that the model using the tour-based approach performs better than the one based on the QRFM approach, when compared to actual truck counts within the study area. However, one should keep in mind that the tour-based approach requires a comprehensive data collection and processing effort, whereas the QRFM approach uses the publicly available data such as household and employment data. The decision on the best approach for adoption in order to explicitly incorporate truck trips into the travel demand model should be made on a case-by-case basis after considering the tradeoffs between accuracy and data availability and processing requirements.

This study confirms the importance of accounting for truck trips in the travel forecasting process and supports the implementation of efficient freight truck modeling applications for the Birmingham region. Moreover, lessons learned from the Birmingham case study provide valuable insights that can guide freight modeling efforts of planning agencies in other small and medium sized communities in the future.

Acknowledgements

The authors wish to acknowledge the contributions of Dr. David Lee of Georgia Institute of Technology and Mr. William G. Allen, Transportation Planning Consultant to the development of the prototype model framework. Special thanks to the RPCGB personnel as well as Mr. Andrew Sullivan and Dr. Michael D. Anderson for their valuable assistance and guidance.

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