Applying High-Fidelity Travel Demand Model for Improved Network-wide Traffic Estimation: New Brunswick Case-Study

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Paper prepared for presentation
at the Best Practices in Urban Transportation Planning Session
of the 2010 Annual Conference of the
Transportation Association of Canada
Halifax, Nova Scotia

Abstract

Traffic volume counts are used by many Departments of Transportation (DOTs) in planning, traffic operations, and asset management programs. Traffic counts are usually collected using sensor-based monitoring tools at limited locations in a network. The sensor-based method excludes low-class roads due to the cost involved. Therefore, in general, there is no volume data count available for local roads; even though they make up the majority of our highway network.

An extensive literature review from this paper revealed that using traditional factor approach, regression-based models, and artificial neural network models failed to present network-wide traffic/truck volume estimation because they rely on traffic counts for model development and they all have inherent weaknesses. Moreover, their traffic estimates have high estimation errors. Traditionally, four-step model (FSM) is based on traffic analysis zones (TAZs) structure which conveniently uses existing census geography to take advantage of socioeconomic data available from Statistics Canada. However, the coarse zone structure used in such models tends to exaggerate the intrazonal trips resulting in biased and unbalanced trip distribution over roadway network and high estimation errors. Also, their purpose is to guide infrastructure development and therefore, they are not appropriate as a tool for estimating traffic at network wide, including low-class roads.

This paper develops a high-fidelity travel demand model (HFTDM) capable of achieving network-wide traffic volume estimation with improved accuracy. This will require using all functional class roadways and spatially disaggregating census-based coarse TAZ structure into fine zones. A case study using an areal interpolation technique, which is based on fine-scale grids, road density and a detailed road network was developed for the Beresford/Bathurst area in the province of New Brunswick. Finally, a few conclusions and recommendations regarding this paper are given.

Introduction

Traffic volume counts are used by many Departments of Transportation (DOTs) and highway agencies in asset management programs to help plan, build, and maintain transportation infrastructure at county, provincial, and national levels. More precisely, they are vital parameters used in transportation planning, traffic operations, highway geometric design, pavement design, and resource allocation. Traffic counts are usually collected using sensor-based monitoring tools, such as loop detectors, at limited locations in a network. Low-class local roads which account for the majority of any road network (65% or more) are in general not included in the counting scheme due to the high cost encountered; therefore traffic volume data on this road class are either not available or very limited, and inaccurate. The consequence is that policies implemented have to be based on very inaccurate traffic estimates and thus increases the risk in decision-making.

Traditional factor approach is the most commonly used method that shows fairly large estimation errors mainly due to incorrect group assignment. Whereas, regression-based models tend to estimate traffic volumes for groups of roads rather than individual ones. Artificial neural network (ANN) approach shows some improved results compared with traditional factor approach, but it mainly stay as a research tool due to the complexity of the technique. Further, all above traditional methods require traffic counts for model development. However, since traffic counts are not available for a significant portion of road network, especially for low-class roads, these techniques fall short in providing network-wide traffic estimates.

Estimating traffic volume with non-survey approach using travel demand model is an effective alternative of traditional approaches for transportation planners. The four-step model (FSM) was initially developed in USA for evaluating large-scale infrastructure projects in the late 1950s. The FSM model was also used as an aid to develop transportation network for large cities and support planning for urban segments of the interstate highway systems. FSM is a widely used and accepted tool to carry out transportation planning and for forecasting future travel demand. Traditionally, four-step travel demand model (FSTDM) is based on traffic analysis zones (TAZs), which conveniently uses existing census blocks, block groups, or census tracts to take advantage of socioeconomic and demographic data readily available from Statistics Canada. Previous research work and state-of-practice clearly showed that most of the FSTDMs being developed were based on roadway networks which ignored local roads or only used them for network connectivity purposes. Also, fairly large TAZs used in FSTDMs yielded a higher percentage of intrazonal trips resulting biased and unbalanced trip distribution over roadway network and high traffic estimation errors.

Limitations above have necessitated disaggregating coarse zonal structure into smaller spatial modeling units such as polygons or grid cells using Geographic Information Systems (GIS). This type of high-fidelity travel demand model (HFTDM) is to further disaggregate census data into smaller and more homogeneous traffic analysis zone system. This disaggregation procedure will insure that fine-grained spatial or attribute data are not lost or averaged through aggregation. Also, it will capture most of the trips generated at each zone by maximizing the interzonal flow while minimizing the intrazonal flow and then effectively distribute traffic onto all roads, including local ones. The disaggregation of the socioeconomic data from coarse zones to grid cells or other smaller areas is based on areal interpolation methods which were initially discussed by Goodchild and Lam (*1*). The areal interpolation method for spatial data conversion can be based on auxiliary variable such as roadway density and house count. Areal interpolation is the process of transferring socioeconomic data from one set of areal unit called source zone to target zones, where the zones are almost of similar size and intersect with each other. Zonal disaggregation is a special case of areal interpolation, in which the source zone is the large one to be disaggregated into a number of small target zones. Also, both source and target zones do not intersect.

This research paper reviews the literature on state-of-the-art/practice for developing network-wide traffic/truck volume estimation using traditional four-step model. The paper then presents the proposed methodology to be applied in developing the HFTDM. Then, the proposed methodology is applied to a case study area of Beresford/Bathurst in the province of New Brunswick. Finally, conclusions and recommendations from this research paper are presented.

Literature Review

FSM is a widely used and accepted tool to carry out transportation planning and for forecasting future travel demand. Regardless of their inherited weaknesses and limitations four-step sequential models have been widely used by transportation agencies to estimate travel demand and traffic volume for a variety of purposes, such as infrastructure planning and capacity/operation analysis. Trips generated at a zone are distributed to other zones by loading and assigning them to highway network. Clearly, zonal aggregation or disaggregation will have an impact on the results in terms of the trips generated and distributed to the network. Intuitively, the size of TAZs affects the amount of interzonal flow. The smaller the TAZ, the more likely trips will cross its boundary and be accounted for which in turn maximizes the interzonal flow (*2, 3*).

Previous studies and research by Crevo (*4*), Ding (5, *6*) studied the effect of TAZ structure on travel demand forecasts. Studies concluded that the use of fairly large TAZs produced results with fairly high reported estimation errors, mainly related to the unbalanced trip distribution and limited traffic assignment over the highway network. The use of smaller homogenous zones will effectively distribute traffic onto all road classes including low-class roads which in turn will improve accuracy of travel demand model. Horowitz and Farmer (*7*) noted that the most prominent problems in implementing statewide models relate to issues of scale. Because of the zonal aggregation in urban areas, there is a large number of intrazonal trips that cannot be captured by the models.

Khatib et al. (*8*) studied the effect of traffic analysis zone (TAZ) structure and different roadway network details on the ability of the statewide travel demand model to replicate the average annual daily traffic (AADT) counts. The authors used GIS to develop 11 TAZ structures representing combination of three levels of census geography (county, census tract, and block group), and four levels of centroid location (geometric centre, city location, population-weighted center, and household-density-weighted center). Also, the model was based on a statewide roadway network which included all interstates, principal arterials, minor arterials and major collectors in both urban and rural areas, and minor collectors in rural areas. TRANPLAN and its four-step process of trip generation, trip distribution, mode choice, and trip assignment were used for traffic demand modeling. The model was calibrated based on the Idaho Transportation Department (ITD) AADT counts collected in 1996. The study concluded that TAZ structure has a considerable effect on the results of traffic demand modeling. The smaller the TAZ, the higher the proportions of assigned interzonal trips and the higher the model estimation accuracy.

Zhong and Hanson (*9*) noted that traffic counts on low-class roads are not available because the existing traffic monitoring programs traditionally focused on the higher functional class roads (collectors and above). Also, the authors indicated that the research work for estimating traffic volumes for low-class roads using travel demand model (TDM) is scarce and the majority of the previous research was regression based. The authors developed a GIS-based travel demand model to estimate traffic volume for low-class roads. The model was applied to York County and Beresford Census Consolidated Subdivision (CCS) in the Province of New Brunswick. The study concluded that reducing the study area size resulted in increased estimation accuracy. The overall average error of the Beresford CCS was reduced to 25% and the estimation errors for local roads were limited to less than 40%, which is comparable to or better than those reported in the literature. Finally, the study concluded that traffic volume on low-class roads can be modeled most effectively by reducing the size of TAZs which can be achieved by further disaggregating socioeconomic data to smaller areas.

NCHRP 365 (*10*) presented a case study of the development and calibration of four-step travel demand model in the city of Asheville, North Carolina, with a population of 110,000. It provides a good example of a small size urban model. The four-step model failed to develop a network-wide traffic volume estimates and they were fairly inaccurate for low-level roads (minor arterial and collector) used in their study. The model underestimated traffic on low class roads with an average assignment ratio (assigned/observed) of 57%. This research paper improved the results on low-class roads to 17%. Finally, the study concluded that traffic assignment on low-class facilities could be improved by disaggregating the zone structure.

The design guidelines (*11*) for four-step models did not explicitly introduce the concept of TAZ disaggregation to fine zone level. Few published research works apply disaggregation procedure based on either cluster analysis (*11*) or areal interpolation (*12*) and utilize vector grid overlay to create homogeneous zones to be used for TDM. Their work was challenged by keeping coterminous Census and TAZ area boundaries. However, it should be noted that the advanced areal interpolation methods have not been utilized and tested in TAZ disaggregation for the purpose of improving estimation accuracy of network-wide traffic statistics. Finally, various published research (*13-15*) concluded that modern technologies, such as GIS and remote sensing, are proven to be efficient tools in defining, designing and disaggregating TAZs, building and coding transportation network, developing zone centroids, developing, maintaining, and updating zonal socio-economical activities.

High-Fidelity GIS-based TDM Development

Development of the proposed high-fidelity GIS-based travel demand model for network-wide traffic volume estimation will be based on the following two major steps: input data preparation and model estimation. Each step will be discussed using general/broad terms then a case study following the general methodology will be presented.

TDM Data Preparation

Travel demand model (TDM) should include a well defined study area, updated data inputs (land use, socioeconomic, and roadway network), a sound TAZ structure, and ground truth traffic counts. Preparing HFTDM data base include the following steps:

Define the Study Area and the TAZ System

This is to decide on the spatial/geographic level of the study area to be analyzed. The high-fidelity model is based on analyzing the census data at the smallest census units called Dissemination Areas (DAs). Statistics Canada (www.statcan.ca) defines dissemination area (DA) as a small relatively stable geographic unit composed of one or more adjacent dissemination blocks. It is the smallest standard geographic area for which all data are disseminated. In practice, the DA level of Census geography is often used as a building-block for TAZs.

The study area is selected so as the DAs will cover an entire urban influencing area (UIA), including urban, suburban, and rural area. This will ensure all relevant urban activities are considered and this will lead to a modeling area with three levels of spatial resolution and degree of heterogeneity. Urbanized areas (e.g. CBDs) tend to include zones which are large in numbers, small in areas, and dense in land use activities. In rural areas the zones tend to be larger in areas and lower in land use density.

Collect Census Socioeconomic Data

Census statistics are the primary source for demographic and economic data at zonal level. They are essential for effective and efficient travel demand modeling. Statistics Canada provides aggregated socioeconomic data for each census unit (DA) within the study area. The socioeconomic profile of the population is a key input to TDM because it determines the trip-making characteristics of the population. Demographic data includes the number of households, total population, income per household, and employment by sector (retail, non-retail, etc.).

Define Roadway Network

The roadway network is a digital format of the road centerline. GIS-based representation of roadway network model consists of nodes, links, centroids, and centroid connectors. Functionally classified roadway network serves several purposes in developing the proposed high-fidelity travel demand model. It includes attributes required for each link including functional classification, area type, link type, link length, link capacity, link speed, lane width, number of lanes, and traffic volume counts. The roadway network is used to estimate the link travel impedance between zones in the study area. The major role of the roadway network is performing traffic assignment process in which zonal trips are loaded and distributed onto the network. There are no specific rules on the level of details of the selected roadway network. It is chosen to match the zonal structure and the goal to be achieved from developing the travel demand model. Oregon State Department of Transportation travel demand modeling guideline suggested the use of a roadway network which includes collector and local roads to capture 90% or more of the vehicle trips (*16*).

Disaggregate the Study Area

TAZs are the basic units of analysis in travel demand model. They are used to link census demographic data with land use which are assumed to be homogenous, and uniformly distributed. Census data at zonal (DA) level are assumed to be uniformly distributed and aggregated averages are used throughout each zone. This assumption does not reflect the behavioral choice of travelers, and lack accuracy especially for large rural zones. These limitations have seriously restricted the accuracy of the four-step travel demand in estimating network–wide traffic volume. Therefore, the spatially aggregated socioeconomic and land use data at DA level will be further disaggregated into a small size zones (grids) within a GIS environment such as TransCAD software. The disaggregation of the socioeconomic data from the DAs to grid cells or other smaller areas is based on areal interpolation method.

The simplest zonal disaggregation procedure is area-weighting method also called piecewise approximation (*17*). The area-weighting method is based on the assumption that the source zones have a homogenous attributes distribution, and the attributes are disaggregated as a function of land area overlap between the target zones and the source zone.

The areal interpolation method for spatial data conversion can be based on auxiliary variable such as roadway density (*18*). Roadway coverage is an indication of the ability of a geographic area in supporting population activities and travel. It is a reasonable allocating factor in distributing household attributes.

Finally, in this paper, wherever appropriate, DAs are further disaggregated into a number of smaller zones using arbitrary grids. GIS overlay function from TransCAD is used to achieve this disaggregation. Creating a set of homogeneous fine zones with disaggregated socioeconomic data, which will help model accuracy by better distributing traffic over road network, is considered to be a critical step in achieving high-fidelity model.

General TDM Estimation Process

TransCAD software fully integrates the traditional four-step travel demand model within a GIS environment. TransCAD will be used to perform trip generation, trip distribution, and traffic assignment in this study. Mode split step is omitted due to the fact that most of the trips occur by private vehicle. According to Statistics Canada (www.statcan.gc.ca) the proportion of Canadian using their cars to work was 72.3% in year 2006 while using public transit was only 11.0%. The percentage of private vehicle mode is expected to be much higher than these national averages in areas covered by very limited transit services.

The theoretical aspects of the travel demand model sequential steps performed using TransCAD is presented briefly in this research. For more details one should refer to the TransCAD reference manual (*19*). The research methodology will follow the traditional travel demand modeling procedure, which includes the following systematic steps:

1. Trip Generation-Production/Attraction
2. Trip Distribution.
3. Traffic Assignment.
4. Model Validation.

The above listed steps will be discussed briefly in the coming section as part of case study development for this research paper.

Case Study

This case study illustrates the proposed methodology for developing a high-fidelity GIS-based travel demand model (HFTDM) based on available resources and technologies. Developing a HFTDM is a complex process and will be achieved using TransCAD, a licensed product of the Caliper Corporation, which is a Geographic Information System (GIS) with travel demand analysis capabilities. TransCAD GIS modeling capabilities, such as a built-in four-step model and accurate representation of roadway network, made it attractive to develop the proposed HFTDM.

Case study area is chosen from Gloucester County located in the North Eastern part province of New Brunswick. The study area is composed of the Census Consolidated Sub-division (CCS) of Beresford and the surrounding urban influencing area (UIA) of the city of Bathurst as shown in Figure 1 below. The study area encompasses communities of Belledune, Point-Verte, Petit Rocher, Nigadoo, Beresford, and part of the city of Bathurst commercial area next to the Beresford (CCS).

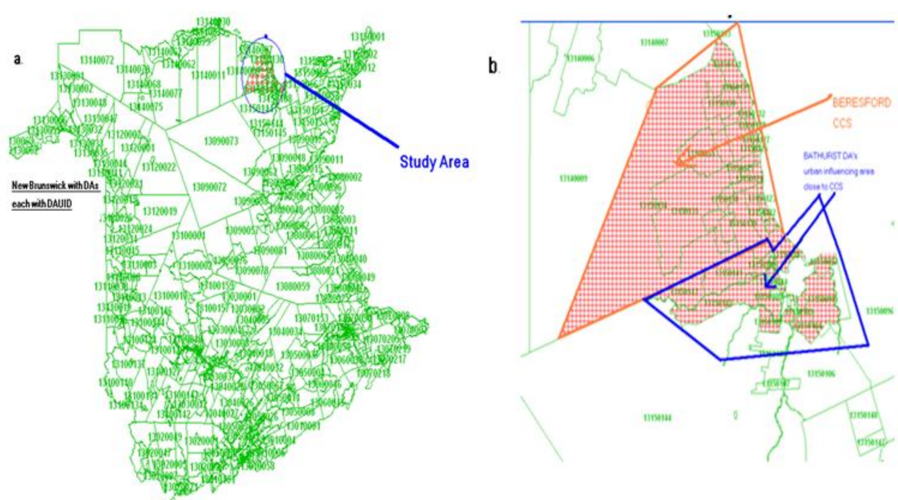


Figure 1 (a) Study Area in New Brunswick (b) Study Area Composed of CCS of Beresford and a Part of the City of Bathurst.

The initial traffic analysis zone (TAZ) structure used for the study area follows dissemination area (DA) boundaries set by Statistics Canada's 2001 census data. New Brunswick dissemination area (DA) map is provided by Statistics Canada with each DA is identified by Dissemination Area Unique Identifier (DAUID). The area was clipped in TransCAD until the final study area with 48 DA's is achieved and presented in Figure 2(a) on below. The study area covers 518 square km of which 330 square km in Beresford CCS and 188 square km in the City of Bathurst.

Within the study area, 48 DA's layer and vector grid layer are overlaid to achieve a disaggregated 97 fine zones as shown in Figure 2(b) below. The vector grid layer contains 49 grids totaling 995 km² with each grid sized at 4.62 km x 4.42 km. Grid sizes are experimented and selected to capture purer land uses in the created fine zones. The smaller the grids are, the more effectively they split the large rural zones into purer fine zones. However, as the size of grids goes down, the number of fine zones will be exponentially increased. Therefore, there is a balance between the size of grids to be used and the resulting number of fine zones to be used in the proposed HFTDM.

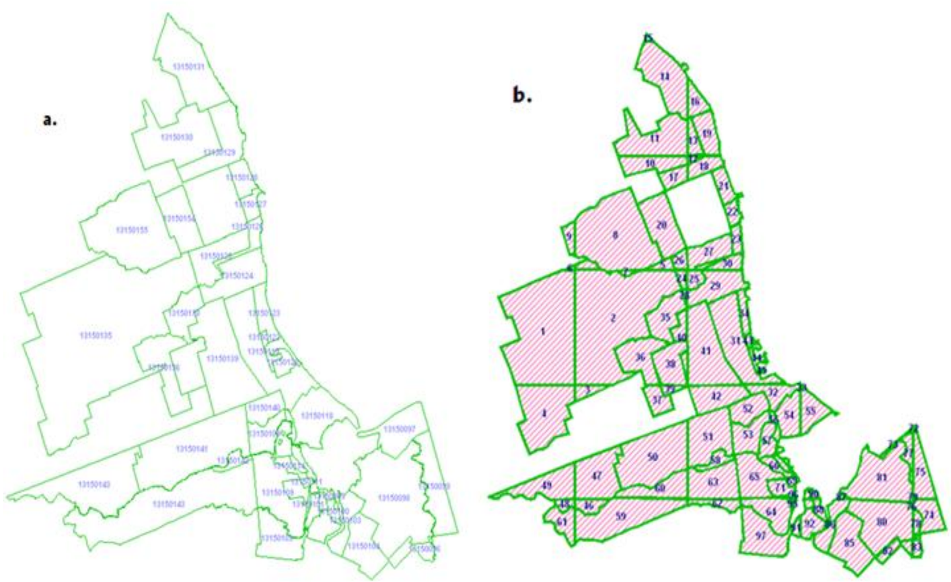


Figure 2 (a) Study Area with 48 DAs Identified by DAUID Number (b)Disaggregated Study Area with 97 Fine Zones

New Brunswick road map was obtained from National Road Network (NRN) included in the Geobase website (www.geobase.ca). The roadway network is clipped for the study area of interest using TransCAD. The clipped roadway network contains 1598 nodes and1822 classified routes totalling 341.49 km. Centroids are added to each fine TAZ and are located to replicate the center of activities within each TAZ. Centroid is the point in each TAZ where all trips are loaded to the network; indeed it is the network representation for the TAZ. Adding 97 centroids and 287 centroid connectors to the original roadway network will result in modifying the number of nodes and links. The total length of the modified roadway network is 493.92 km making the added centroid connectors equal to 152.43 km (493.92 km-341.49 km). The average length per centroid connector is =152.43/287= 0.53 km, which seems to be a reasonable length for local roads.

Roadway network is checked for discontinuity, which is a serious problem that can cause inaccurate trip assignment. Roadway network coding error could result in dangling links that are not connected to other link at a node. Besides to a visual examination to obvious network connectivity problems, TransCAD allows modelers to check thoroughly for unnoticeable ones.

Figure 3a and 3b below shows the roadway network with dangling links problems and the same network treated after applying TransCAD network connectivity tool. The final roadway network of the study area contains nodes 1695 and 2125 classified routes totalling 501.23 km (Figure 3b below)

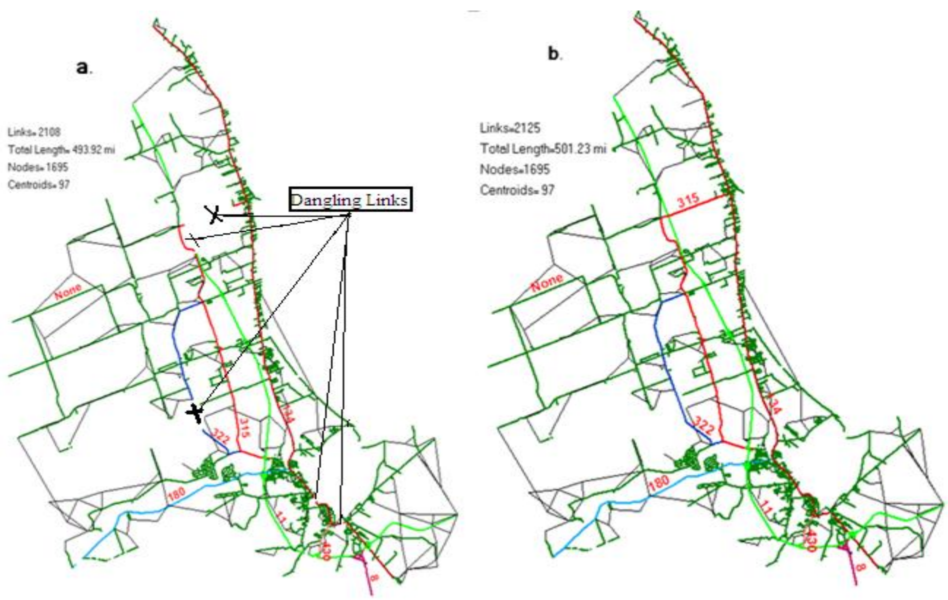


Figure 3 (a) Roadway Network with Connectivity Problem
(b) Roadway Network Treated for Connectivity Problem

Socioeconomic data of the study area is needed for conducting the trip generation of the travel demand model (TDM). The following socioeconomic parameters from dissemination area (DA) layer were used in this case study: total number of population, total number of households, and average income per household, retail employment, and non-retail employment. The socioeconomic data collected for each DA is disaggregated to the fine zones following the areal interpolation method discussed earlier in this research paper. The criterion for splitting socioeconomic data in this case study is based on roadway density in each fine zone. Socioeconomic data of each DA is disaggregated to the related fine zones utilizing the one-to-many relational table between DA and the fine zones.

Modeling Approach

The modeling process is carried out using TransCAD 4.8 software by performing the following sequentially structured steps:

1. Trip Generation (Production/Attraction)

Trip generation step produces estimates of trips being produced and attracted to each TAZ within the study area. Three types of trips are used in this model: home-based Work (HBW), home-based-non-work (HBNW) and non-home-based (NHB). TransCAD Quick Response Method (QRM) trip production procedure is based on default trip rate table from NCHRP report number 187 (*20*). Data input to TransCAD QRM trip production are the total number of household (HH) and the average income per household for each zone. On the other hand, QRM trip attraction model is a regression based, which uses three regression equations, one for each trip purpose HBW, HBNW, and NHB. Regression equations used to estimate the number of trips attracted to a zone are based on the retail and non-retail employment in the zone and on the number of dwelling units in the zone. Trip production and attraction in TransCAD is generated using separate models which will lead to discrepancy between the estimated number of trips produced in an area and the number of trips attracted to the same area. TransCAD provides a procedure to balance the trip productions and attractions for each trip purpose for a study area.

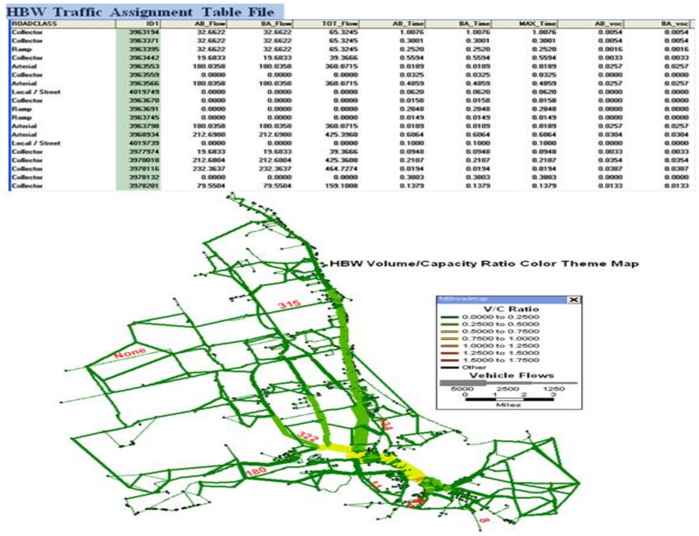
2. Trip Distribution

Trip distribution step tries to predict the spatial pattern of trips between origins and destinations. Trip distribution is accomplished using the well-known gravity model. Production-Attraction (P-A) trip matrices generated in trip distribution step are non-directional and trips must be conserved meaning that $\sum P = \sum A$. Traffic assignment modeling step requires Origin-Destination (O-D) trip matrix because trip values represented by rows and columns (cells) have directional meaning, i.e. trips are defined by value or quantity following direction from an origin to a destination. Also, O-D trip matrix does not require to comply with flow conservation principle i.e. $\sum O=\sum D$. TransCAD can be used to convert the 24-hour P-A matrices to 24-hour O-D matrix. Vehicle occupancy factor can be applied to convert the person trips to vehicle trips using the default recommended average occupancy value of 1.62 persons per vehicle (*20*).

2. Traffic Assignment

Traffic assignment is basically to load vehicle trips from the O-D matrix onto the roadway network based on travel time or other travel impedance of the road links. Traffic assignment will estimate traffic flow (user volume) on each roadway link. Then, link volume is compared to the capacity of the link to study volume/capacity (v/c) ratio and performance of the network.

User Equilibrium traffic assignment method is performed within TransCAD to provide more accurate results by disturbing traffic on most links of a roadway network. Upon successful completion, TransCAD traffic assignment output will include assignment table file, summary text file, and volume/capacity (v/c) ratio a colorized theme map. Figure 4 on the next page shows a screen shot of traffic assignment procedure output for HBW trip purpose.



HBW Traffic Assignment Table File

ROADCLASS	ID1	AB_Flow	BA_Flow	TOT_Flow	AB_Time	BA_Time	MAX_Time	AB_voc	BA_voc
Collector	3963194	32.6622	32.6622	65.3245	1.0076	1.0076	1.0076	0.0054	0.0054
Collector	3963371	32.6622	32.6622	65.3245	0.3001	0.3001	0.3001	0.0054	0.0054
Ramp	3963395	32.6622	32.6622	65.3245	0.2520	0.2520	0.2520	0.0016	0.0016
Collector	3963442	19.6833	19.6833	39.3666	0.5594	0.5594	0.5594	0.0033	0.0033
Arterial	3963553	180.0358	180.0358	360.0715	0.0189	0.0189	0.0189	0.0257	0.0257
Collector	3963559	0.0000	0.0000	0.0000	0.0325	0.0325	0.0325	0.0000	0.0000
Arterial	3963566	180.0358	180.0358	360.0715	0.4859	0.4859	0.4859	0.0257	0.0257
Local / Street	4019749	0.0000	0.0000	0.0000	0.0620	0.0620	0.0620	0.0000	0.0000
Collector	3963670	0.0000	0.0000	0.0000	0.0158	0.0158	0.0158	0.0000	0.0000
Ramp	3963691	0.0000	0.0000	0.0000	0.2848	0.2848	0.2848	0.0000	0.0000
Ramp	3963745	0.0000	0.0000	0.0000	0.0149	0.0149	0.0149	0.0000	0.0000
Arterial	3963798	180.0358	180.0358	360.0715	0.0189	0.0189	0.0189	0.0257	0.0257
Arterial	3968934	212.6980	212.6980	425.3960	0.6064	0.6064	0.6064	0.0304	0.0304
Local / Street	4019739	0.0000	0.0000	0.0000	0.1000	0.1000	0.1000	0.0000	0.0000
Collector	3977974	19.6833	19.6833	39.3666	0.0948	0.0948	0.0948	0.0033	0.0033
Collector	3978010	212.6804	212.6804	425.3608	0.2107	0.2107	0.2107	0.0354	0.0354
Collector	3978116	232.3637	232.3637	464.7274	0.0194	0.0194	0.0194	0.0387	0.0387
Collector	3978132	0.0000	0.0000	0.0000	0.3803	0.3803	0.3803	0.0000	0.0000
Collector	3978201	79.5504	79.5504	159.1008	0.1379	0.1379	0.1379	0.0133	0.0133

Figure 4 HBW Traffic Assignment Model Output

Model Validation

The first step after TDM development and prior to its implementation is to ensure that the traffic estimates over a roadway network are properly validated. Network model validation compares the predicted and observed volumes via validation tools for traffic assignment model such as percent root mean square error (%RMSE), percent assignment error (%PAE), and coefficient of determination (R^2). Traffic assignment model validation tools are employed to evaluate and test an overall model prediction accuracy. The following section will proceed in model traffic assignment validation using %PAE and R^2 validation tools based on observed versus assigned traffic volumes.

Percent Traffic Assignment Error (PAE) indicates the accuracy of the model in replicating the actual traffic counts. Percent error is more widely used than absolute numerical difference between estimated and observed values because it better reflects the volume of the roadway and identifies any forecasting biases. PAE is simply equal to **(Assigned−Observed)* 100⁄Observed**. The US Federal Highway Administration (FHWA) set up an acceptable level of validation errors, which is related to the roadway functional classification as shown in Table 1 below (*21*). Also, FHWA suggested a general urban model validation targets such as a maximum acceptable overall model PAE of 10% and a minimum acceptable Coefficient of Determination **(**R^2) of 0.88. R^2 shows the proportion of variation around the mean explained by the linear regression model. The remaining of the variation is related to random error, which cannot be explained.

Facility Type	Percent FHWA Error	Coefficient of Determination (R^2)
Freeways	+/- 7 percent	0.88
Principal Arterials	+/- 10 percent	0.88
Minor Arterials	+/- 15 percent	0.88
Collectors	+/- 25 percent	0.88
Local Roads	+/- 25 percent	0.88
Overall Acceptable	+/- 10 percent	0.88

Table 1 Acceptable Validation Criteria for Daily Traffic Volumes by Facility Type

Network assignment validation requires defining all roadway links covered with traffic volume counts. Then, classifying those links based on facility type. Roadway network included in the study area contains 1695 nodes and 2125 classified routes totalling 501.23 km. New Brunswick Department of Transportation (NBDOT) provincial traffic flow map (hardcopy), which included Average Annual Daily Traffics (AADT) for year 2006, was used to code nine highways with ground truth traffic counts into TransCAD, as shown in Figure 5 below. Traffic counts were available as follows: two counts on Highway 11 (arterial), two counts on Highway 134 (collector), one count on Highway 180 (collector), One count on each of the Highway 315, 322, and 430 (local numbered), and one count on Bridge St (local named).

Comparing observed AADT at each highway facility to the model assigned traffic volume is used to estimate PAE. Then, the estimated PAE is compared to FHWA model validation targets. Table 2 on the next page shows that the overall PAE (OPAE) is only -8 percent meaning that the model underestimated traffic volume on overall basis by 8%, which is within FHWA validation target limit of ±10%.

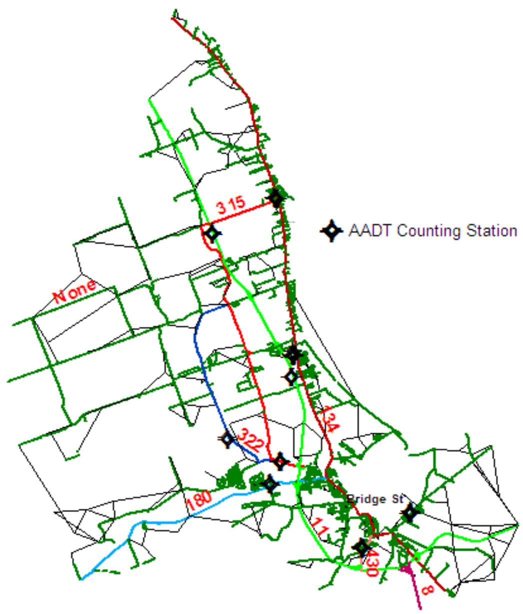


Figure 5 Road Network Links Covered with Traffic Volume Counts

However, even though overall the model is within acceptable FHWA validation limit, the model failed to estimate volumes on few links within acceptable FHWA accuracy standards. Despite the fact that the overall PAE statistical measure is being used to evaluate overall model estimation performance, it is misleading and do not represent the actual average of all PAE estimated for each counting location over the roadway network. For this reason, the absolute PAE (APAE) is more realistic and accurate in representing the overall model estimation accuracy. The overall model APAE is 19 percent as shown in table 2 on the next page.

Functional Class	Highway Number	Observed AADT	Assigned AADT	PAE	Over/Under-estimated
Arterial	11 N	1250	1450	+16	O
Arterial	11 S	3800	2987	-21	U
Collector	134 N	7913	6034	-23	U
Collector	134 S	10887	7944	-27	U
Collector	180	1120	1376	+22	O
Local Numbered	430	3110	4113	+32	O
Local Numbered	315	4150	4892	+17	O
Local Numbered	322	1250	1292	+3	O
Local Named	Bridge St	3110	3361	+8	O
Overall Network PAE	___	36590	33449	-8	U
Overall Network APAE	___	___	___	19	___

Table 2 Comparison of Observed Versus Assigned Traffic Volumes by Facility Type

Another useful measure for evaluating model estimation accuracy is plotting a scattergram of the observed versus the assigned traffic volume and compare to a 45 degree line as shown in Figure 6 below. The plot as a validation tool can be useful in locating data points (links) that locate far away from the perfect regression line (45 degree line). Also, the location of the majority of the scattergram data points above or below the 45 degree line indicates overestimation or underestimation of traffic volume by the model. Moreover, the 45 degree line represents ideal (perfect) regression, which can be used to account for biases and errors in the assigned (estimated) AADT.

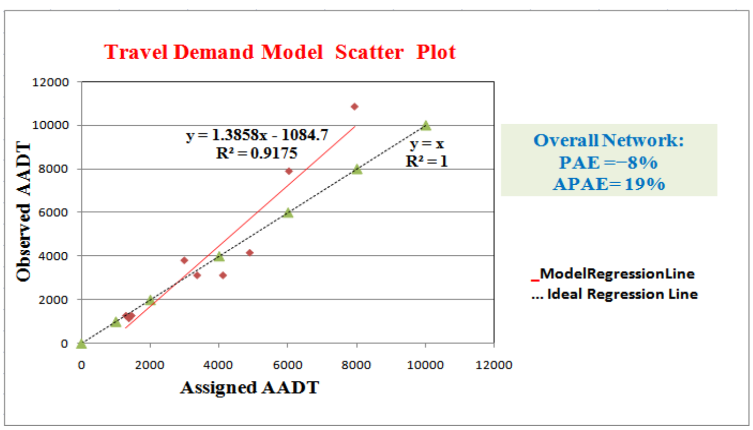


Figure 6 Observed Versus Assigned AADT Scatter plot

Most often "data points" that were plotted based on pairs of the observed and assigned AADT do not lie on this line as mentioned before; therefore they can be adjusted and calibrated based on the regression model developed.

Consider the regression model for local roads presented in Figure 7a on the next page as an example of such a calibration analysis. Since the traffic on all local roads are overestimated, a regression model using observed AADTs as dependent variables and assigned AADTs as independent variables can be used to correct this systematic bias. As shown in Figure 7a below, the regression model indicates that all assigned AADTs to local roads should be adjusted with the equation (y=0.764*x+296.3). The calibrated assigned AADT when plotted against observed AADT will locate closely to the ideal fit line (45 degree line) with slop and intercept equal to 1.00 and 0.003 respectively (Figure 7b). Additionally, the regression calibration significantly reduced APAE form 15% to 6%. However, even with this regression calibration procedure, there is always an amount of uncertainty and bias enough R-squared.

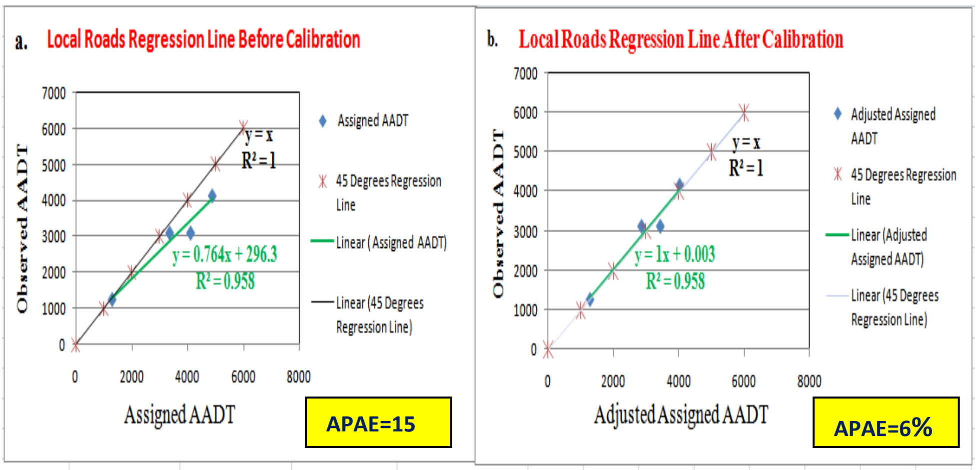


Figure 7 (a) Local Road Observed vs. Assigned AADT Regression Line (b) Local Road Calibrated AADT Regression Line.

Regression calibration analysis has useful application for each road functional class provided the availability of adequate sample size and significant estimation error to justify the analysis. In this modeling exercise this analysis is unwarranted due to the limited number of observations from other functional class roads. Finally, coefficient of determination, R^2, is calculated from a linear regression analysis of observed and assigned traffic volumes. R^2 is applied as a measure of overall model estimation accuracy with a value closer to 1.00 indicates a perfect match between observed and estimated values. The developed model with an overall network-wide R^2 of 0.9175 indicates that there is a strong linear relationship between the observed and estimated values. Also, it is an indication of the overall model estimation accuracy.

Model Results and Discussions

Generally speaking, overall, the model underestimated trips within 8 percent of the observed traffic. The model has met the FHWA urban model validation target of 10 percent and is expected to fairly well predict future travel demand. Whereas, the absolute APE is much higher with 19 percent assignment errors reported by the model. Even though AAPE is not included in the FHWA validation target limits, it should be part of the overall model performance evaluation. Indeed, AAPE is the true average indicator of the model miss-assignment. The developed model slightly improved the 9 percent accuracy from a previous study for Beresford CCS (*22*). The study was based on Dissemination Area (DA) TAZ structure. The improved overall estimation accuracy for the HFTDM is mainly due to the fine TAZ structure employed. The developed

HFTDM showed a general trend of overestimation when applied to the roadway network at link level. Also, the overestimation trend was obvious in all cases of local roads.

Route No. 11 (arterial) is the main North-South corridor crossing the study area and is recorded with an observed AADT of 4510 and 7060 vehicles per day at two temporary short-term counting stations along the north and south section of the highway respectively. Observed AADT is adjusted by removing external-external (through) trips. Through trips of 3260 vehicles per day are roughly estimated as the average AADT of three counting stations (two short-term and one permanent) north of the study area. Then, the adjusted AADT from observed traffic count is compared to the assigned traffic volume by the model. The model overestimated and underestimated traffic volume by 16 and 21 percent at the north and south locations respectively on this highway. It seems that the model failed to predict traffic volume on this arterial within acceptable FHWA validation standards. Despite the modeling accuracy of this high-function road is expected to be higher than the lower class roads and in general it should be within 10% of the true values, one could also say that the approximate method used in dealing with through traffic may influence the outcome. Additionally, it is worth mentioning that modeled highway 11 showed the similar estimation trend (*21*). Admittedly, the small sample size does not allow a definitive conclusion to be drawn on the behaviour of the model in modeling arterials.

Through traffic on collector highway 134 was treated in a similar way as mentioned above. The adjusted two short-term counts after accounting through traffic volume of 7913 and 10,887 vehicles per day are compared to the assigned traffic volumes of 6034 and 7944 vehicles per day at each of the two locations on the highway. One should note that the model mostly assigns traffic to this highway, which is consistent with the observed short term counts collected by NBDOT. Although, the model successfully limited the estimation errors to 23% and 27% at the two locations, which are fairly close to the FHWA validation target limit, it seems that through traffic is underestimated on this North-South major corridor. Additionally, the validation included collector highway 8 which runs West-East through the study area to join with the main collector highway 134 (Figure 5, pp12). Observed traffic count of 1840 vehicles/day near the junction with highway 134 is treated for through traffic by subtracting the traffic count of 720 vehicles/day located at a station east of the study area. The model overestimated traffic volume on this highway by 22 percent which is with FHWA target limit of 25 percent. As mentioned before is seems that through traffic is underestimated in the analysis. Finally, the overall APAE for collector functional class group is 24 percent which is within FHWA target.

Four local roads (three numbered and one named) are included in the validation process. Highways 315, 322, 430, and Bridge St are covered with short-term counts of 4150, 1250, 3110, and 3110 vehicles per day respectively. Since local facilities carry minimal through traffic, the observed short term traffic counts are compared with assigned traffic volumes for each local road included in the validation process. The estimated PAE for Highways 315, 322, 430, and Bridge St are 17, 3, 32, and 8 percent respectively. This clearly shows a general trend of overestimation on local road group. The overestimation of traffic assignment on those local roads could be attributed to the high residential developments surrounding them. For this reason, the model assigned most of the generated traffic onto those major local corridors ignoring other local roads surrounding them. It may also indicate that the disaggregated zones are still too large to effectively distribute traffic over all local roads. In fact, the model overestimated local road traffic by 15 percent based on the absolute average of all local roads and limiting the maximum assignment error to 32 percent on local road 430. Generally speaking, the overestimation is within the FHWA validation target limits (25%) for this group.

It is worth mentioning that the model estimation for local roads in this study showed moderate improvements when compared with the average absolute error of 25 percent on all validated local roads and the maximum assignment error of 40 percent presented in a previous study (*22*). Not to mention that both studies showed a consistent overestimation on local roads number 315 and 322. Most important, in our opinion, this may explain the improvements in local traffic estimation in relation to the fine zone structure used in our model compared to the coarse zones structure (DA) used in the previous study (*22*). In fact, the promise of HFTDM is fulfilled by improving estimation accuracy on local roads. Even though, the achieved improvement is moderate primarily due to the crude disaggregation method used arbitrary grids.

Model validation conducted for this study is faced with limited traffic counts available. Hence, the validation is limited to nine traffic facilities in the study area with the road network consisting of 2125 links. In addition, model results are heavily dependent on the accuracy of traffic counts used in model validation. In this case, traffic counts were extracted from a hard copy traffic flow map provided by, rather than in a GIS format. Consequently, connecting road link with the corresponding counting station is performed visually. No doubt, this could result in validation error due to miss-assignment of the ground truth traffic count station to the correct road link. Furthermore, traffic counts included a significant portion of through traffic which should be dealt with based on the procedure described NCHRP report 365 (*10*). However, due to the lack of supportive cordon line counts for the study area, this research paper applied a crude approximate method for treating through traffic at each validation location. Admittedly, the method used for the treatment of through traffic has substantial influences to the network validation process and the resulting traffic estimation errors.

Additionally, modeling an area with a limited number of counts can be problematic. Needless to say, the less the number of counts entering the model, the more weight each of these counts will receive during the statistical analysis of the model performance. For example, a single count from the arterial No. 8 will take 50 percent of the weight in the overall model accuracy estimation for all the arterial class, due to only two arterials exist in the study area.

Finally, there is a justified concern that using arbitrary vector grid zone system to disaggregate data most likely would bring various biases and errors into the molding process. Vector gird overlay is a blindly disaggregation process, which in most cases will result in that zone boundaries cut through main highways, busy intersections, major trip generators, and various jurisdiction boundaries. The concern grows for central business district (CBD) area, where grids might cut right through blocks and parcels of commercial and residential developments. Moreover, disaggregating rural, suburban, and urban areas using the equal grid structure ignores the fact that zone size should vary depending on the intensity of human activities within the zone. For example, CBDs with intense human activities should use small size zones, while rural areas should employ larger zones, which can be determined by following building foot prints and neglecting open green areas.

The previous discussion clearly indicates that the proposed HFTDM did show a rationale of overestimation in predicting traffic volume, which was conclusive with previous study that modeled almost the same area and highways (*22*). Also, it can be argued that disaggregating the study area from 48 DAs to 97 fine zones resulted in improved traffic estimation accuracy on local roads, even though the disaggregation was based on a "rude" procedure. Indeed, the model is still in its primary stage of development and is faced with quite a few issues mentioned above. Subsequently, the model needs be revised and refined. Further, the model should include various accuracy checks, which have been established as part of validation process for each step in the modeling process (*23*). Usually, traffic assignment errors can be attributed to errors added form previous steps, such as trip generation and trip distribution, including traffic assignment step. Special attention should be given to the validation of the traffic assignment step component, including network accuracy, link attributes, centroid locations, and centroid connectors (number and location).

Conclusions and Recommendations

The primary goal of this research paper was to build a high-fidelity three-step travel demand model, which is capable of providing network-wide traffic estimates including low-class local roads with improved accuracy. Technological advances in GIS and improvements in GIS-based software such as TransCAD made it a realistic and a feasible goal to achieve. In fact, two modeling concepts presented in this research paper worth further research work. First, limitations of the aggregated traditional TDM due to the coarse zonal structure can be resolved through disaggregating the coarse zones into smaller spatial units such as polygons or grid cells. Zonal disaggregation techniques are based on GIS and weighted areal interpolation method, which utilizes vector grid overlay to create homogeneous zones for building HFTDM. This disaggregation procedure will insure that fine-grained spatial or attribute data are not lost or averaged through aggregation. Consequently, it improves traffic estimation from a TDM. Secondly, to use a more detailed roadway network with fine TAZ structure. The use of all class roads including low-class locals will ensure better assignment results. Moreover, the concept of HFTDM provides network-wide traffic estimation with improved accuracy using practical, non-invasive, and low-cost method.

Recent advancements in computer hardware and software technologies made it possible to easily integrate data between GIS and remote sensing (RS). Integrating remote sensing data into GIS software packages allowed the analyst to overlay RS data layers with other spatial data layer. Also, the integration will provide continuous regional view of the area and the opportunity of extracting GIS data layers such as building foot print from remotely sensed imagery. Indeed, this integration could be further enhanced by including GIS-based parcel tax assessment (PTA) data into the supporting database. Certainly, this tri-integration (GIS/RS/PTA) opens up doors for developing HFTDMs with improved network-wide traffic estimation.

One of the main challenges facing building and validating HFTDM is the lack of data available at fine TAZ level. Analysis at fine zone level will require validation data at "fine-grain" level. Therefore, traffic counting schemes should be extended beyond higher-functional class roads to include low-class ones, such as local. Moreover, the accuracy of the network-wide traffic estimation will rely heavily on the availability of updated, detailed, and accurate roadway network coded with comprehensive and accurate traffic count in a GIS environment. Documented validation standards recommends obtaining traffic counts on 10 percent or more of the region-wide highway segments being analyzed, if resources allow. Also, it is recommended to obtain traffic counts on 10 percent in each functional class over the modeled network (*24*).

The following recommendations are introduced based on the results of this study:

- Applying HFTDM as a source for network-wide traffic volume estimation could reduce our dependency on costly traffic counts collected from traditional sensor-based monitoring programs.
- This research paper recommends running three steps out of the four-step traditional model by omitting mode split step due to the fact that most of the trips to work in Canada occurred by private vehicle (automobile, van, and truck).
- This research paper recommends improving the traditional zonal-based four-step model by introducing a fine TAZ structure instead of the coarse one traditionally used. This fine-zone based three-step model is expected to effectively distribute traffic onto all classes of roads including low-class locals, which in turn will improve the model's capability and accuracy in estimating network-wide traffic flows.
- This research paper recommends using dissemination areas (DAs) as initial traffic analysis zones (TAZs) to start with. This zone structure was selected due to the availability of socioeconomic data from Statistics Canada at this geographic unit. Moreover, DA is considered to be the smallest census zone system which provides a good base for developing high-fidelity TDMs.
- This research paper recommends using improved weighted areal interpolation methods for TAZ disaggregation, which utilizes number auxiliary distributing factors, such as road density and house count, in developing, running, and calibrating the high-fidelity TDM.
- This research paper recommends validation checks for roadway network in terms of network connectivity, network coding errors (missing nodes and links, link directions, etc) and network attribute data.
- This research paper recommends using traffic count data managed in a GIS environment for model validation. Also, traffic counts from a roadway network should be reviewed to ensure that each of them is correctly linked with an appropriate road segment.
- This proposed research paper recommends supporting the validation of traffic estimates with screen line counts and cordon line counts to account for through traffic accurately account for through traffic.

In conclusion, the developed HFTDM modeled low-class local roads with improved estimations. It is believed that disaggregating DAs using vector grids mainly contributed to this improvement. Nevertheless, as mentioned previously, the model is still at an early stage of its development and has to go through a series of refinement and improvement steps. Consequently, one could say that there are still an enormous opportunities to improve traditional four-step model through developing a high-fidelity travel demand model (HFTDM), which is capable of achieving network-wide traffic volume estimation with improved accuracy. This will require using all functional class roadways and spatially disaggregating census-based coarse TAZ structure into fine zones using advanced areal-interpolation techniques. Furthermore, real opportunity exists in employing GIS, remote sensing and tax assessment data for a more realistic/accurate TAZ disaggregation, which consequently would provide improved traffic estimation accuracy at network-wide level.

Acknowledgement

The authors would like to thank New Brunswick Department of Transportation (NBDOT) for the data used in this study and Natural Science and Engineering Research Council (NSERC) and New Brunswick Innovation Foundation (NBIF) for the financial aid to this study.

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