Developing a GIS-based detailed traffic simulation model for the Montreal region: Opportunities and challenges

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1. INTRODUCTION

Deciding on an appropriate transportation planning policy can be difficult. One approach is to try and model the travel behaviour of individuals and then use these models to test the impacts of various policy options. But accurate modeling of individual behaviour is not straightforward. Any analysis of travel behaviour requires an acknowledgement of a vast array of externalities and unpredictable outcomes. While this difficulty will never be completely resolved, the advent of low-cost computing power now affords researchers the capability to process enormous amounts of data quickly. As a result, complex models accounting for thousands or even millions of variables and observations can be constructed and evaluated. Given sufficient data, it is now possible to build - at relatively low-cost - detailed models of urban regions which can be useful in informing public policy.

The road networks in many cities throughout the world, including Montreal, have been modeled according to the deterministic user-equilibrium framework. The present research is not breaking new ground in this respect but one or two departures from the norm are worth noting. First of all, the majority of large-scale traffic models use the EMME/2 software. The model described in this paper uses TransCAD. Secondly, while most models use greatly simplified networks containing only highways and major streets, the present model contains *all* streets in the region. Such detail is possible due to the integration of Geographic Information Systems (GIS) with conventional transportation modeling tools in the TransCAD software.

GIS is a powerful transportation planning tool for several reasons. First and foremost, it can be used to efficiently link travel behaviour patterns and socio-economic data within a spatial framework. Secondly, it incorporates geographic details which are essential in the construction of realistic links and nodes as well as in the discretization of space. Thirdly, it requires little formal programming although such capabilities are available for complex analyses. Finally, GIS generates visual output of the analysis results which are invaluable in both the application and validation of the model.

The retention of local streets and detailed network geometry may bestow only small benefits on a static model of automobile traffic, especially if the assignment method remains aggregated to a system of zones. But these details become essential in accurate models of transit where the precise location of bus stops and their corresponding intersections is necessary to measure walking distances, transfer times, accessibility and overall performance of the transit system. The importance of geographic detail is even greater if an integrated transportation-land use model is the ultimate goal. Land use data exists at the parcel level and transportation data must therefore be at least as disaggregate and as detailed.

2. REVIEW OF CURRENT PRACTICE

Most of the recent research in traffic modeling describes theoretical formulations of dynamic modeling that are ever more adept at capturing the temporal distribution of choices and activities. Static models, meanwhile, are rightly criticized for poorly representing utility-maximization theory and being unable to handle situations where demand exceeds capacity or where congestion is not continuous (Verhoef, 1997). While dynamic models are undoubtedly better at applying the theory, there are usually no direct comparisons of results with static models when used in planning practice (Wu et al., 2001; Nagel et al., 2000; Boyce and Bar Gera, 2003). Researchers are encouraged to pursue investigations into dynamic, micro-level modeling due to the ever-increasing computing power made available.

Modelers likely face the law of diminishing returns whereby enormous additional investment in spatial-temporal complexity will generate only marginal improvements in model quality. This is especially true when the model is used to forecast several years into the future. The fact that most transportation planners working both inside and outside academia continue to use static model frameworks such as EMME/2 is evidence of their persistent relevance (Florian, 1999; JPINT, 1998; Tremblay, 2004; Krajczar, 1998).

If static models continue to represent the norm in large-scale transportation modeling, methods of improving the static framework are of natural interest. One of the significant events in this regard is the advent of Geographic Information Systems (GIS). Since the early 1990s, enormous progress has been made in the development of GIS which offer solutions to problems inherent in the transport modeling process, including the modifiable areal unit problem (MAUP), boundary problems and spatial sampling, spatial dependency and spatial heterogeneity (Miller, 1999). Spiekermann and Wegener (2000) provide a good example of how GIS can be used to mitigate the problems inherent in the use of zone systems for transportation analysis. Furthermore, GIS allows for greater flexibility in managing data sources, can be used to construct highly detailed transportation networks and generates easily-decipherable visual output (Arampatzis et al., 2004). Also, the general user-friendliness of a GIS interface can greatly reduce the costs, in terms of both time and money, incurred in the construction of a transportation planning module (Souleyrette and Anderson, 1998; Johnston and de la Barra, 2000). Finally, as the modeling practice becomes more and more concerned with spatial and temporal disaggregation, GIS plays an increasingly important role (Frihida et al., 2002).

3. DATA

The study area for the traffic assignment model was defined as the three census metropolitan areas (CMAs) of Montreal, St-Jean-sur-Richelieu and Salaberry-de-Valleyfield. The census tracts and enumeration areas of these regions formed the basis of the system of traffic analysis zones. The travel demand data was based upon the

1998 O-D Survey undertaken by the Agence Métropolitaine de Transport (AMT, 2001). Detailed street network data with link travel times was acquired through DMTI Spatial Ltd. This network contained approximately 135,000 bi-directional links.

4. METHODOLOGY

4.1. Zone system and O-D matrices

The three CMAs comprising the study area were segmented into 947 zones. The centroid of each zone was the point from which traffic was generated. In addition, 34 pre-existing network nodes located around the perimeter of the study area were used to generate external trips. The result was a 981x981 O-D matrix.

Three one-hour O-D matrices for auto-drive trips were constructed based on the trip data provided in the O-D survey. The first matrix contained all trips that began between 6 am and 7 am, the second matrix contained trips beginning between 7 am and 8 am, and the final matrix contained trips beginning between 8 am and 9 am. Total travel demand for the three hours was roughly 878 000 trips.

4.2. Construction of the network

Traffic assignment models in TransCAD require the construction of network files. A network file is a digital representation of a line layer as a series of nodes and directional links. When a network file is built, the user is asked to provide a set of links in a line layer that will form the basis of the network file, as well as link attributes to be included in the network. Examples of link attributes are segment length, travel time and capacity.

In order to model congestion, additional line layer attributes had to be incorporated into the network file. The BPR volume- delay function has two parameters, alpha and beta, which vary by segment according to the road's functional class and free flow speed. Each network link therefore had to be assigned values for alpha and beta. The present model is based upon parameters estimated by Horowitz (1991) – see Table 1. Horowitz did not provide an estimate for global parameters on urban roads operating under interrupted flow conditions because factors other than the volume-to-capacity ratio – such as signals and intersection characteristics – affect the link performance. Nevertheless, global values were required and were estimated ad hoc: alpha was taken to 0.6 and beta was taken to be 2 based on the trends in parameter variation by road functional class (see Table 1). Delays incurred at intersections had to be estimated in a similarly coarse fashion and were applied globally. A left turn was assigned a cost of 0.5 minutes, a right turn 0.2 minutes and a through movement 0.05 minutes.

The next step in the network construction process is the connection of centroids to the actual network using centroid connectors. These dummy links are supposed to substitute for local roads. Therefore, they should not connect directly to highways or highway access ramps but rather to collector streets or local roads. TransCAD's GIS capabilities were used to select those nodes that were not connected to highways or ramps. Only nodes in this set would be considered as candidates for connections to centroids.

Once constructed, the centroid connectors were assigned a travel speed of 40 km/h – the same as for local streets. The travel time over the link was simply the length divided by the speed. Finally, each centroid connector was assigned a capacity of 99999 vehicles per hour in order to prevent travel time increasing with volume.

4.3. Validation and adjustment of the model

Overall model performance is evaluated based upon comparisons between predicted and observed flows on those links for which there are observation data. The observed flow data provided by the MTQ contained 197 observation posts, each one corresponding to a single directional link.

Several statistics could be computed to quantify the model's performance. The first is the percentage error which is simply the difference between total observed and predicted counts divided by the total observed counts. In general, the predicted flows were expected to be lower than the observed flows, especially when aggregated over all the observation posts. While it is possible for the O-D survey to under-represent the population, it is unlikely that it is over-representative in the aggregate. The detailed nature of the street network was expected to provide many alternate paths and thereby reduce flows over some routes.

The next statistic that can be computed to measure performance is the percent root mean squared error (% RMSE). This is an aggregate statistic which measures the performance of the model as a whole, comparing forecast flows to observed counts. The U.S. Department of Transportation's Travel Model Improvement program recommends a %RMSE of less than 30 (TMIP, 2001).

Finally, a linear regression model was employed to measure the correlation between forecasts and counts. Ideally, the intercept of the linear function should be zero and the slope of the line should approach 1. The USDOT recommends a region-wide R-squared of at least 88% (TMIP, 2001.).

After the level of performance had been assessed using the above statistics, an error investigation began. One major potential source of error lies with the O-D matrix and its validity was checked immediately following a trial run using visual inspection and the text output of the assignment procedure. The matrix should display an expected level of travel demand and this demand should be equal to the total demand expressed by the appropriate records in the tabular survey data.

The first level of assignment error-checking was accomplished using the flow map. The flow map is a combination of two thematic map types: a colour theme, and a scaled symbol theme. Each link is assigned a colour based upon its volume-capacity ratio and a width based upon its hourly volume (see Figure 1). Serious network problems were apprehended by looking at this map. For example, a link on a major highway may have had no colour and only a hairline width, indicating that there was no traffic on that link. Such occurrences suggested either there is no access to this link due to an error in digital representation, or the link had faulty attributes that rendered alternative paths less costly.

The flow map also displayed illegal traffic movements. These were especially common on bridges and freeways where access was limited. If traffic was jumping onto overpasses instead of using ramps, it would usually be apparent in the flow map. These problems could be corrected by adding turn prohibitions and TransCAD provides a tool for doing this.

Another method of error detection involved looking at a scatter plot of forecasted vs. observed traffic volumes. Data points that were especially far from a line traced from the origin with a slope of 45 degrees represented locations where the model was performing poorly and these were investigated. Determining the root cause of these inaccuracies, however, was very difficult, especially if the link in question is a controlled urban road.

The Montreal region affords a natural benefit to modelers because of its geography. Both the city of Montreal and the city of Laval occupy islands in the St. Lawrence River. Both of these islands are accessible by 22 bridges, 21 of which hosted MTQ observation posts. Obviously, there is no other way for a vehicle to enter these two islands, so this setup allows for a very efficient screen-line and cordon analysis (see Figure 2). It was hoped that, even if predicted flows on individual bridge links did not match the observed flows, the forecasts for each region taken as a whole would be a good fit with observations. If this was in fact the case then the characteristics of individual bridges could be modified so that the flow was properly distributed.

A similar approach was taken with freeway links. In an interrupted flow regime, it is usually the signaling and signage that determines the road capacity. The performance of arterial, collector and local roads was not expected to be very good due to the complete absence of intersection data in the model. The capacity of freeways, on the other hand, depends mostly upon the free-flow speed and the number of lanes, both of which had been accurately represented on most freeway segments. It was therefore expected that the performance of freeway links would be good indicators of the validity of the network and the model in general. Since most of the region's large bridges carry freeways, freeway links were of interest in the validation process because their performance has a direct effect on the performance of bridges.

5. RESULTS

Model performance results appear in Table 2. This table shows that the r-squared for all 3 hours of 0.8759, and the %RMSE is 30.3. The two columns on the right-hand side of the table show the number of bridge and freeway links whose forecast flows were within 5% of observed values. Overall, the model is still approaching the minimum TMIP performance standard but the accuracy of forecast flows on individual links varies considerably.

In addition to the %RMSE and the r-squared, the %error can also be used to evaluate model performance. As can be seen in Table 2, the first hour of the AM peak generates traffic flows 15% below observed levels. In the second hour, forecast flows are nearly 6% above observations. In the third hour, flows are roughly 2.5% too low. It is difficult to explain the “missing” traffic in the first hour based solely upon the aggregate performance measures. However, the “excess” traffic forecasted between 0700 and 0800 may be due to the inability of the static model to deal with queues. During this hour, many Montreal arteries experience demand well above capacity resulting in queue formation upstream of the link and forced flow on the link itself. The static model cannot represent either of these phenomena and so flow continues to appear on links even though absolute capacity has been reached. The fact that the static model performs well when all three hours are taken together is evidence of this phenomenon. By 9 am, most of the queues on the region’s roads have cleared and so, over the three hour AM peak, total demand has been met and the total percent error is around -3%.

Three additional aggregate measures were used to test the model’s validity. Average trip length, average trip time and average trip speed were calculated based upon output generated by TransCAD in the traffic assignment procedure. Average trip length was computed by dividing the number of vehicle-kilometres traveled by the interzonal travel demand. Average trip time was obtained by dividing total vehicle-minutes traveled by interzonal travel demand. Finally, average speed can be computed by dividing average trip length by average trip time. The results are enlightening (see Table 3).

The longest trips, both in terms of distance and time, occur in the first hour of the AM peak. This hour also contains the smallest percentage of intra-zonal trips (which are not assigned to the network), and the smallest travel demand. These findings are intuitively correct. People who must make longer trips must depart earlier if they wish to arrive on time. Also, since most stores and schools are still closed between 6 and 7 am, there are very few local trips being made. Furthermore, this hour displays the highest average vehicle speed which can be attributed to the relatively low level travel demand and therefore low congestion. Moreover, people making longer trips are more likely to use high-speed facilities like freeways.

During the second hour, between 7 am and 8 am, average trip length is considerably shorter while average trip duration is only slightly shorter than in the previous hour. Travel demand has nearly doubled and the percentage of intra-zonal trips has increased. Once again, this situation seems to correspond well with reality. This is the hour during which most people leave for work or school and local trips become more prevalent as stores start to open. Travel demand reaches a peak. Therefore, roads are highly congested and average speed drops. Trips are shorter on average, but most of the time savings are cancelled out by the increased congestion.

During the final hour of the AM peak, demand drops off only slightly, but trips are noticeably shorter and the intra-zonal percentage is much higher. Average speed increases due to easing of congesting indicating that fewer trips are being made along high density corridors. This, in turn, suggests that trip purposes are more local and more “random”. Many people are commuting to work and school, others are running errands, going to meetings or dropping off family members or colleagues.

The progressive diversification of trip purposes with each successive hour can be verified in the analysis of the O-D survey presented in Table 4. In the first hour, work trips comprise nearly 80% of the total. By the third hour, that share has decreased to 57% while the share of “other” trip purposes has risen to 36%. Also note the increase in the percentage of shopping trips from 0.4% in the first hour to 5.2% in the third. It seems, therefore, that the model is accurately representing these changes in travel patterns.

6. CONCLUSIONS

The goal of this research was to build a detailed model of travel behaviour in the greater Montreal area. It was hoped that current GIS technology would allow this goal to be accomplished fairly easily without an enormous allocation of labour and monetary resources. Indeed the authors, working over a 2-year period, have been able to construct a 240,000 link network that can reliably predict current traffic flows. In fact, the present network performs sufficiently well that the next stages of the regional planning research can be contemplated, while the model itself is improved over time.

Such a detailed transportation model lends itself to integration with land use models where the areal unit of interest is the individual parcel. Indeed, this integration is essential in effective forecasting of land use, urban development and the interaction of built form with travel patterns. The transportation model described in this paper serves as a strong foundation for achieving this objective.

7. REFERENCES

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8. TABLES

Table 1 – Estimated BPR function parameters (Horowitz, 1991)

Coefficient	Freeways			Multilane		
	70 mph	60 mph	50 mph	70 mph	60 mph	50 mph
alpha	0.88	0.83	0.56	1.00	0.83	0.71
beta	9.80	5.50	3.60	5.40	2.70	2.10

Table 2 – Performance of AM peak hour models

Hour	R-squared	% RMSE	% Error	Bridge links within target range (out of 42)	Autoroute links within target range (out of 44)
0600-0700	0.8692	35.89391	-15.1613	2	6
0700-0800	0.8305	36.49927	6.222203	6	8
0800-0900	0.8201	35.31554	-2.54309	7	5
AM Peak (all 3 hours)	0.8759	30.34158	-3.27609	8	7

Table 3 – Performance of AM peak hour models; trip data

			Trip Lengths		
Hour	Total Demand	% Intra-zonal	Minutes	Kilometres	Avg. Speed
0600-0700	193559.47	7.75	22.44	21.07	56.33
0700-0800	378600.05	8.80	20.06	16.60	49.67
0800-0900	352772.96	11.36	14.17	13.52	57.21
AM Peak (all 3 hours)	924932.48	9.56	18.37	16.40	53.58

Table 4 – AM Peak auto-drive trips classified by purpose

	Work Trips	School Trips	Shopping Trips	Other
0600-0659	79.66633	1.633656	0.3913191	18.3882659
0700-0759	67.96934	4.385146	1.2195222	26.8132624
0800-0859	56.57752	4.329476	5.2275161	36.1289279

9. FIGURES

Figure 1 – Traffic assignment model output

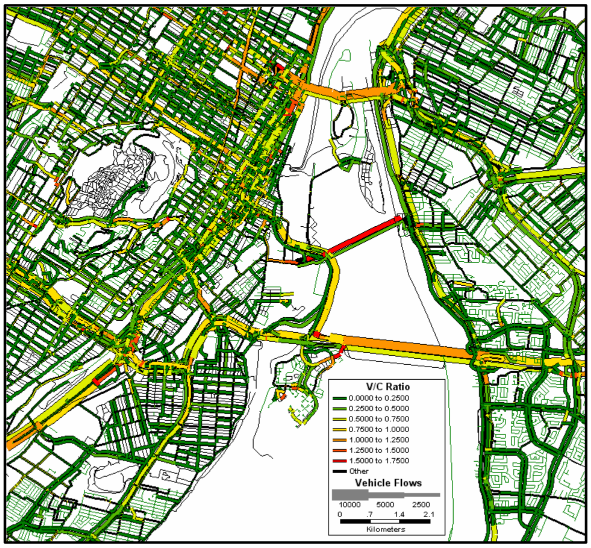

Figure 2 - Montreal Area bridges