Dynamic Spatial Analysis of Urban Travel Survey Data using GIS

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Abstract

GIS-T is already recognized as an important domain for the analysis of urban transportation context. However, for the visualization of planning and modeling situations, some new tasks have to be deployed to illustrate complex phenomena emerging from large-scale regional telephone-interviewed household travel survey data such as those conducted at a 5% sampling in Montreal, every five years (400,000 trip records with 80 attributes). Using ArcGIS, several applications about an average weekday are developed: demonstration of the active population dynamics, in space and time, within an urban area, measure of the difference of accessibility between public transport and private car, assessment of the respective residents' consumption of road network resources and infrastructures, and estimation of spatial modal shares and vehicle occupancy.

Key Words: Origin-destination travel survey, spatio-temporal GIS, urban transportation

Introduction and research background

Nowadays, urban transportation systems analysis and modeling require several know-how and knowledge for responding to actual challenges and issues (energy, environment, urban sprawl, demographics, congestion, infrastructure planning and rehabilitation). Amongst specialized tools used for medium and long-term studies, information technologies and visualization tools are becoming prominent.

Generic in nature but specific to the methodological procedures undertaken in the Greater Montreal Area (GMA), the CATI (Computer-Assisted Telephone Interview) household survey is conducted about every five years over a 5% sample. Typically, it represents about 160,000 people belonging to 65,000 households declaring some 400,000 individual trip records for an average weekday. Individual trips are geo-referenced for the residence, trip origin and destination, modal junction points (kiss-and-ride and park-and-ride locations), and are described for their household and personal characteristics (age, gender, car license, car ownership, income) in addition to the trip attributes (purpose, mode, departure time, train-subway-bus routes taken if traveling by transit, bridges and highway taken if traveling by car). The validation of the interviews' answers and the completion of the trip details are executed by a GIS-based program (address matching, geo-coded trip generators, access calculations, transit network in service, shortest path computations). The survey method has been described in several papers (Chapleau 2001, 2003). Figure 1 shows the three most important screens of the CATI software to explain how the travel survey data are gathered.

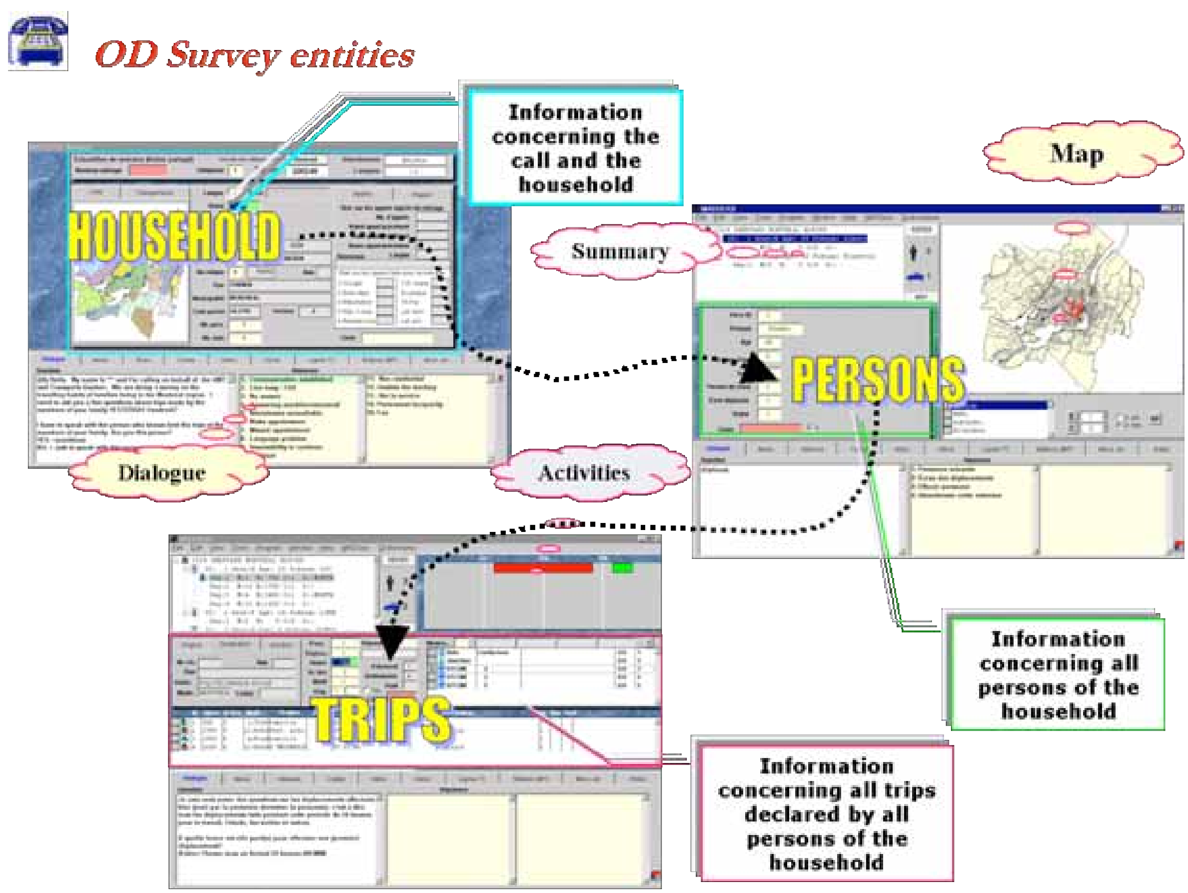


Figure 1. CATI household travel survey in Montreal: respective screens upon household composition, person attributes, trip characteristics (from Chapleau, 2003).

In the context of this survey, the travel and trip data are processed within a so-called Totally Disaggregate Approach (TDA, Chapleau, 1992) which means that all the information (travel demand, networks, territory) is processed simultaneously, and at a very fine level of spatial resolution. For example, Figure 2 shows the information elements considered in a public transport trip. The framework is adapted to many sorts of analysis: travel demand, socio-demographics, transit network trip assignment, cost and revenue allocation, etc.

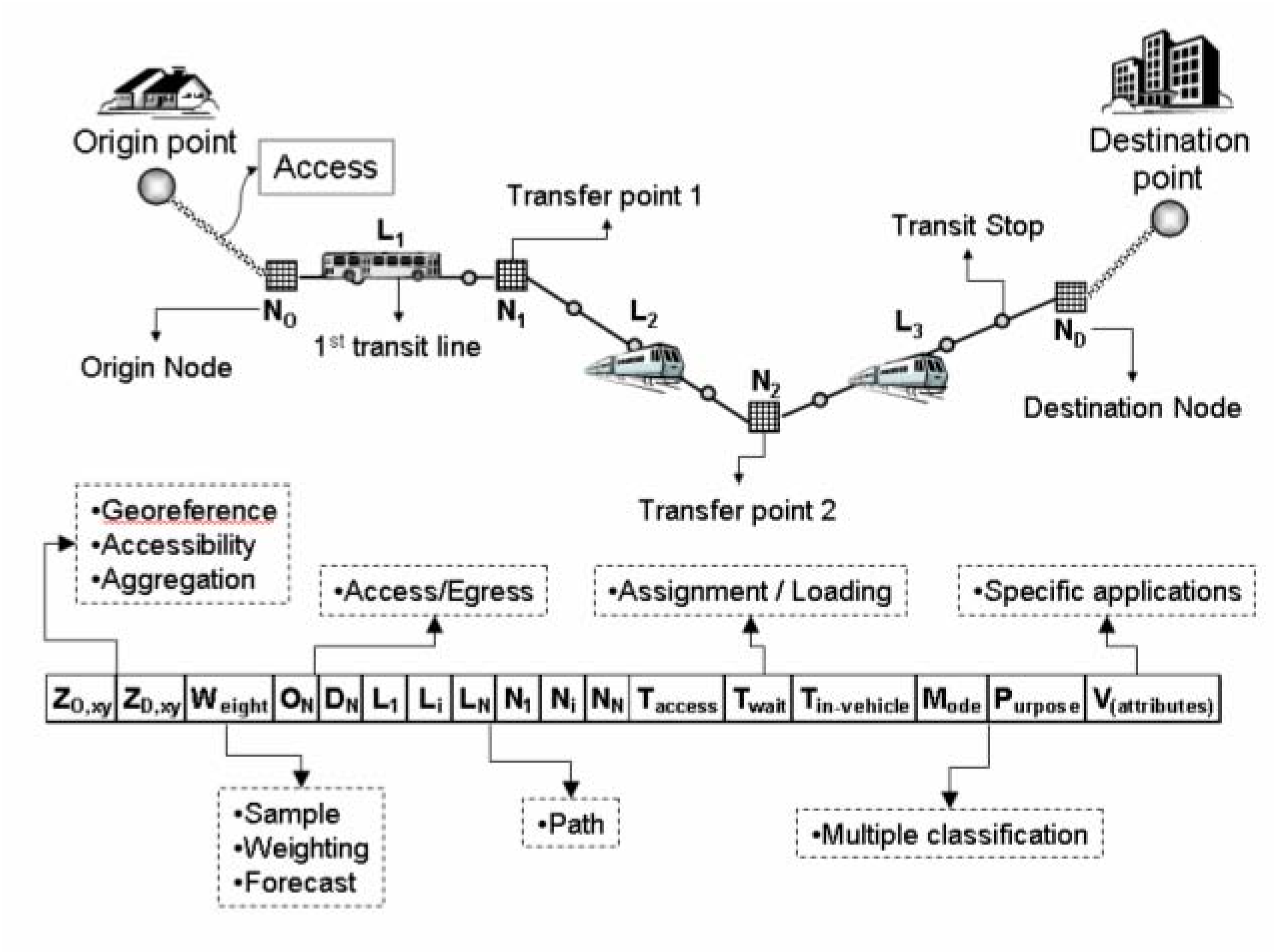


Figure 2. Modeling of a transit trip (access, travel, transfer travel times, and person attributes) within the totally disaggregate approach.

The purpose of this paper is to illustrate different kinds of analysis done with these data when some of the best functionalities of the actual GIS systems (like ArcGIS) are contributing to a comprehensive and practical urban transportation analysis as experienced in the Greater Montreal Area. As such, it follows efforts on visualization already made by Goodchild (2000) and more recently on travel diary data (Yu and Shaw, 2004). The following sections present six aspects of urban transportation analysis and modeling undertaken with data coming from the database environment developed around the travel survey: the dynamics of the urban space occupancy, the modeling of the general laws affecting urban transport, the measure of transit performance, the comparison of car and transit accessibility, the illustration of transport consumption in a geopolitical context, and the illustration of special travel phenomena typical of a Central Business District. Data from the Montreal case are used to demonstrate the relevance of the selected GIS concepts and methods.

The Dynamics of urban land use

Two phenomena are suitably well represented by animation, where the layer structure facilitated the construction of images at different times. The first example shows the dynamics of the active population within the Greater Montreal Area for an average weekday – result from the processing, by an object-oriented model, of the individual Origin and Destination trips hour by hour. Figure 3 emphasizes the importance of the Central Business District for work, study and shopping trips.

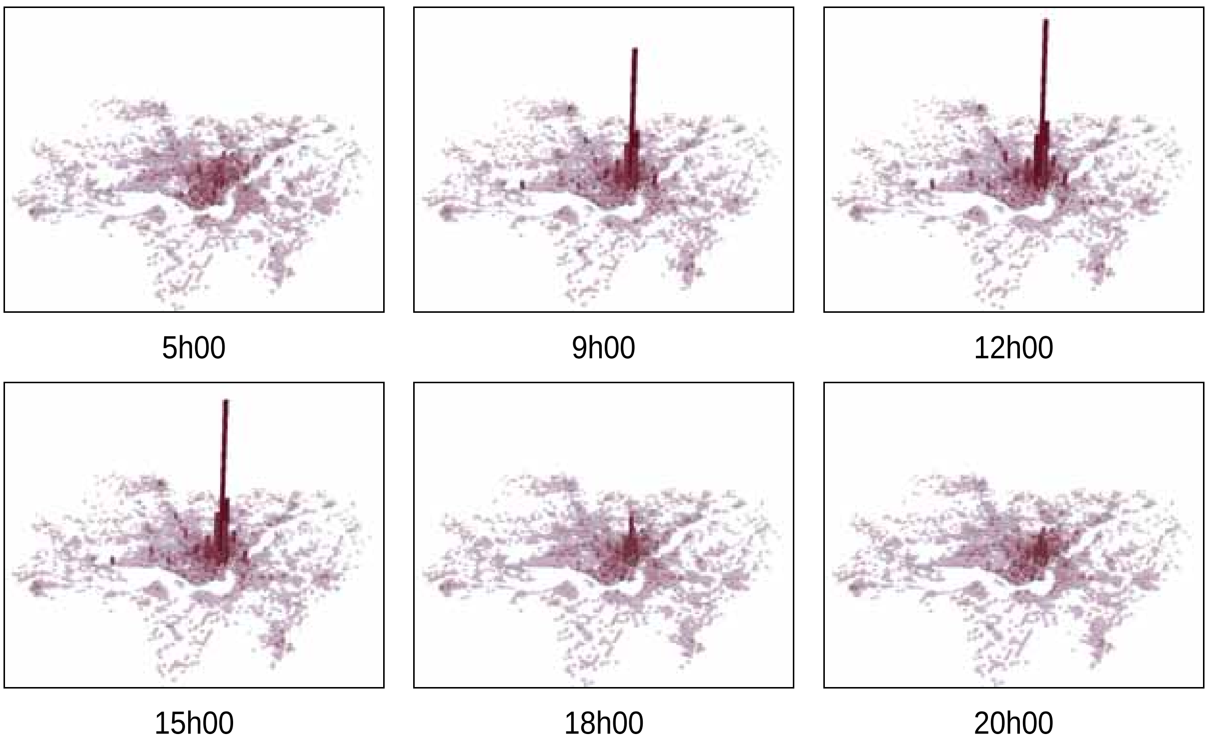


Figure 3.Temporal dynamics ,showing the CBD occupancy resulting from the processing of every O-D trip over time (source: GMA 1998 O-D travel data, 5% sample).

A similar demonstration is obtained when processing data from the 1996 Statistic Canada Census, with the variable “dwelling construction period”. The respective relationship between the transportation infrastructures (highways, bridges, commuter rail lines, subway) and the dynamics of urban sprawl is then scrutinized in the context of accessibility indices (Morency, 2004) and network-oriented definition of space (Figure 4).

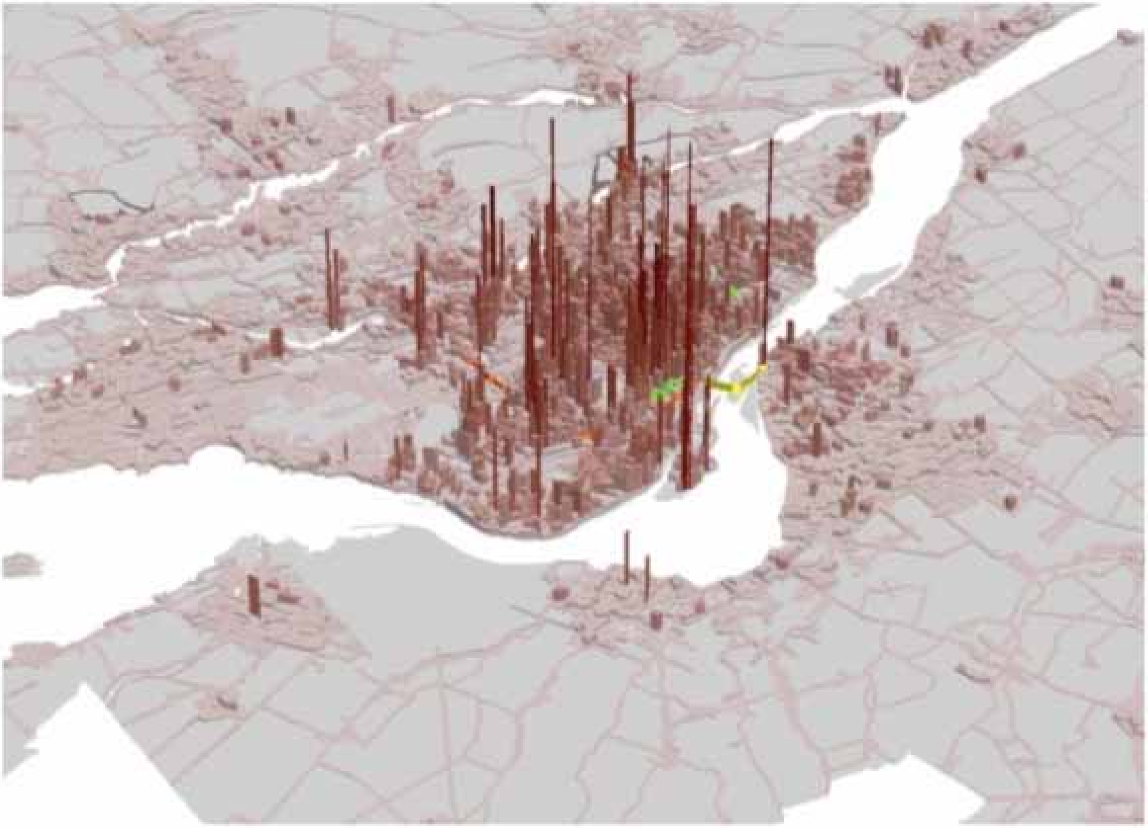


Figure 4. .Dynamics of urban sprawl expressed by dwelling construction periods for about 5000 enumeration areas over time (source: 1996 StatCanada Census, by enumeration areas).

The Modeling of General Laws affecting the Urban Travel

The main goal of the large-scale Origin and Destination surveys is to understand the principal trends affecting travel behaviour. Over the years, it happens that the Greater Montreal Area has a very monocentric (around the CBD) pattern for several characters. The most substantial issues concern the respective spatial characteristics of the modal split in terms of public transport; this phenomenon is inversely correlated with car ownership and household size. Figure 5 shows these typical trends over the Greater Montreal Area. Household size is very low in the CBD and its periphery, and has been always declining with time, for any specific location, since 1970. Urban sprawl consequences are multiple: declining transit share, higher motorisation, younger, richer and more mobile people at longer distances from work and study. Spatial demographics is a new area for studying medium and long-term consequences of urban sprawl (Chapleau, 2003).

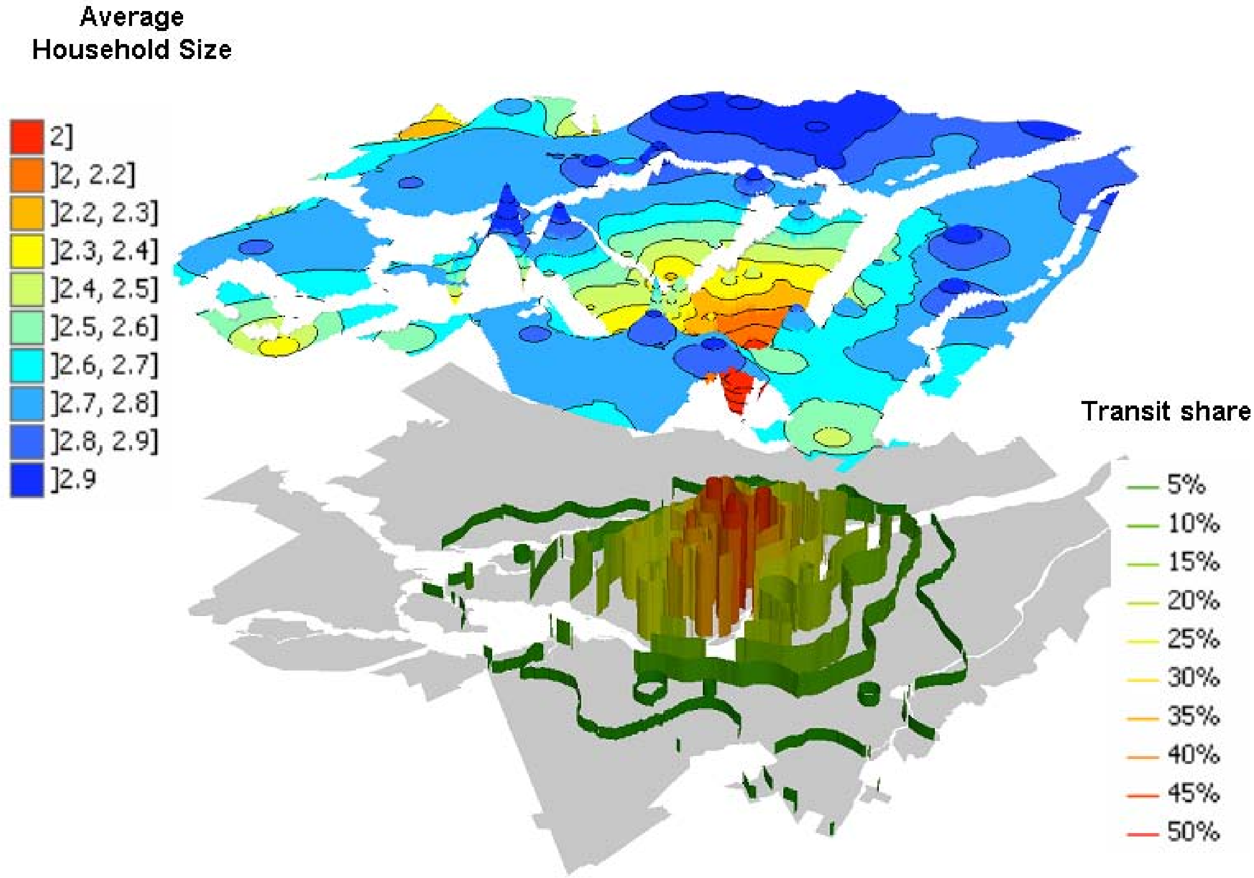
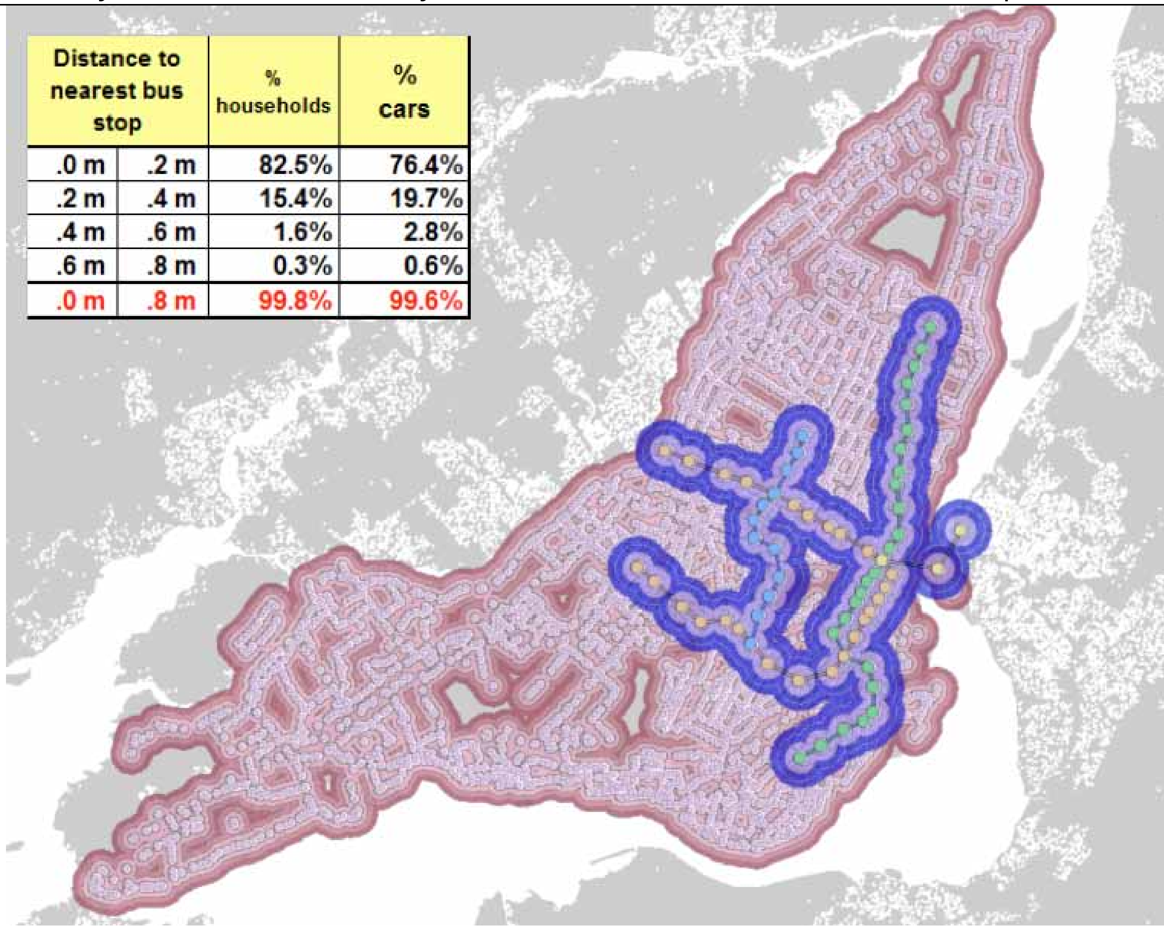


Figure 5. Two unrelated phenomena: evolution of household size with distance from CBD, and transit share declining with distance from CBD (illustrated with ArcGis, from 65 municipal sectors values (1998 survey)).

Measuring the Role of Transit Accessibility and Performance

Planning equity and efficiency in public transport is a strict reality of life. A long tradition of level of service standards has conducted the transit planner to structure the geometry of the network to satisfy mostly the ones who need the public service. The following figure (Figure 6), produced with standard buffer functions of GIS tools, shows the dynamic measure of relative accessibility of households (measured with appropriate buffers). In this case, the transit network is clearly oriented to serve people without cars.

The credibility of transit planners is often weak when they use such arguments that a bus is equivalent to 50 or 60 cars in terms of road occupancy; this may be true on some occasions, but one would be interested to know where and when. To look at this issue, a very strict experiment has been undertaken for the Montreal transit authority network, comparing real planned service for a 6:00 to 9:00 a.m. peak period to the ridership assignment over the respective components of the network. Incidentally, these are the more favorable conditions for transit usage. The question consists to measure spatially the average occupancy ratio of any segment of the bus routes. The result, as illustrated in Figure 7, is surprising and does not correspond, on the average, to the declared policy of the public messages. In fact, very few segments are reaching the public targets that would be really benefiting to the environment. This reality should suggest other strategies to convince people to use transit. Moreover, for policy reasons, it is necessary to convert the linear bus occupancy to some geopolitical values. This last output is shown in Figure 8, where transit link data have been aggregated to municipal sectors. In fact, the average bus occupancy is around 25 passengers for the complete three-hour peak period; this is considered as a very good performance.



Distance to nearest bus stop		% households	% cars
.0 m	.2 m	82.5%	76.4%
.2 m	.4 m	15.4%	19.7%
.4 m	.6 m	1.6%	2.8%
.6 m	.8 m	0.3%	0.6%
.0 m	.8 m	99.8%	99.6%

Figure 6. Access measure to transit network for households and cars, for increasing distances to nearest bus stops; Montreal transit Authority, 1998 O-D survey).

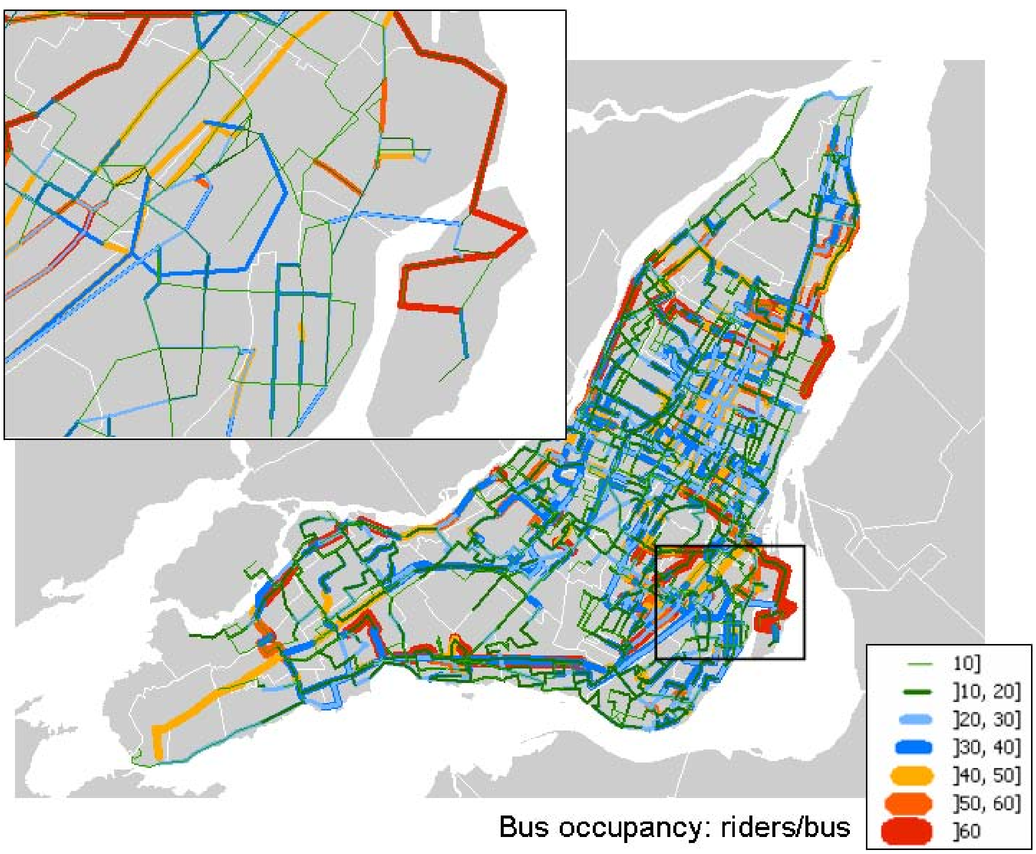


Figure 7. Calculation of bus occupancy for every transit segment of the network, as measured for the a.m. peak period of fall 1998 (Montreal data).

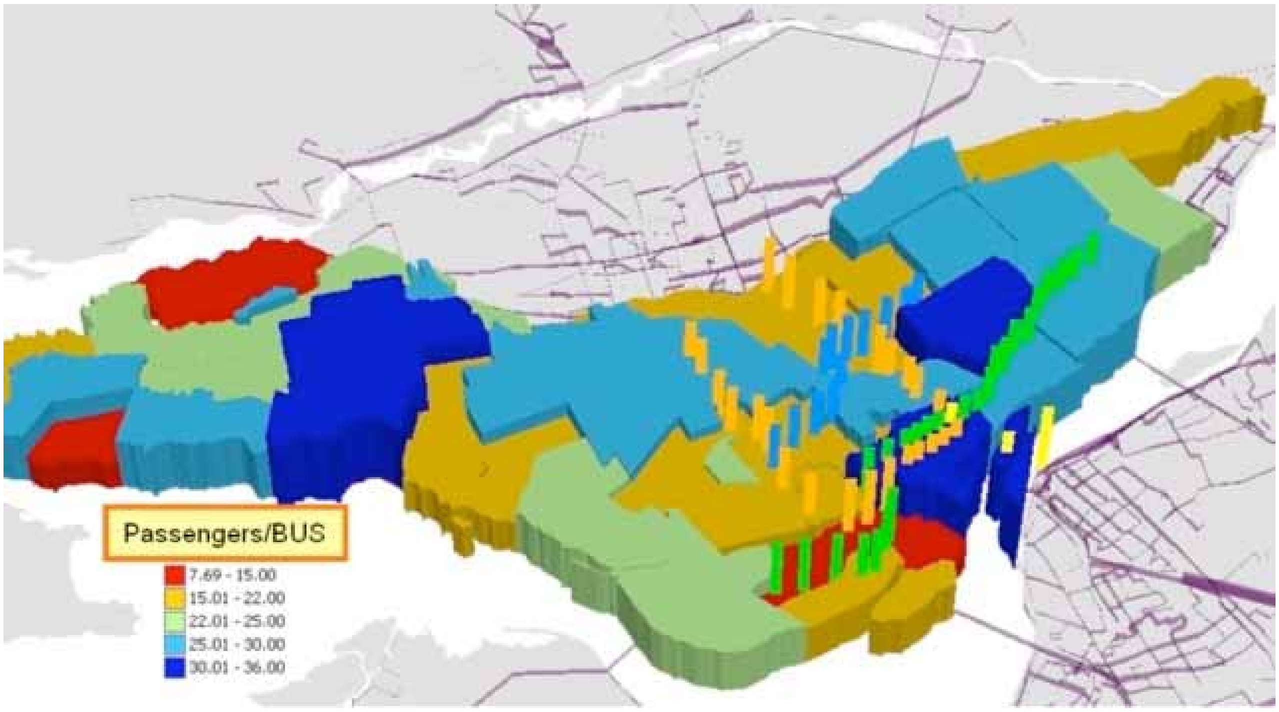


Figure 8. A.m. peak period bus occupancy for the Montreal Transit Authority, by municipal sector: observed demand from O-D travel survey against operational data (departures before 9:00 a.m.); Montreal subway is illustrated and subsists as the major component of regional transit usage.

Overall, the Greater Montreal Area has a specific spatial pattern, in relation with low car ownership, aging people and presence of a quality transit supply (subway). The spatial distribution of modal split is clearly defined (Figure 9).

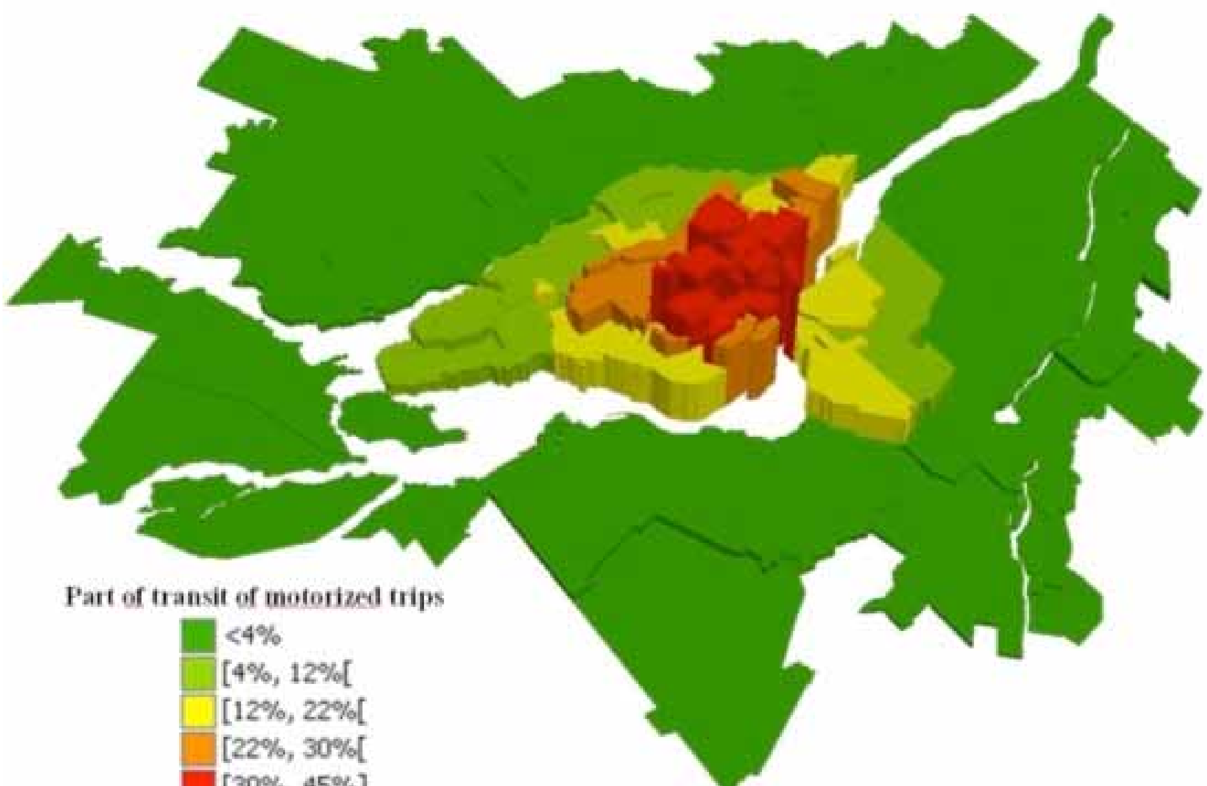


Figure 9.Transit modal share, spatially distributed around the subway in the Greater Montreal Area (source: 1998 O-D travel survey).

Comparing accessibility by car and by transit

To illustrate the importance, in terms of general accessibility, of the respective urban transportation networks, a special procedure has been derived. In the case of the coverage of the road network, we define a measure called “road network occupancy index” (as the percentage of territory accessible with a 100-meter buffer around the road network). Figure 10a shows the resulting coverage. For the public transport network where bus stop are considered accessible within a 500-meter buffer representing by foot access, the resulting image shows a very poor service in outer suburbs (Figure 10b).

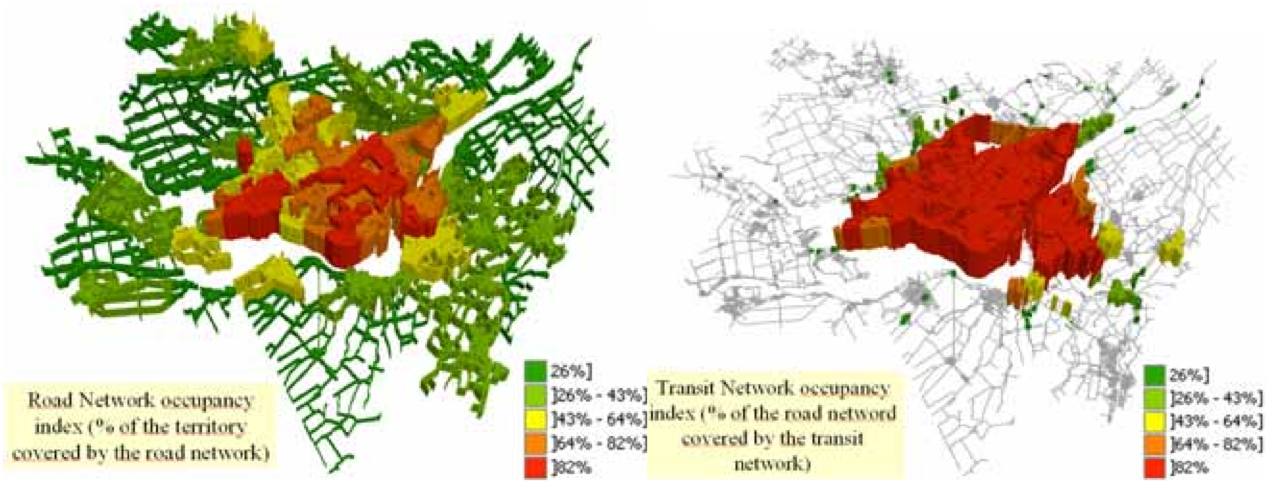


Figure 10. a)Road network occupancy index: coverage area % with a 100-meter buffer from every road segment.

b) Transit network occupancy index: % of the road network covered by a 500-meter buffer from every bus stop.

Illustrating the infrastructure usage in a geopolitical context

Very often, in the metropolitan context, we observe strong discussions about the relative consumption of transportation infrastructures, and the consequence of the maintenance burden associated to it. A congestion charges program could be implemented. To identify the relative benefits of different communities, the following analysis tasks are elaborated:

- For the 15 bridges around the Montreal Island, calculations are undertaken to measure the relative usage of these very congested infrastructures; every individual trip is simulated along its shortest path from the trip origin to the declared bridge (question answered in the survey) and from the bridge to the destination; meanwhile, knowledge of the residence of the person making the trip is known and the respective volumes are calculated. (Figure 11)
- Figure 12 shows the result of a comprehensive exercise of a trip assignment on the road network of the respective share made by the residents of the five large geopolitical territories of the Greater Montreal Area. The vehicle-kilometers made by every trip of any resident is accumulated and assigned on the shortest paths from origins to destinations. It enables the transportation planner to identify the benefits and the externalities of the sources of private travel demand. The results coming from the O-D travel survey (large numbers coming from the 5% sample) appear to be significant and coherent. It seems sufficient to test and derive some policies about environmental impacts and respective cost allocation for the maintenance of the infrastructure.

The visualization of those who benefit and those who are impacted by the traffic – we recall that, thanks to the disaggregate approach, all the attributes of the trip are maintained available for the analysis (age, gender, residence location, income, trip purpose) – may facilitate negotiation upon who must pay or who must be compensated in urban transportation. Recent emergence of health concerns in urban transportation makes these representations relevant.

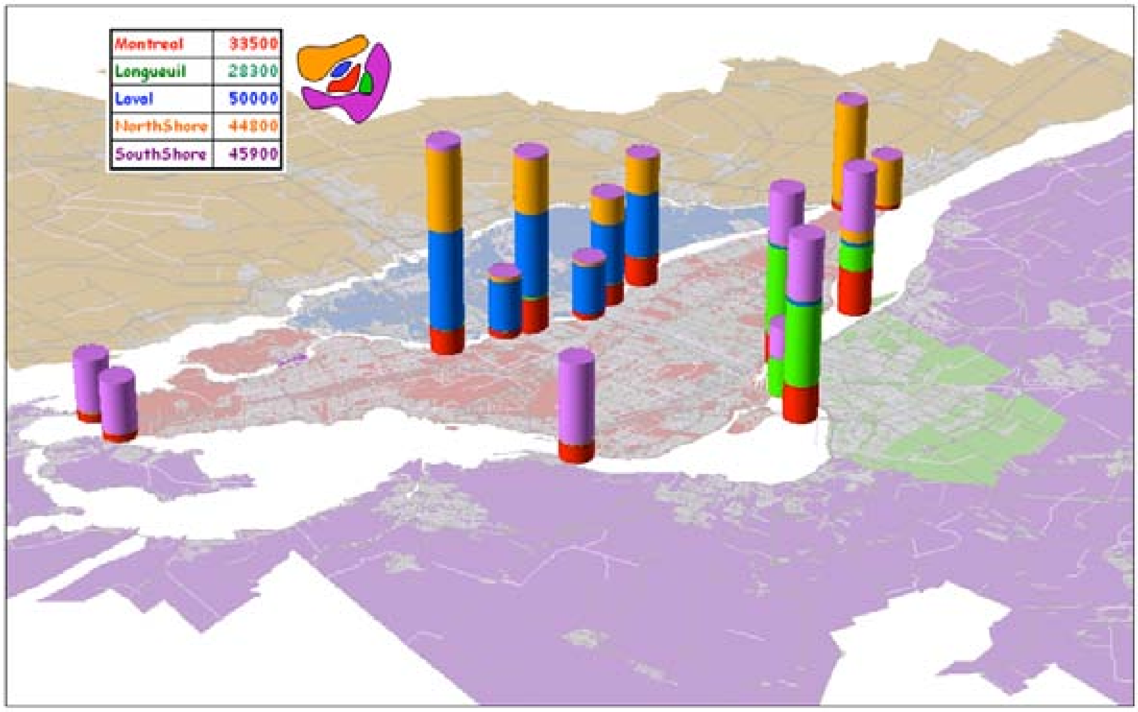


Figure 11. 15 bridges around the Montreal Island. The colors correspond to the traffic volumes by car from residents of the respective territories, in the a.m. peak period. Source: 1998 O-D survey.

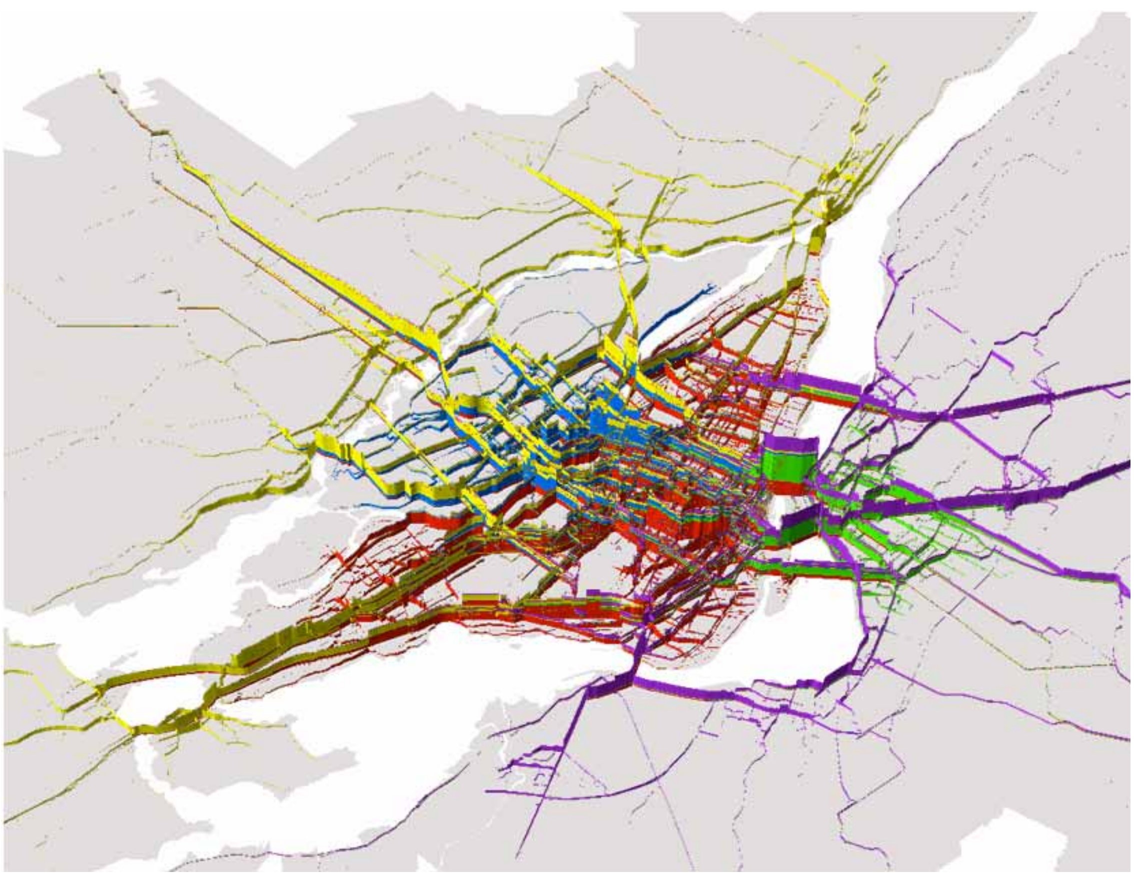


Figure 12. Respective usage of the road network by the inhabitants of the 5 geopolitical (colored) districts of the Greater Montreal Area in the a.m. peak period. Source: 1998 O-D survey.

Illustrating specific mobility phenomena: activities related to the CBD

Amongst the numerous questions about urban travel behavior, most of the time individual and household activity patterns are scrutinized. It is relatively rare that the Central Business District is the focus of the analysis. In the following representations, several GIS techniques are used to look at patterns that lead to special differentiation between some trip attractors and interchange stations.

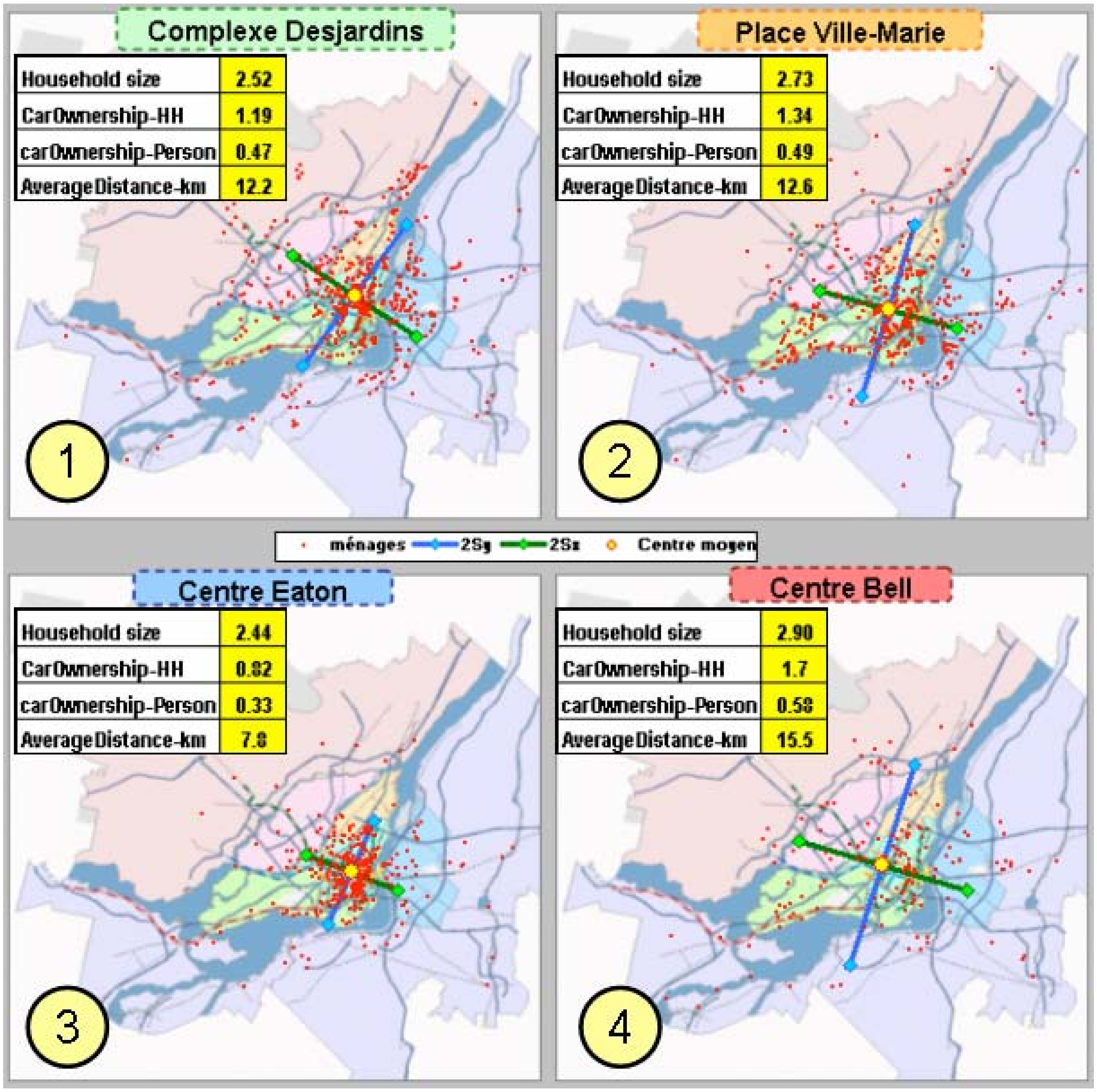


Figure 13. Comparison of four CBD Montreal trip attractors: 1) Mostly institutional employers; 2) Mostly business employers; 3) Mostly shopping center; 4) Mostly entertainment center.

Figure 13 shows the different characteristics of four of the most important trip attractors in the Montreal CBD. The drawings represent the distribution of trip origins and the standard deviation ellipse axes. The measures of household size, car ownership (income) are highly correlated with distance from CBD and language spoken (French in the East, English in the West). The first two are of the business (workers' areas) type; ellipse axes indicate the influence of income and language character of the sites. The third trip generator is a shopping center attracting more urban and more transit-oriented customers. The fourth generator is notably the hockey arena of the Montreal's Canadiens: the influence of the site reaches the outer suburbs. This exercise is an example of the kind of disaggregate analysis that can be undertaken on the trip destination perspective.

The study of the behavior of the weekday travelers in the CBD is significantly affected by the underground (an interconnected underground network of 30 kilometers, well suited to the winter season). Subway stations, rail terminals and suburban bus terminals act as major intermodal interfaces to this walking (privately managed) network. A specific research (Piché, Chapleau, 2005) is ongoing on the geo-coding of this 3D underground, and a GIS analysis (Figure 14) shows the respective origin and destination pedestrian flows involved.

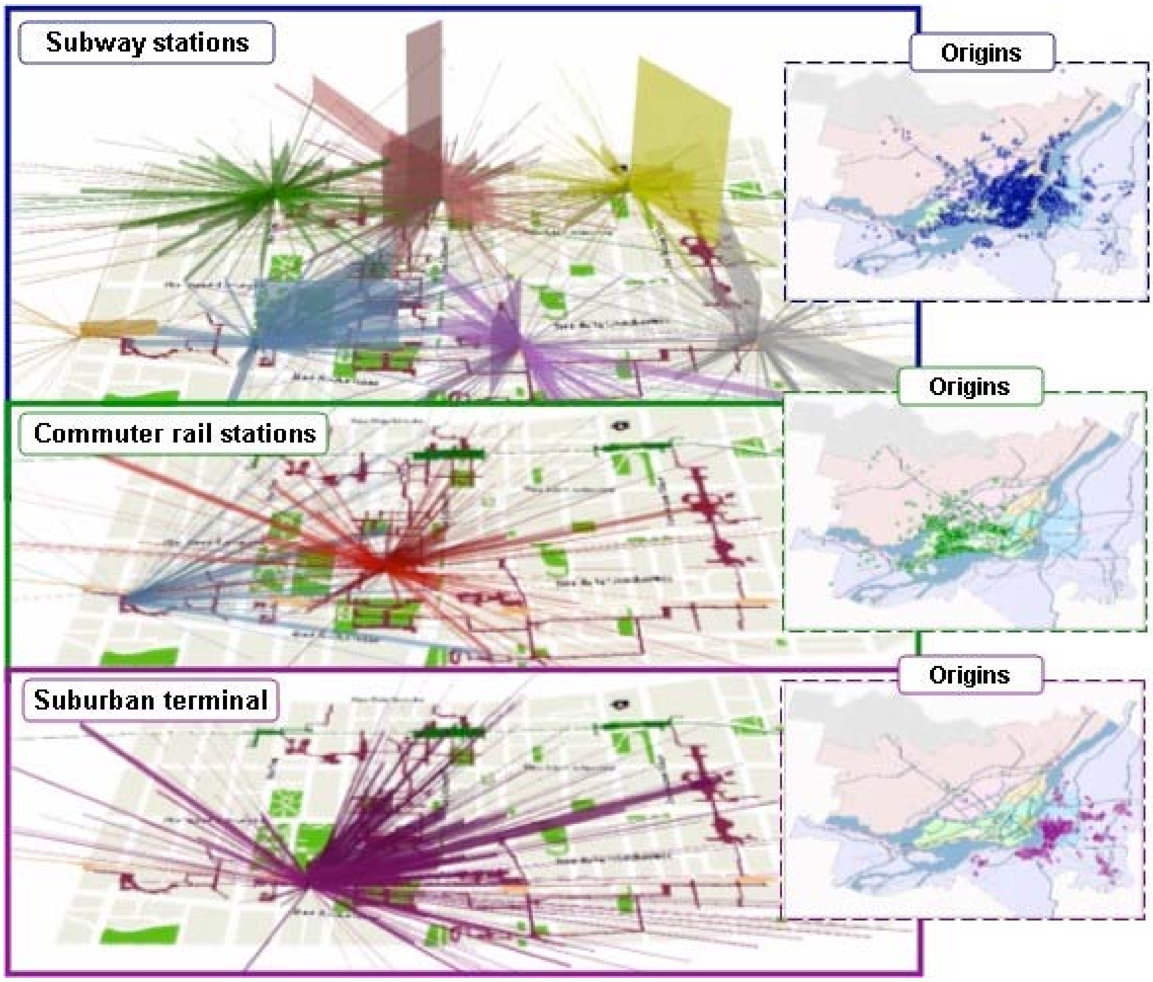


Figure 14. Illustration of the pedestrian flows in the CBD, coming from the subway stations, the commuter rail stations and the South suburban terminal.

GIS is also put to contribution into the experimentation of a better travel information system with the inclusion of VRML (Virtual Reality Modeling Language). Figure 15 shows the modeling of three CBD subway stations and, at right, the complete definition of inner corridors and escalators in one of the CBD station.

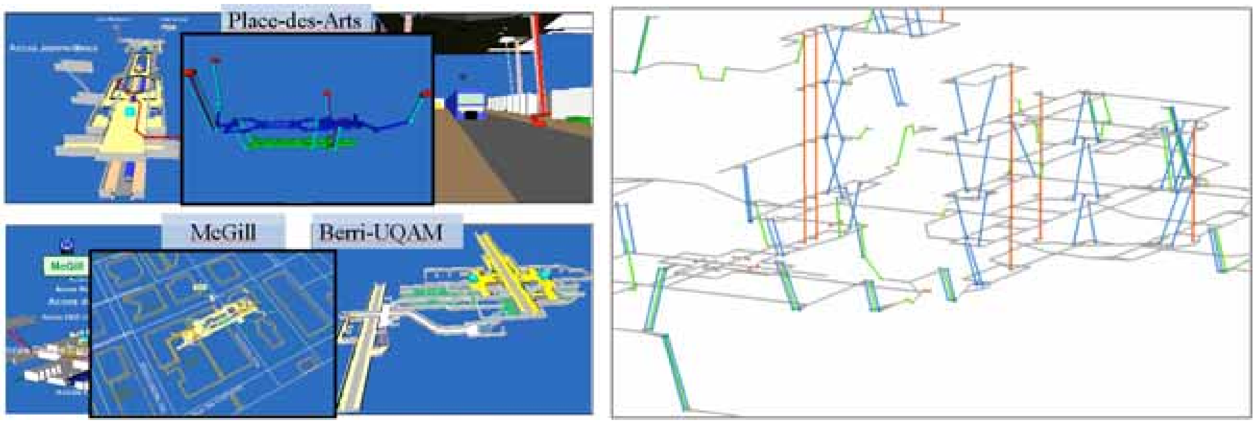


Figure 15.At left, underground subway stations in VRML; at right, 3D network coding (corridors and escalators)

Because the Montreal travel survey consists of a large and significant number of trips done in the CBD (about 20,000 declared trips), there is enough data to consider a precise market analysis of the occupancy of the CBD on an average weekday. The dynamics of the spatial distribution, by hour, of activities (work, study, shopping, leisure, home return) derived from the individual analysis of the trip chain (time departure, trip purpose, travel mode, destination x-y coordinates, time departure of the next trip) and the consequent duration of the activity involved.

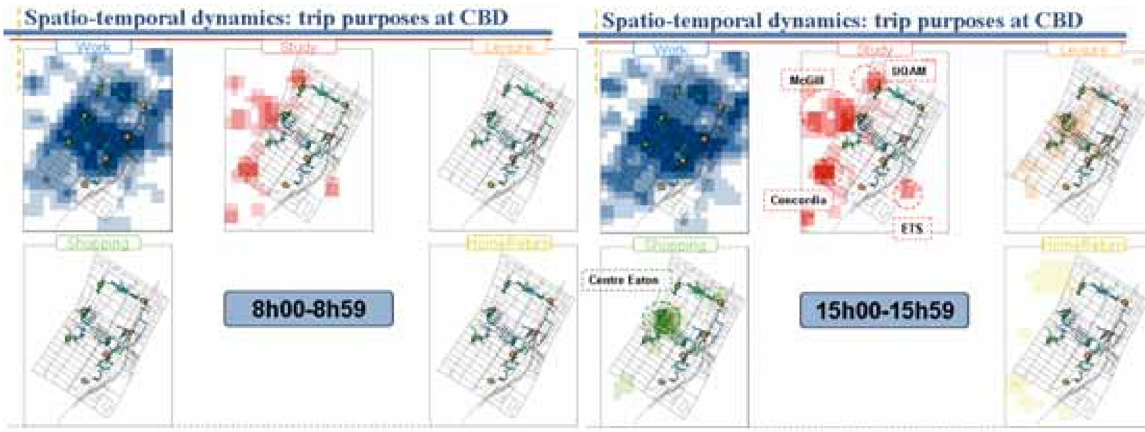


Figure 16.The dynamics of the people (work, study, leisure, shopping, home return) activities in the Montreal CBD with a 100m grid. (Source: 1998 O-D survey), derived from the individual trip chain analysis).

Conclusion: the next urban transport analysis

The present paper has put forth a series of demonstrations developed from the totally disaggregate processing of a large sample household travel survey conducted in the Greater Montreal Area. The substantial role of GIS in facilitating the integration of territory data, road and transit network data (vector and grid) with several transport modeling analysis techniques (trip chain analysis, path calculation and trip assignment) may lead to a better understanding of the complex equilibrium of urban transport and may suggest new means of managing congestion charges in the future.

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