A Posteriori Impact Analysis of a Subway Extension in Montreal

R. CHAPLEAU, P. LAVIGUEUR, AND K. G. BAASS

An impact analysis of a subway extension in Montreal is presented. Opened in 1976, the extension began operating just before the summer Olympics and included two stations allowing easy access to the Olympic stadium. The analyses are based on large-scale regional origin-destination surveys carried out by the Montreal Urban Community Transit Corporation (the local transit operator) every 4 years since 1970. Because of the amount and nature of data as well as the programming package MADITUC (a Model for the Disaggregate Analysis of Trips on a Transit Network), it was possible to perform specific studies, identifying the main impacts of the extension. On a short-term basis, no urbanistic structuring effect was observed following the subway extension: general trends of population decrease and aging continued in the surrounding sectors. However, the extension had a positive influence on transit ridership. Transit users experienced significant reductions in travel time and a decrease in the number of transfers required. Nevertheless, the effect on modal split was limited in space and time, thus being very local. This attraction phenomenon appears to be significant only within a distance of 1.6 km from the subway line. After an initial increase, the market share for public transit began to decrease, sometimes reaching levels lower than those in the pre-extension period.

The subway system of the city of Montreal has been gradually extended since the inauguration in 1966 of the first 3 lines comprising 26 stations. One of the most important extensions was opened to the public in 1976, the year of the Olympic games hosted by Montreal. Line 1 was then increased by nine stations to the east (two of these stations provided easy access to the Olympic site); 2 years later, eight stations were added to the west on Line 1. Because of the data involved, this paper focuses on impacts caused by the eastern extension.

To legitimate large investment projects, transportation planners, in an era of evolving technology and information systems, are required to use more and better models to forecast relevant and most probable impacts of different scenarios. The present study [for more details, see Lavigueur et al. (*1*)] attempts to contribute to the still-limited knowledge of the impact of rapid transit lines. A posteriori, the predicted impact could be compared to the one that was really observed, thus enabling the authors to confirm, reject, or improve the hypotheses used a priori. Thus, the a posteriori analysis becomes the motor of the evolution of the techniques, principles, and hypotheses used in transportation systems planning.

This paper contains first a description of analytical methodology (data and tools); the general status of public transport in Montreal is presented followed by the identification of the influence zone of the eastern subway extension. Finally, multiple impacts are considered on the basis of a before-after comparison: demographic characteristics, modal split, travel attributes, central business district (CBD) accessibility, and benefits evaluation.

Section Génie des Transports, Département de Génie Civil, Ecole Polytechnique de Montréal, Case Postale 6079–Succursal "A", Montréal, Québec H3C 3A7, Canada.

PLANNING AND EVALUATION METHODOLOGY

The main purpose of the proposed analysis is derived from a distinctive point of view. Instead of examining all the possible impacts observed after the implementation of a subway extension—such as new residential or commercial developments, added value of adjacent lands—the experiment consists primarily of an evaluation exercise performed strictly under the same conditions (data and tools) as those considered available before the project. This tends to validate planning techniques and to evaluate several of the more commonly made hypotheses concerning the impact of subway extensions. The main opportunity of analysis comes from the fact that the 1976 eastern subway extension is surrounded by two large regional O-D surveys conducted in the fall of 1974 and 1978 by the MUCTC's Service Planning Department. Moreover, the 1978 trends can be validated by using the 1982 survey. All these surveys were of the telephone interview type with an average sampling rate of about 5 percent, including the coded and validated answers of 43,000, 55,000 and 75,000 households, respectively.

For each traveler interviewed the surveys provide socioeconomic data (such as age, sex, car ownership, etc.), the zones of origin and destination of every trip made and, for transit trips, the sequence of lines used (*2–5*). This detailed information on transit lines actually used will permit comparison, at a very disaggregate level, of the route and mode choices before and after the subway extensions. Supply-related data on public transport are those used in 1974 and 1978 for planning purposes; this level of resolution is sufficient for network simulation or capacity analysis for a peak period, but is still too crude for a precise evaluation of the operational costs involved. For comparative analyses, however, they provide a good representation of the supply issues during the 1974 and 1978 surveys. For instance, the 1978 MUCTC transit network is coded with about 140 lines (subway, train, bus), 2,000 nodes, 1,400 centroids of zones, and 5,000 transit links. Thus, the error margin may be considered well under 10 percent for large volumes, such as those involved in a subway analysis. To deal with these large data bases, two software packages were used: (a) the transit network planning package MADITUC for processing of network data (*6*), modeling of access links, computation of shortest paths according to a calibrated impedance function, and loading of the observed or simulated trips on the network; and (b) the statistical analysis system (SAS) for files manipulation—merging, sorting, new variable generation, statistical comparative analyses—and for graphical representation of results in reference to the territorial system.

PUBLIC TRANSPORT IN MONTREAL

The city of Montreal is located on an island in the St. Lawrence river, where it forms, with 26 other surrounding municipalities, the Montreal Urban Community (MUC). In the MUC territory (corresponding nearly to the island), the MUCTC is responsible for public transportation. Figure 1 shows the island and the locations of the subway network (1974–1978), the Olympic complex, and the CBD, which attracts an important part of work-related trips.

On the island of Montreal, public transport represents 37 percent of the motorized trips; this percentage becomes as high as 63 percent when considering trips to the CBD. During the morning peak hours, 385,000 passengers use the transit network (*9*). Because of its importance, the CBD is the center of the radial subway system; the surface transit network has a grid configuration.

INFLUENCE ZONE OF THE EASTERN EXTENSION

A study of the origins of the transit trips using the subway lines, all destinations considered in the O-D survey of 1978, provides a good characterization of the respective drainage (catchment) areas (Figure 2). Some zones are clearly attracted by both lines, one of them being chosen by the transit rider according to travel time and location of the destination. Subways are often considered by urban planners to have a strong impact on socioeconomic factors. These impacts are apparently not measurable over a short period of time.

The evolution of the demographic profile of the island of Montreal between 1970 and 1982 (Table 1) was marked by combined aging and urban sprawl, which have well-known corollaries: decrease of population and household size, increase of mobility and automobile ownership. Locally, these phenomena may act quite differently. A key issue of the impact analysis is to distinguish clearly between the effects of the subway extension and the historical evolution had the subway not been built. To summarize:

1. Urban sprawl affects principally the most densely populated sectors; even if the metro was implemented in these sectors, it did not succeed in reversing this population trend.
2. Household size, the most changing variable in modern times [e.g., Baltimore 1985 (*10*)], decreases everywhere, but slightly more near the subway Line 1, probably because of the massive numbers of young people (one- or two-person households from baby boom) reaching adulthood and purchasing property and the new accessibility to the CBD. Examining the available data, no significant change in this trend could be detected over a 6-year period.
3. During the last 15 years, automobile ownership has continuously increased, a trend slowed by the economic recession

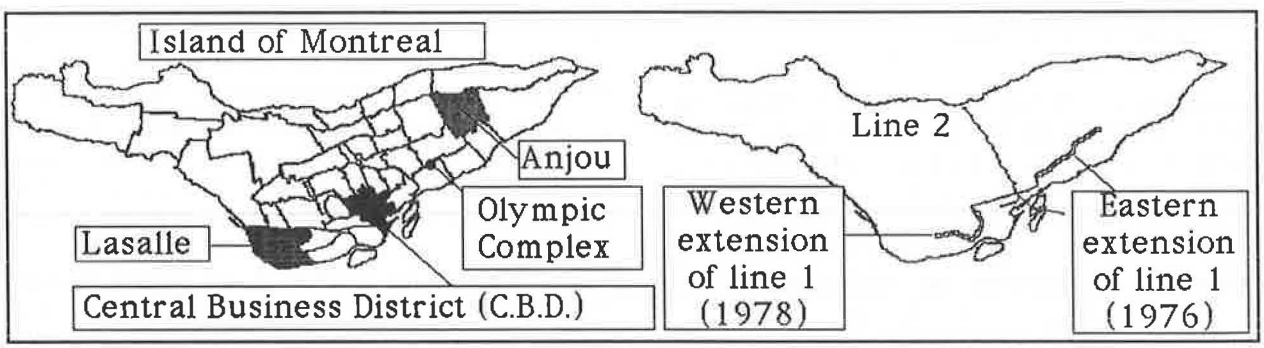

FIGURE 1 Line 1 extensions.

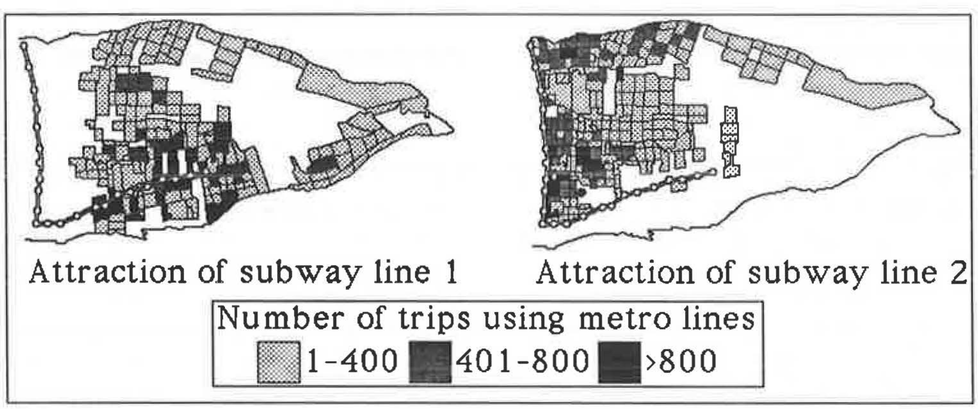

FIGURE 2 Areas of attraction of subway Lines 1 and 2.

TABLE 1 EVOLUTION OF THE POPULATION ON MONTREAL ISLAND

Year	Population	Decrease of Population (%)	Car Ownership (car/ persons)	Household Size	Density (persons/ km^2)
1970	1,945,000		0.24	3.3	3,995
		1.0			
1974	1,926,000		0.28	3.0	3,955
		1.9			
1978	1,889,000		0.31	2.7	3,880
		5.9			
1982	1,777,000		0.32	2.5	3,650

of 1981. As with household size, a strong relationship exists with distance from the CBD, but the observed increases near the new extension are in all points similar to the average values of the entire MUC. This observation suggests that the extension had no discernible influence on automobile ownership.

4. An overall aging of the population on the island can be observed; the oldest sectors being those where the subway already existed in 1970. A similar evolution can be seen in the areas touched by the new subway extension between 1974 and 1978. This continuous trend suggests the subway extension had no influence on this population characteristic.

Thus, on the basis of the Montreal case, it may be concluded that if a subway has any structuring effect on urban (and maybe underprivileged) sectors, it may take at least 10 years before it can be measured.

TRANSIT TRAVEL DEMAND

The number of trips made by public transport has increased at a rate of 11 percent every 4 years since 1974, which is significant considering the population decrease in the MUC. According to an extensive study of mobility behavior in the Montreal area (*11*), both (average weekday per capita) total and transit trip rates have grown between 1974 and 1982 from 1.79 to 2.05 for total trip rate and from 0.52 to 0.66 for transit trip rate. The increase in transit use is not distributed uniformly over space (Figure 3).

The sectors located along the Line 1 extensions experienced high increases, but not as high as the zones at the east and west ends of Line 1 (58 percent in Anjou and 43 percent in Lasalle). During the 1974–1978 period, new housing development occurred, which might have attracted potential metro users not yet used to driving to work. It appears to be difficult to induce drivers to use the metro and as can be observed, modal changes were often of a temporary nature.

The new subway extensions have had a positive effect on transit ridership, but it may also be surmised from Chapleau and Girard (*11*) that transit benefited mostly from demographics: progression of specific age–sex cohorts (15 to 24 year olds, senior citizen's groups) in the nearest suburbs.

MODAL SPLIT

Share of the Market

The transit modal split was remarkably stable over the 1970–1982 period (around 37.0 percent of motorized trips), but it was significantly different between sectors. Based on the 1978 survey, it was observed that the new extensions resulted in a local increase in the market share. However, in 1982, this gain was partly lost and the market share decreased below the 1974 level in many zones. Data appear to prove that, as long as the network is stable, the market share tends to stabilize or decrease. A new metro line temporarily improves the market share in the adjacent zones, but the initial downward trend is resumed after a fairly short period.

The municipalities of Anjou and Lasalle were the most successful sectors with respect to the change in market share (Anjou: 1974 > 25.8 percent; 1987, > 32.4 percent; 1982, > 31.9 percent. Lasalle: 1974, > 29.5 percent; 1978, > 37.7 percent; 1982, > 36.4 percent), showing nevertheless decreasing shares between 1978 and 1982. It will be interesting to validate this trend with the new 1987 survey; although, it should be remembered that total ridership is still increasing, the relative loss being the result of increased mobility.

Radius of Influence of the Metro Line Extensions

The influence of the metro line extension was studied with the most disaggregate survey data; zones were grouped with respect to their distance from the nearest metro station. A net gain of approximately 5 percent was observed over a distance of 1.25 km (0.75 mi) followed by a steep decline, so that after 1.67 km (1 mi) the positive influence of the subway disappears (Table 2). The zone of influence for modal split appears to be limited to a band of approximately 1 mi on both sides of the metro extension.

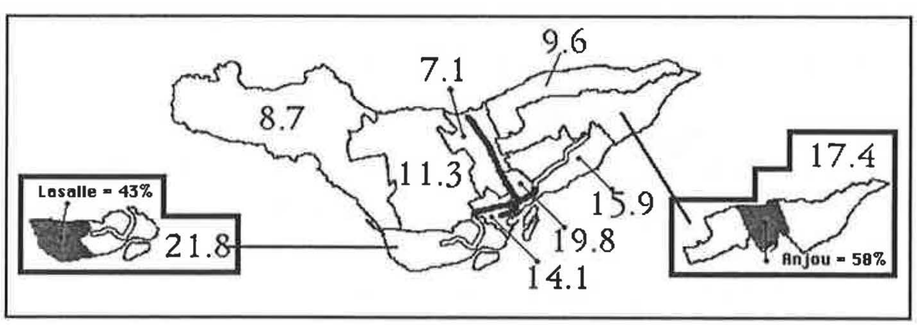

FIGURE 3 Rate of increase, number of trips per person between 1974 and 1978.

TABLE 2 MODAL SPLIT VERSUS DISTANCE FROM THE METRO LINE

Grouping	Distance Km	Distance Miles	Modal Split (%) 1974	Modal Split (%) 1978	Difference (%)
A	0.00–0.42	0.00–0.25	39.9	44.7	4.8
B	0.42–0.83	0.25–0.50	37.7	43.6	5.9
C	0.83–1.25	0.50–0.75	38.4	43.5	5.1
D	1.25–1.67	0.75–1.00	41.2	42.9	1.7
E	1.67–2.08	1.00–1.25	38.9	37.9	−1.0
F	2.08–2.50	1.25–1.50	42.7	40.0	−2.7

TRAVEL DEMAND CHARACTERISTICS

The main contribution of subway implementation is speed substitution (commercial speed of the metro is about 35 to 40 km/hr versus an average of 15 to 20 km/hr for bus). Low headway and regularity also contribute to the reduction of travel time of subway users, often at the expense of an increasing number of transfers. From every transit trip observed in the 1974 and 1978 surveys, the MADITUC simulation model estimated travel attributes such as average travel time (which is, strictly speaking, an impedance function composed of walking access, waiting, in-vehicle times with appropriate weighting factors, in addition to transfer and modal penalties) and average number of transit lines taken by transit riders. Figures 4 and 5 show the differences between 1974 and 1978.

Normally, a subway implementation has a detrimental effect on the number of transfer users experiment. Here, because of the very nature of the line extension, the opposite has been observed. It appears that the users from the sectors adjacent to the metro extension needed fewer transfers and got to their destinations faster in 1978 than in 1974 in spite of longer trips. In summary, large areas have benefited from the service improvement and the consequent user cost reduction.

ACCESSIBILITY TO CBD

The main role of the Montreal metro is to facilitate accessibility to the CBD. The extensions confirm this role, and so far, have contributed a net 5 percent increase in modal split. As shown earlier, the CBD is served by Metro Line 1, which brings people from east and west, and Line 2 from the north. Shortest paths, with the same previously calibrated impedance function, were computed with the respective attributes of the 1974 and 1978 networks (line lengths, commercial speeds, headways). Results (Figures 6 and 7) represent calculations done for a CBD destination near each metro line; this last precaution was taken because of the importance of transfers. Good coherence is noted between areas of larger reductions in travel time and zones of influence of the subway extension already shown in Figure 2. Remarkably, the sector with the largest time savings is Anjou, where MUCTC recorded its best modal split results. Considering both destinations, these maximum savings were an estimated 25 to 30 min (in generalized time units). In the second case, the area experiencing this maximum gain is much larger, comprising almost the whole Anjou municipality. In order to identify the strengths and weaknesses of a metro extension scenario, this type of analysis offers the interesting

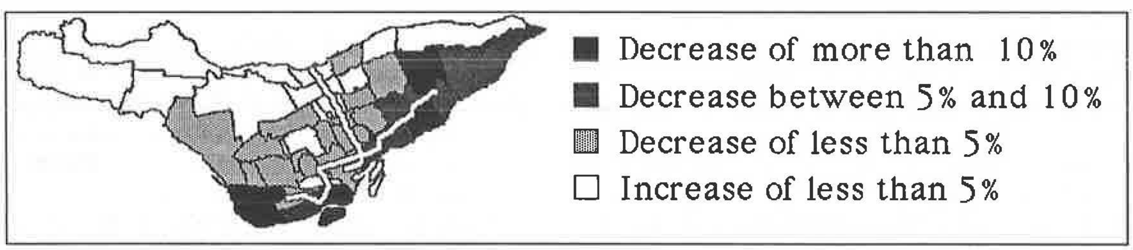

FIGURE 4 Evolution of average trip time between 1974 and 1978.

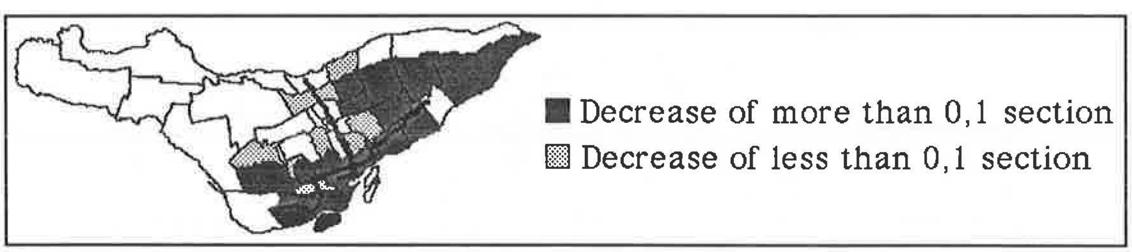

FIGURE 5 Evolution of number of lines used for a trip between 1974 and 1978.

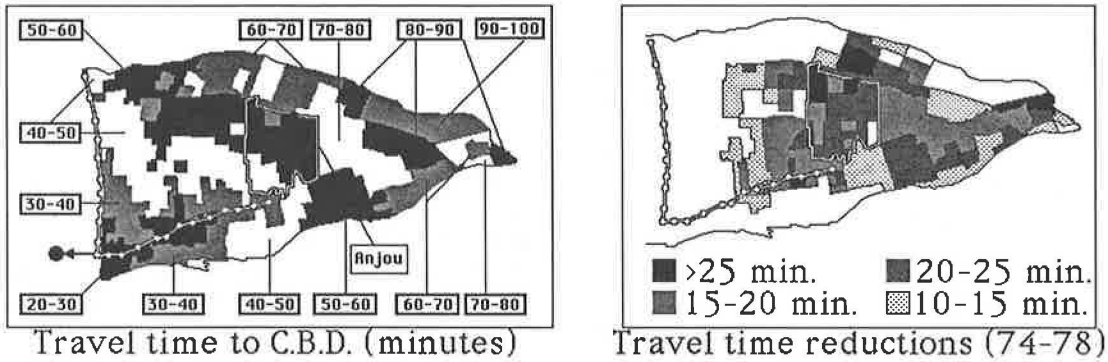

FIGURE 6 Access to CBD near Line 1.

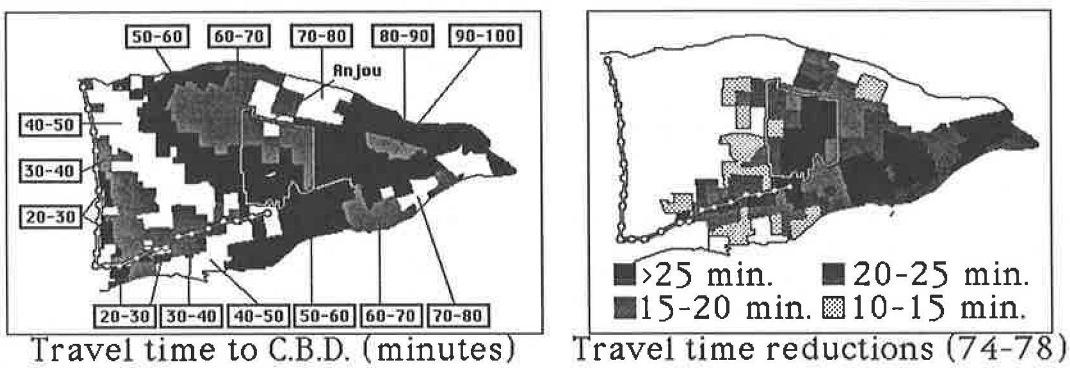

FIGURE 7 Access to CBD near Line 2.

possibility of measuring the spatial distribution of the time benefits. An a posteriori impact study allowed the authors to understand partly why residents of Anjou significantly increased their use of public transit.

TRAVEL BENEFITS' ESTIMATION

The present analysis is carried out on the whole network, in part to simplify the analysis but also because most trips are made on the subnetwork adjacent to the metro extension as well as on the remaining network. Travel time savings were obtained by loading the 1978 a.m. peak demand on the 1974 and 1978 transit networks, applying a calibrated "all or nothing" assignment model. Simulation indicated an overall reduction of 11,500 hr of generalized travel time during the weekday a.m. peak period, consisting mainly of significant time differences; for example, for all trips originating from the Anjou sector, the average time saving is 9.75 min per transit trip. In the neighborhood of the eastern subway extension, approximately 50 percent of these savings experienced by about less than 20 percent of the total demand can be observed.

Estimates of the operational resources (vehicle hours) computed with the network data used in the trip assignment model give the following for the surface network touched by the eastern extension: decrease of 270 vehicle hours for parallel bus routes, increase of 180 vehicle hours for perpendicular bus routes (feeding line 1) and an increase of 70 vehicle hours for other services in the east. The net gain is slim compared with the added costs of supplying resources for the corresponding lengthening of subway Line 1 (mostly tripling the metro vehicle hours because of the simultaneous east and west extensions).

Factors exterior to the analysis are worth mentioning. The extension of a subway line has, in any case, a detrimental effect on the utilization ratio (passengers-km/seats-km), if no short line is introduced. All things being equal, the maximum load point volume increases, requiring more vehicles that have to travel a longer distance to complete their circuit. At this point, for the a.m. peak period in 1978 compared with 1974, maximum link volume on Metro Line 2 dropped by 4,500 from 52,500, while maximum link volume on Metro Line 1 increased by 11,000 from 33,000. Finally on the surface network, the economy of buses is counteracted by another phenomenon: because of the improved regularity of metro service, transit riders have a tendency to reduce the spread of the peak period, accentuating the requirements of the feeder bus fleet and increasing the resources involved.

CONCLUSION

The MUCTC's O-D surveys allowed an analysis, on a before-after scheme, of the impacts of some transportation investments. A new survey is planned for the fall of 1987; 10 years later it is hoped that more medium-term impacts will be observed. From a planning point of view, precise historical supply data were not truly available or recoverable. When these projects were planned, more attention was given to the technology aspect (capacity analysis) instead of cost or productivity dimensions. This explains why the analysis was not capable of discriminating factors related to scale economies on resources usually obtained with rail transit investment projects.

Nevertheless, the multidimensional analysis conducted so far allows some conclusions to be drawn:

- Contrary to the beliefs of many urban planners, based on the Montreal case, subway extensions have no significant structuring effect on a short-term horizon: no distinct trend in demographics was noted around the new metro stations.
- Overall transit ridership has been positively maintained with the subway extension, owing essentially to the general increase in mobility.
- With respect to modal split, the opening of the extension had a stepping-up effect. Nevertheless, this gain declines over time. Six years later, the positive effect remained over only two municipalities (Anjou and Lasalle). The modal split has decreased in all other sectors to or below the level observed before the opening of the extension.
- The subway appears to have, on a short-term basis, a localized impact on transit use. The increase in market share for public transit is diminishing rapidly with distance from the subway stations. In fact, there was no gain outside a 1-mi area on both sides of the subway line. Transit users experienced significant reductions in travel times and needed fewer transfers to make a trip during peak hours. This last result is fortuitous for a subway implementation; here, it depends on the nature of the 1974 surface network: all those having direct access to the new Line 1 extension saved a transfer if the CBD was their destination. Other aspects have also been investigated but may not be validated because of the "weak" quality of operational data available for network situations existing more than 12 years ago. Since then, planners have learned to invest in data characterizing the supply side of urban transport.

Finally, the main result emerging from the Montreal case is that planners must refrain from relying too much on short-term benefits that result from a transit infrastructure. Real benefits appear to come from the dynamics of the urban demography, which would be more easily explainable. It is a conjecture to be validated in future research.

ACKNOWLEDGMENT

The authors would like to thank the MUCTC for the use of data from its O-D surveys for this study. Special thanks are extended to M. Claude Boucher, chief, Research Division, Network Planning Service, for his interest, comments, and contribution to the technical and editorial aspects of this paper. This research project has been partly sponsored by the Natural Sciences and Engineering Research Council of Canada and the FCAR fund of the province of Quebec and the Montreal Urban Community Transit Corporation. The authors are also grateful to the TRB reviewers for their useful comments.

REFERENCES

1. P. Lavigueur, R. Chapleau, P. Trottier. *Mesure a posteriori des impacts d'un prolongement de metro.* Preliminary research report RPR8513. Montreal Urban Community Transit Commission, Canada, May 1985.
2. *Gńéralités et déplacements, enquête O-D 1970, région de Montréal.* Planning Service, MUCTC, Canada, 1972.
3. *Mobilité des Montréalais, enquête origine-destination 1974, région de Montréal.* Planning Service, MUCTC, Canada, July 1985.
4. *Mobilité des Montréalais, 3e enquête Origine-Destination 1978.* Planning Service, MUCTC, Canada, July 1979.
5. *Mobilité des personnes dan la région de Montréal, 4e enquête régionale Origine-Destination 1982.* Network Planning Service, MUCTC, Canada, Dec. 1983.
6. R. Chapleau. *Rapport annuel. Conception et développement d'un systéme intégré de planification opérationnelle d'un réseau de transport urbain collectif (le logiciel MADITUC),* Dec. 1984.
7. *SAS User's Guide: Basics.* SAS Institute Inc., Cary, N.C., 1982.
8. *SAS/Graph User's Guide.* Version 5, SAS Institute Inc., Cary, N.C., 1985.
9. *Strategic Plan 1984-1986.* Montreal Urban Community Transit Commission, Canada, 1984.
10. *Baltimore Metro Impact Study.* Technical Memorandum 51. Regional Planning Council, Baltimore, Md.
11. R. Chapleau and D. Girard. Effects of Population Aging and Urban Dispersion on the Use of Urban Transport in the Future. Presented at the World Conference on Transport Research, Vancouver, 1986. Publ. 461, Centre de Recherche sur les Transports, University of Montreal, Canada.

Publication of this paper sponsored by Committee on Rail Transit Systems.