Modeling Rail Access Mode and Station Choice

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Access mode and station choice by commuter rail and subway users are modeled using morning peak-period work trip commuting in the greater Toronto, Ontario, area as a case study. Based on observed station choice behavior, rules for determining access station choice sets for both commuter rail and subway were developed. For commuter rail, the two closest stations on the two closest lines (relative to the worker's place of residence) define the access station choice set. For automobile access to the subway, the five closest subway stations define the choice set. A nested logit model of commuter rail access mode and station and a multinomial logit model of subway automobile access station choice were then developed. Consistent with the findings of other researchers, credible models of access mode and station choice were obtained. Directions identified for further work include testing alternative overall main mode plus access choice structures, properly capturing parking supply and price effects with these models, developing improved representations of the automobile passenger mode, and development of improved network modeling software for dealing with "mixed" modes of travel.

As urban areas continue to suburbanize, transit work trips increasingly become multimodal in nature. That is, a typical trip may consist of driving to a commuter rail station, taking the commuter train into a central station, and then taking the subway to the final destination. The access mode for commuter rail and subway trips for suburban residents is an increasingly important component of the overall "choice bundle" facing these commuters. This importance is reflected in the emphasis that many suburban transit properties place on providing feeder services to rail systems. It is also reflected in the emphasis that many jurisdictions place on the concept of "gateways," that is, points at which automobile users can be intercepted and encouraged to leave their cars and complete their journey by public transit. In addition, the provision and pricing of parking at commuter rail and subway stations are ongoing concerns to most rail operators.

Given the inevitable continuing suburbanization of North American commuting patterns, the importance of rail services can be expected to grow significantly over the forseeable future. Thus, credible forecasts of expected rail ridership attracted from these growing suburban areas are essential to planning activities. Such forecasts are, however, difficult to generate without a proper understanding of the access component of the trip. Unfortunately, the current modeling state of practice does not adequately address the access mode question, either in terms of representing the access mode choices being made by commuters or in terms of representing the impact that changes in access mode characteristics will have on line-haul mode choices. The purpose of this paper is to explore this problem in depth.

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LITERATURE REVIEW

Few explicit models of rail access mode and station choice are reported in the literature. Kumar and Gur (*1*) present a sequence of logit models that predict choices among automobile and transit, rail, and express bus given the use of transit and the choices among walk, bus, park-and-ride, and kiss-and-ride access to the chosen line-haul mode. This model, however, is not fully consistent with random utility choice theory and does not deal explicitly with the question of access station choice. Sargious and Janarthanan (*2*) report a simple logit model developed for Calgary, Alberta, for the choice among automobile, transit all-way, and park-and-ride for work trips. Access stations are assumed to be chosen on a "least cost" basis.

In the late 1970s, Talvitie (*3*) developed a model of the joint choice of access mode (walk, bus, drive, kiss-and-ride) and access station for Bay Area Rapid Transit (BART). Up to three access stations were considered per origin zone, based on stations observed to be chosen by workers living in a given zone. Important conclusions from this paper include (a) the kiss-and-ride mode proved very difficult to model adequately, (b) the joint model did not demonstrate significant violations of the independence of irrelevant alternatives (IIA property), and (c) proper representation of the access network is critical to access mode and station choice model development.

Mukundan et al. (*4*) present a nested logit model of Washington, D.C., Metro rail access mode and station choice. This model assumes access mode (walk, bus, automobile drive, automobile passenger) as the upper-level choice, with access station as the lower-level choice, conditional on the access mode choice. The two best access stations for the walk mode and the six best stations for the other three modes were used to define the access station choice set, where "best" is defined in terms of predetermined modal "impedance" functions. Similar to Talvitie's findings, the automobile passenger mode proved difficult to model.

Miller and Cheah (*5*) present a multinomial logit model of work trip mode choice for the Greater Toronto Area (GTA). The model includes six modes: (a) automobile (drive or passenger), (b) transit with walk access, (c) subway with automobile access, (d) commuter rail with transit or walk access, (e) commuter rail with automobile access, and (f) walk all-way. The commuter rail access station that provides the maximum utility for the trip is chosen for each commuter rail mode.

The subway automobile access station is specified for a given origin zone based on patterns of station use observed in ridership surveys. No test for IIA violations within this joint access and line-haul mode choice model was performed.

At least three issues are raised by this brief review. First, to date, little empirical investigation into access station choice set definition appears to have been performed. Second, little explicit investigation into access mode and station decision structure has been undertaken. Talvitie's results support his assumed joint decision structure. Mukundan et al.'s results, on the other hand, support an assumed nested decision structure. Finally, practical issues associated with coding access network components and incorporation of access mode and station calculations within available modeling software, among others, are critical to the development of access mode-station models and to their practical application within operational planning models.

DESCRIPTION OF DATA

The GTA, which is the study area for this paper, provides a good opportunity to study rail access mode and station choice issues because it contains both commuter rail and subway systems, which both compete with and complement one another in providing essentially radial service into the Toronto Central Area.

The commuter rail system for the GTA, GO-Rail, is a radial system, focused on Union Station, located at the southern end of Toronto's Central Area (see Figure 1). Union Station is also a major station of Toronto's subway system, thereby providing convenient transit connections between the commuter rail system and downtown Toronto. The GO-Rail system is primarily designed to carry commuters from residential suburban areas lying outside metropolitan Toronto to employment locations within downtown Toronto. On-board surveys of GO-Rail riders are performed every 2 years. The travel choice data used in this paper are obtained from the 1987 survey.

Subway access is treated differently from commuter rail access in this paper in that only subway access station choice is modeled, given that the automobile is used as the access mode. This approach is based on the following assumptions:

- Surface transit access to subway is not a sufficiently distinct "choice bundle" relative to taking surface transit for the entire trip that it requires explicit representation within the set of modal alternatives,
- Subway access station choice for surface transit is adequately modeled within current transit assignment procedures, and
- The key distinction that needs to be made within the work trip mode choice model is, therefore, between the "transit all-way" mode and the "transit part-way, auto part-way" mode (i.e., automobile access to the subway). Data from the 1986 Transportation Tomorrow Survey (TTS) were used in the analysis of subway automobile access station choice behavior. Figure 2 shows the location of the 12 park-and-ride stations within the subway system. This study focusses on six of these stations (Finch, Kipling, Islington, Kennedy, Wilson, and McCowan, in order of use), which are used by most automobile-access subways users.

All level of service data required for model development were generated using computerized representations of the GTA automobile and transit networks maintained within the EMME/2 modeling system.

DETERMINING ACCESS STATION CHOICE SETS

Commuter Rail Access Station Choice Sets

Figure 3*a* presents approximate access "catchment areas" for each GO-Rail station, as defined by the home ends of trips using each station, given that the tripmaker used the automobile access mode (as either a driver or a passenger). These catchment areas were constructed by first deleting the 5 percent longest trips in the sample (so as to eliminate unnecessary clutter in the plot) and then identifying the trip origin furthest from the given access station for each 30-degree arc segment. These "furthest points" were connected to form the catchment area.

Significant overlap exists among these catchment areas, indicating that not all trip makers use their closest access station and that trip makers traveling from approximately the same home locations make different access station choices. These results imply that more than one access station must, in general, be included in trip makers' choice sets and that selection of an access station is likely to be best modeled probabilistically. Figure 3*b* presents similar information for rail commuters using transit access to the system. This plot is generally far simpler than the one for automobile access users, indicating that a large number of transit access users travel to their nearest station. Nevertheless, sufficient overlap among catchment areas exists to indicate that transit users' access station choice should also be modeled probabilistically.

Various cross-tabulations were performed in the search for any systematic structure in the distribution of chosen access stations. This analysis ultimately resulted in Table 1, which tabulates the observed station choices with respect to the closeness of the chosen line to the traveler's home. "Closeness" is simply defined on the basis of the straightline distance between home and stations on the given line. Thus, the "closest" line is the one containing the absolute closest station. From Table 1, 98.8 percent of the observed trip makers use an access station on the rail line that is either closest or second closest to their homes, while 94.5 percent use either the first-closest or second-closest station on either the first- or second-closest line. Table 1 presents this same information broken down by access mode, which indicates that these results hold by access mode as well. These results suggest that a simple rule for determining the access station choice set is to include the two closest stations on the two closest lines, where distances are calculated on a straightline basis. This simple rule accounts for virtually 95 percent of observed behavior on a station basis, while it accounts for almost 99 percent of observed behavior on a line basis.

Subway Auto Access Station Choice Sets

Figure 4 plots the spatial distribution of subway park-and-ride station automobile access origin (home) locations for the

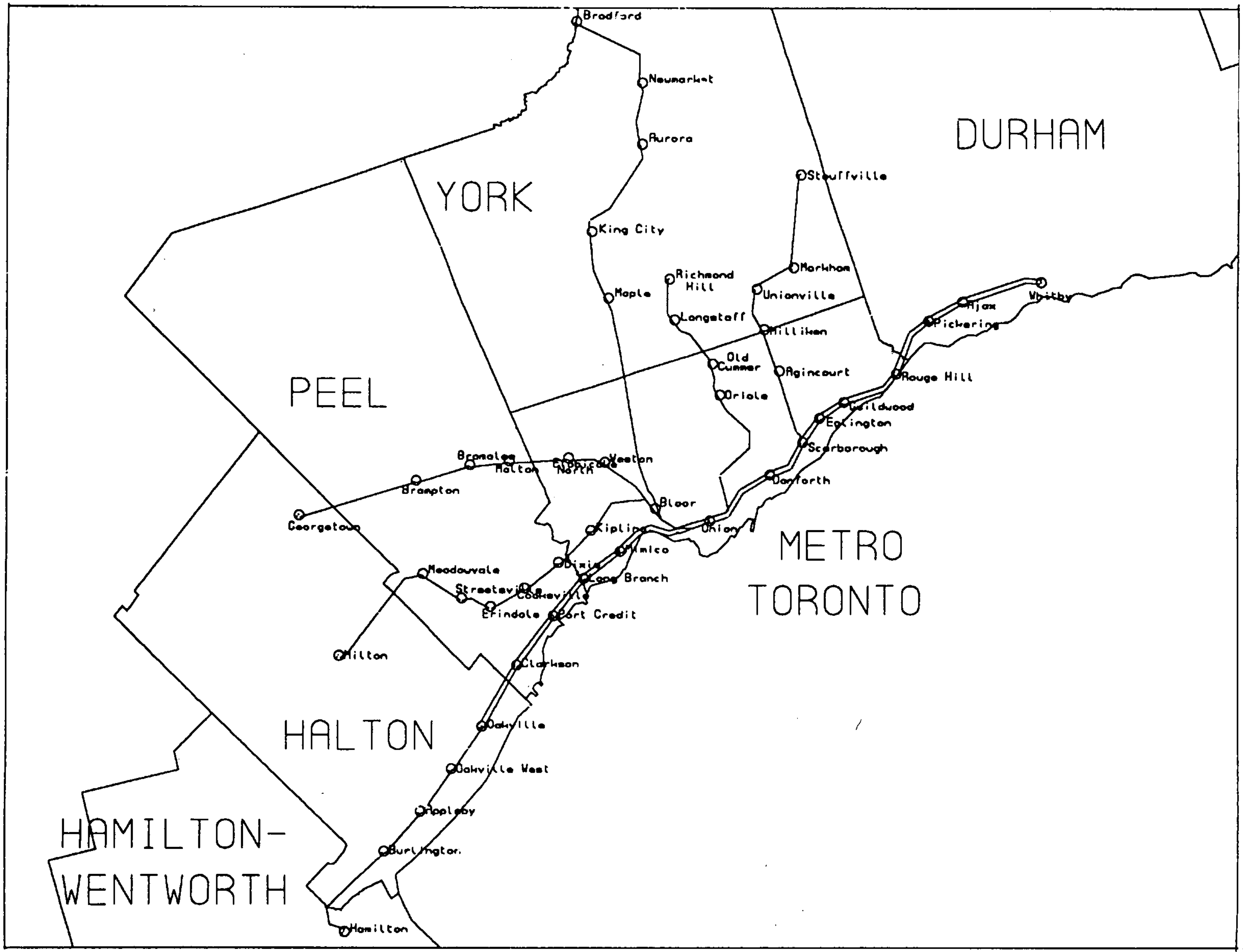

FIGURE 1 GO-Rail network.

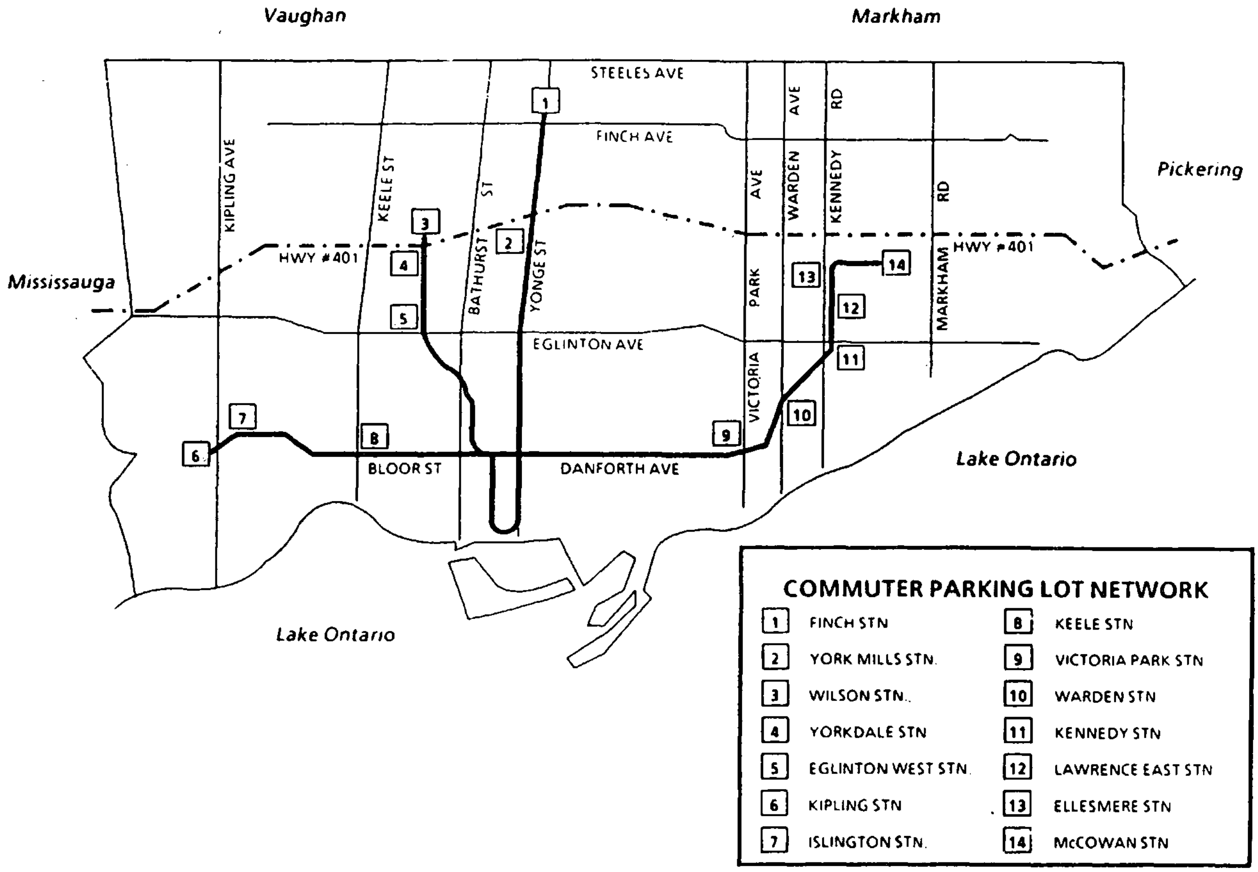

FIGURE 2 **TTC subway system showing park-and-ride stations (*6*).**

1986 TTS sample. This plot indicates that, as expected, these trips originate within the suburban fringe areas of Metro and the areas outside the Metro boundary. The effect of regional east-west highways in providing access to the subway system can be seen in the way the catchment area is generally "stretched" in the east-west direction.

Figure 5 similarly plots the spatial distribution of destinations (workplaces) for these trips. With the exception of a few outliers, these destinations clearly are clustered in the Toronto Central Area. The majority of trip destinations are within walking distance of egress subway stations, indicating that is unlikely that many subway automobile access users transfer to surface transit routes after exiting the subway.

Plots of origin and destination catchment areas for each of the six main park-and-ride stations have also been prepared. Figure 6 shows one such plot for Finch Station. This plot is typical of the general pattern in station-specific origin and destination catchment areas. In particular, note that destination catchment areas tend to be relatively compact and generally focus on the access station's subway line. Further, origin catchment areas generally appear sensible with respect to the access station's location within the region and the subway system, although clearly not all workers use the station closest to their homes to access the system.

Figure 7 summarizes the extent to which the observed origin catchment areas for the six stations overlap. Two types of overlaps occur. One involves stations on competing lines, such as Wilson and Finch Stations. The second involves competing stations on the same line, such as Kipling and Islington Stations. Again, a probabilistic choice approach is required to capture the complexity of the observed subway access station choice.

Various tabulations were constructed to identify any systematic structure in subway access station choice that would aid in specifying access station choice sets. In particular, the GO-Rail choice definition (the two closest stations on the two closest lines) was applied to the subway access case, using both straightline distance and equilibrium automobile travel time as the "distance" measure. In both cases, more than one-third of the observed choices (34 and 40 percent, respectively) fell outside this choice set definition, indicating that it is inadequate for the subway access station case.

Table 2 presents tabulations of unweighted observed station choice rankings, where these rankings are based on various combinations of trip automobile and transit travel times. For example, 87 users of the automobile-drive access mode are observed in the sample to choose their "first best" access station if a combination of automobile travel time plus transit in-vehicle travel time plus twice the transit out-of-vehicle travel time is used to define the "goodness" of the station. It is clear from this table that automobile access time alone (i.e., ignoring transit travel times entirely) is the best indicator of access station choice in that 66, 94, and 98 percent of the observed station choices fall into the first, top two, and top

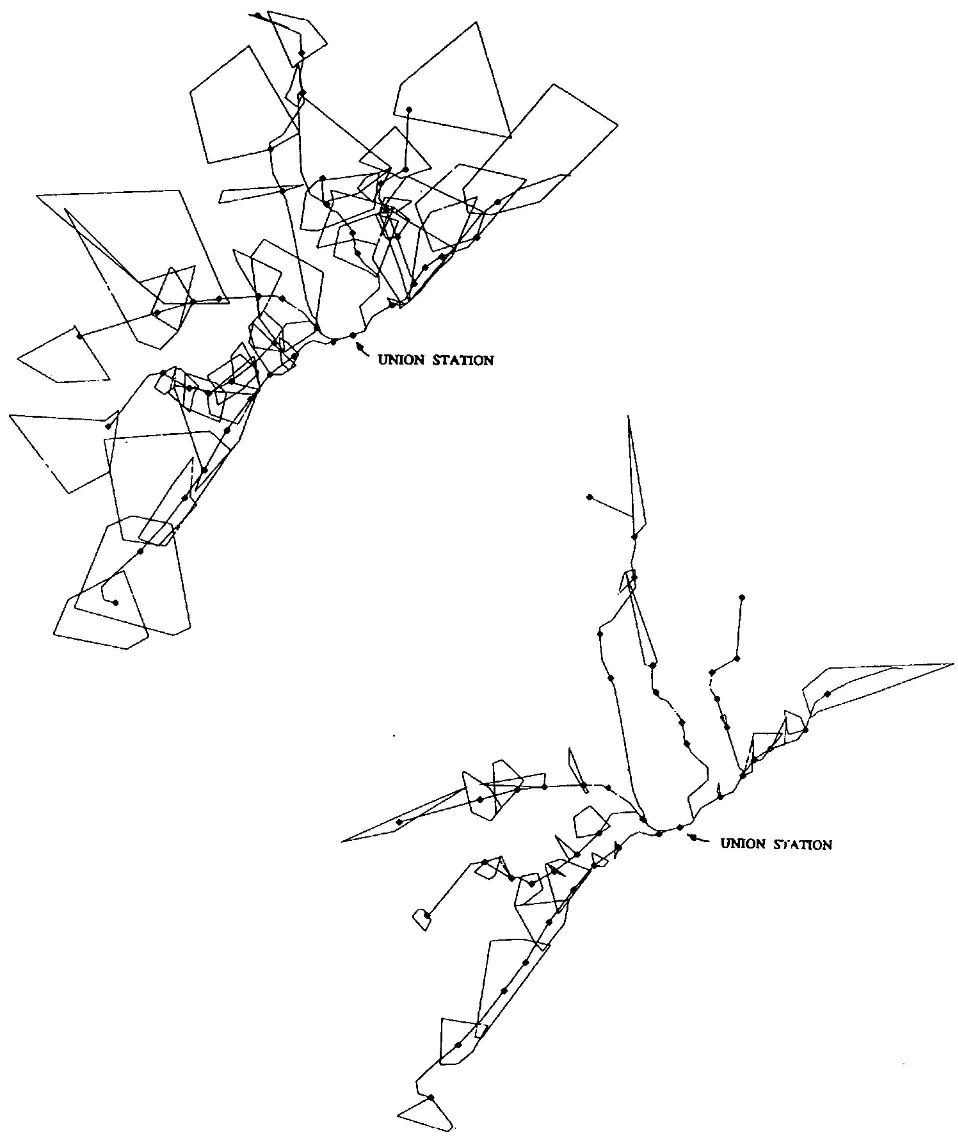

FIGURE 3 Observed GO-Rail catchment areas: ***top*****, automobile access mode;** ***bottom*****, transit access mode.**

five rankings, respectively, when this measure is used to define station rankings.

Thus, 98 percent of subway access station choices are accounted for by a choice set defined as the five stations closest to the worker's home. In model estimation, both home-to-station automobile travel time and straightline distance were used to define the five closest stations, and identical models were estimated using both choice set definitions. While both models yielded numerically similar results, the models based on the straightline distance rule were consistently found to perform better than their automobile time-based counterparts (e.g., the model presented in the next section has an adjusted ρ^2 that is 8.2 percent higher than the identical model based on the automobile time choice set definition).

ACCESS MODE AND STATION CHOICE MODELS

Commuter Rail Access Mode and Station Model

Two nested logit models were tested in this study. The first assumed that access station choice is the upper-level decision and access mode choice is the lower-level decision in the access station-mode choice decision bundle. Although statistically significant and correctly signed parameter estimates and good goodness-of-fit statistics were obtained for these models, the inclusive value parameter estimate was found to be 7.97, which considerably exceeds the maximum value of 1.0 permitted for a properly specified nested logit model. Thus, this decision structure is strongly rejected for the To-

TABLE 1 Access Station Choice (Percent of Total Trips) by Line and Station

Auto and Transit Access Modes (Total Trips: 10875)

LINE[1]	STATION[2] Closest	2nd Closest	Other	Total
Closest Line	73.51	13.40	3.90	90.80
2nd Closest Line	6.45	1.16	0.34	7.94
Other	0.00	0.00	1.25	1.25
Total	79.95	14.56	5.49	100.00%

Auto Access Mode

LINE	STATION Closest	2nd Closest	Other	Total
Closest Line	67.31	15.90	4.93	88.14
2nd Closest Line	8.15	1.57	0.45	10.17
Other	0.00	0.00	1.69	1.69
Total	75.46	17.48	7.06	100.00%

Transit Access Mode

LINE	STATION Closest	2nd Closest	Other	Total
Closest Line	81.55	11.70	2.43	95.69
2nd Closest Line	3.83	0.27	0.05	4.15
Other	0.00	0.00	0.16	0.16
Total	85.38	11.97	2.64	100.00%

Notes:

1. Indicates the percentage of rail passengers who access the line closest to their home, second closest, etc.; e.g., 90.8% of the observed passengers use the rail line that is closest to their homes.

2. Indicates the percentage of rail passengers who access the closest station to their home, the second closest station, etc., given the chosen rail line. For example, 73.51% of all rail passengers use the closest station on the closest line, while 13.4% use the second closest station on their closest line (note that this station need not be the second closest station overall, it is defined conditional on the chosen line).

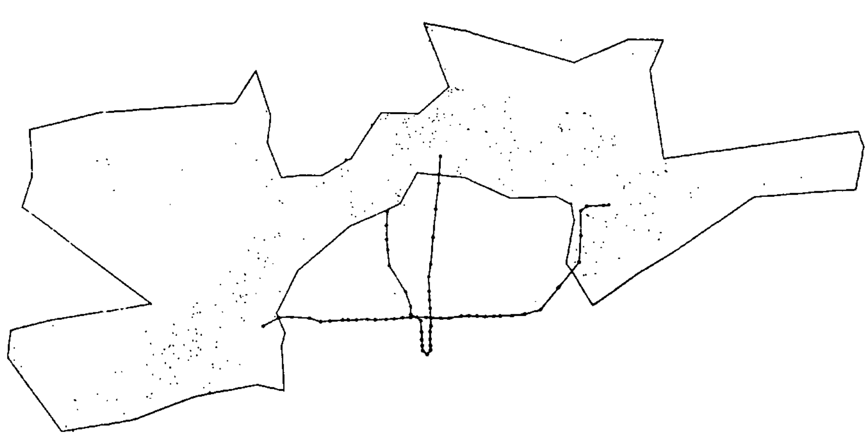

FIGURE 4 Subway automobile access origin catchment area, six major park-and-ride stations.

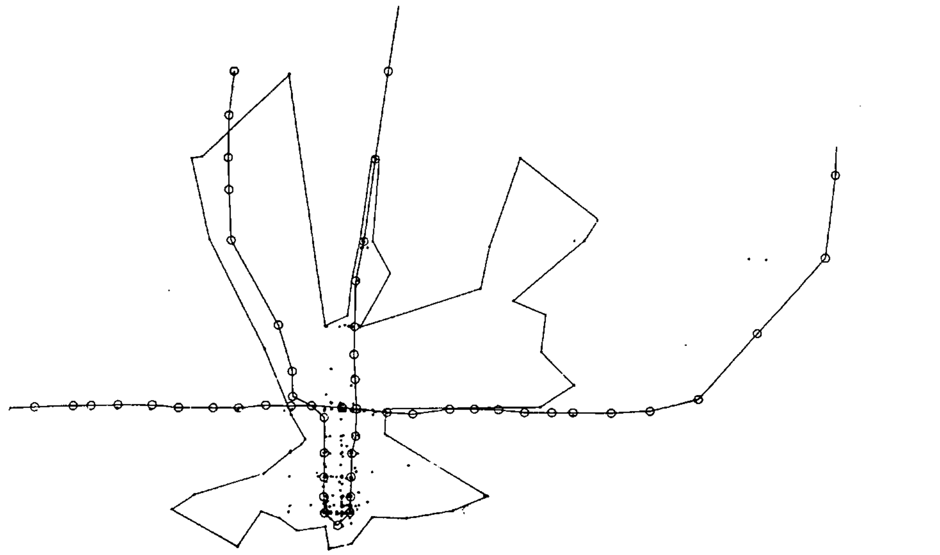

FIGURE 5 Subway automobile access destination catchment area, six major park-and-ride stations.

ronto data base in favor of the second nested model considered, where access mode is the upper-level choice and access station is the lower-level choice, conditional on access mode choice. The following estimation results are based on this latter decision structure.

Table 3 presents the variables included in the final specification of the lower-level access station model. This model applies to the automobile and transit access modes (GO-Rail stations are sufficiently far apart that at most one station will be within feasible walking distance of a worker's home) and was estimated as an ordinary multinomial logit model, conditional on access mode choice. This yields consistent but somewhat inefficient parameter estimates. The combination of access and line-haul in-vehicle travel time is used on the basis of previous estimation results in which the access and line-haul travel time parameters were generally found not to have statistically different parameter estimates [this is also consistent with the findings of Talvitie (*3*) and Miller and Cheah (*5*)]. Statistically reliable, correctly signed parameter estimates could not be obtained for transit out-of-vehicle access time, automobile access cost, and rail line-haul fares. This was most likely due to insufficient variation in the variable values across stations.

A closest station dummy variable is included in the automobile mode station utilities because it yields a significantly improved model, in terms of both goodness of fit and reasonableness of the other parameter estimates obtained. Models that exclude a closest station dummy tend to predict that trip makers will use access stations that are closer to their workplaces than is actually the case.

Table 4 presents the maximum likelihood estimation results for this model. All variables are statistically significant and correctly signed. The goodness-of-fit statistics are extremely strong, reflecting the tendency of the closest station to dominate the process.

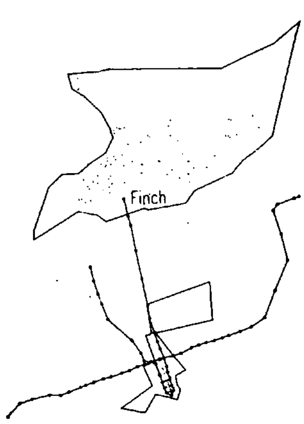

FIGURE 6 Origin and destination catchment areas, Finch automobile access station.

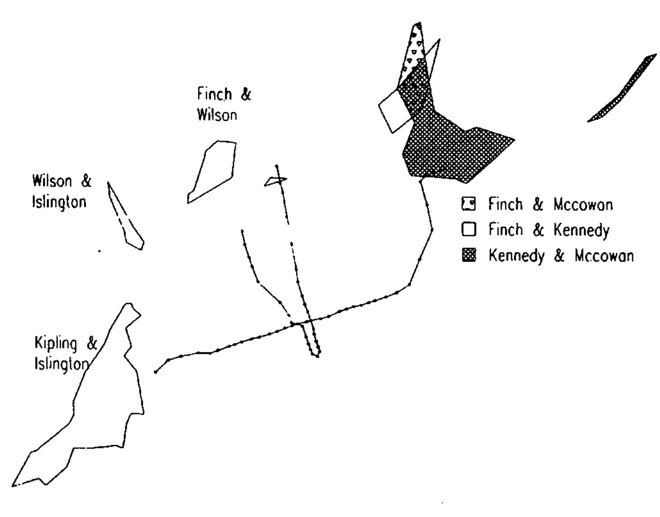

FIGURE 7 Overlapping origin catchment areas, six major park-and-ride stations.

TABLE 2 Rankings of Subway Automobile Access Station Choice Using Various Combinations of Automobile and Transit Travel Times

	Rank										
	1	2	3	4	5	6	7	8	9	10	Sum
AUTO + IVTT + 2*OVTT											
Drivers	87	57	47	25	16	5	1	5	1	1	245
Passengers	71	49	28	12	7	8	2	8	2	0	187
1.5AUTO + IVTT + 2*OVTT											
Drivers	136	63	23	9	7	4	1	0	1	1	245
Passengers	102	47	10	11	7	7	0	2	1	0	187
AUTO + IVTT + 10*OVTT											
Drivers	56	61	38	49	17	12	2	5	4	1	245
Passengers	40	54	28	29	12	9	2	10	1	2	187
2*AUTO + IVTT + 2*OVTT											
Drivers	147	75	14	3	1	2	2	0	0	1	245
Passengers	112	50	11	7	2	3	1	0	1	0	187
AUTO + 2*IVTT + 3*OVTT											
Drivers	15	74	43	45	27	20	6	6	6	3	245
Passengers	16	65	29	24	16	15	6	10	3	3	187
JUST AUTO											
All	285	120	14	4	2	4	1	0	2	0	432

NOTE: a*AUTO + b*IVTT + c*OVTT indicates the weighted sum of auto in-vehicle, transit in-vehicle, and transit out-of-vehicle travel times, where a, b, and c are the weights assumed, used to compute the rankings of observed access station choices (e.g., 87 auto drivers and 71 auto passengers in the sample were observed to choose their "closest" access station when the weighted sum of AUTO + IVTT + 2*OVTT is used).

TABLE 3 Lower-Level Access Station Choice Model, Definition of Variables

NAME	DESCRIPTION
tgivtt	transit access plus rail line-haul in-vehicle travel time (min.) for transit access mode; = 0 otherwise
t-fare	transit access fare ($) for transit access mode; = 0 otherwise
t-gfrq	total number of a.m. peak-period trains stopping at the station for transit access mode; = 0 otherwise
agivtt	auto access plus rail line-haul in-vehicle travel time (min.) for auto access mode; = 0 otherwise
a-gfrq	total number of a.m. peak-period trains stopping at the station for auto access mode; = 0 otherwise
a-gpak	natural logarithm of the number of parking spaces at the station for auto access mode; = 0 otherwise
a-sdmy	= 1 if station is closest of all stations to the home for auto access mode; = 0 otherwise

TABLE 4 Lower-Level Access Station Choice Model, Parameter Estimation Results

NUM.	NAME	VALUE	T-STAT
1	tgivtt	-0.34310E+00	-9.4692
2	t-fare	-0.80154E+00	-1.9303
3	t-gfrq	0.13782E+01	6.6196
4	agivtt	-0.17339E+00	-8.2001
5	a-gfrq	0.42972E+00	5.4076
6	a-gpak	0.13948E+01	4.9530
7	a-sdmy	0.15579E+02	3.3599

No. of weighted observations =	1824
No. of cases =	5473
No. of parameters =	7
Degrees of freedom =	5466
Log likelihood at B=0, =	-2529.3
Log likelihood at conv. =	-243.1
Log likelihood ratio =	4572.3
Adjusted RHO-square =	0.9037
Expected percent right =	92.3

Table 5 presents the variables included in the final specification of the upper-level access mode choice model. This model was estimated as an ordinary multinomial logit model, treating the inclusive value (logsum) term as an ordinary explanatory variable. Since this variable is, in fact, computed using estimated parameter values from the lower-level access station choice model (which include sampling error), the asymptotic t-statistics computed by the estimation software and reported in this table are biased upward (in practice this bias is usually found to be relatively small). This does not affect the conclusions drawn from the model estimation results, except perhaps for the AGE variable, whose parameter estimate may or may not be statistically significant, depending on the extent of the bias in the asymptotic t-statistic.

As in the lower-level model, transit access out-of-vehicle time is omitted because of a lack of statistical significance. This failure of transit out-of-vehicle time to enter either model may reflect inadequacies in the current transit network representation for the suburban areas served by GO-Rail. Also

TABLE 5 Upper-Level Access Station Choice Model, Definition of Variables

NAME	DESCRIPTION
d-tran	= 1 if transit access mode; = 0 otherwise
d-walk	= 1 if walk access mode; = 0 otherwise
logsum	inclusive value term for auto and transit modes; = 0 for walk mode
age	= 1 if 31-50 years old for auto and transit modes; = 0 for walk mode
sex	= 1 if female for auto mode; = 0 otherwise
fgi	= 1 if annual income is ≥ $50,000 (Can., 1987) for auto mode; = 0 otherwise
walkd	= walk distance, home to station (km) for walk mode; = 0 otherwise

note that attempts to include rail line-haul variables into the walk mode utility function failed to yield a priori reasonable results.

Table 6 presents the estimation results for this model. All parameter estimates are correctly signed and statistically significant, with the exception of the sex variable (and, as noted in the table, possibly the age variable). The model's goodness-of-fit statistics are very strong. Further, the inclusive value parameter estimate is 0.414 and is significantly different from both 0 and 1 in value, indicating that the assumed nested decision structure cannot be rejected for this dataset.

The estimation results obtained from the 1987 GO-Rail survey data strongly reject a decision structure of "station then mode" in favor of a decision structure of "mode then station." This result is consistent with the Mukundan et al. (*4*) results, in which a mode-then-station model was successfully developed. These results also reject the Talvitie hypothesis (*3*) of a joint access station and mode choice decision process (which would have been implied if an inclusive value scale parameter of value 1.0 had been estimated).

This result appears to be reasonable given the likely sources of correlation among alternative access modes and stations. In particular, it is quite reasonable to assume that a number of "unobservables" enter into trip makers' choices of access mode and hence that mode-station choice bundles involving the same access mode may well be correlated. It is less clear that trip makers' evaluations of access stations are likely to be similarly subject to significant unobservable, idiosyncratic factors. Hence it is not unreasonable to expect a relative lack of cross-station correlation.

TABLE 6 Upper-Level Access Station Choice Model, Parameter Estimation Results

NUM.	NAME	VALUE	T-STAT
1	d-tran	0.62868E+01	18.2922
2	d-walk	0.50987E+01	12.7460
3	logsum	0.41382E+00	18.4039
4	age	0.31815E+00	1.8925
5	sex	0.16561E+00	1.0186
6	fgi	0.62312E+00	3.5913
7	walkd	-0.11873E+01	-8.7149

No. of weighted observations=	1900
No. of cases=	3450
No. of parameters=	7
Degrees of freedom=	3443
Log likelihood at B=0,=	-1945.2
Log likelihood at conv.=	-667.1
Log likelihood ratio=	2556.2
Adjusted RHO-square=	0.6564
Expected percent right=	78.6

Subway Automobile Access Station Model

Table 7 presents the variables included in the final specification of the subway automobile access station choice model, and Table 8 contains the estimation results for this model. All parameter estimates are statistically significant and correctly signed, and the goodness-of-fit statistics are quite strong. Points to note include the following:

- The utility weight attached to automobile in-vehicle access time differs depending on whether the tripmaker is an automobile driver or a passenger. This difference is both statistically and numerically significant (i.e., automobile drivers weight automobile access time over 64 percent more heavily than automobile passengers). This probably reflects automobile passengers having less control over their choice of access station than do automobile drivers.
- Transit out-of-vehicle travel time is weighted more than an order of magnitude more heavily than transit in-vehicle travel time (−0.72 versus −0.065). This can be contrasted with results derived from main mode choice models that typ-

TABLE 7 Subway Automobile Access Station Choice Model, Definition of Variables

NAME	DESCRIPTION
aivt-a	auto in-vehicle travel time (min.), home to access station, if the trip-maker drives; = 0 otherwise
aivt-p	auto in-vehicle travel time (min.), home to acess station, if the trip-maker is a passenger; = 0 otherwise
tivtt	transit in-vehicle travel time (min.), access station to destination
tovtt	transit out-of-vehilce travel time (min.)
clsdmy	= 1 if the station is the closest station to the worker's home; = 0 otherwise

TABLE 8 Subway Automobile Access Station Choice Model, Parameter Estimation Results

NUM.	NAME	VALUE	T-STAT
1	aivt-a	-0.16112E+00	-10.45
2	aivt-p	-0.97992E-01	-7.01
3	tivtt	-0.65272E-01	-5.71
4	tovtt	-0.72376E+00	-9.63
5	clsdmy	0.10892E+02	3.17

No. of weighted observations=	1698
No. of cases=	6792
No. of parameters=	5
Degrees of freedom=	6787
Log likelihood at B=0,=	-2732.9
Log likelihood at conv.=	-1054.3
Log likelihood ratio=	3357.3
Adjusted RHO-square=	0.6139
Expected percent right=	67.9

ically indicate a ratio in the range of 2 to 5. This result is consistent, however, with analysis results, not shown in this paper, that strongly indicate that minimization of subway-to-subway transfer times and egress walk times, or both, appear to be significant in explaining access station (line) choice (*6*).

- Parking capacity was not found to be a useful explanatory variable in this model.
- Transit fare is constant across all station alternatives and therefore cannot enter the model. Similarly, subway line frequencies and parking charges do not vary sufficiently to warrant inclusion in the model.

In comparing the subway automobile access model defined by Tables 7 and 8 with the GO-Rail access station model presented in Tables 3 through 6, the following points should be noted:

- A closest station dummy variable seems to be needed in both models, indicating the strong "bias" effect exerted by the closest station. The effect appears to be stronger in the case of GO-Rail access (a parameter value of 15.6 versus 10.9 for subway access), although the two parameter estimates are not statistically different.
- Automobile access time parameter estimates are quite consistent between the two models (-0.173 versus -0.161) and are not statistically different from one another.
- Transit line-haul in-vehicle time appears to be far more significant in the choice of automobile access station for GO-Rail users than for subway users (a utility weight of -0.173 versus -0.0653).

IMPLICATIONS FOR MODEL DEVELOPMENT AND FUTURE WORK

The models presented here assumed a joint, main mode decision structure in which GO-Rail and subway with automobile access compete with other main modes, such as automobile all-way, transit all-way, and walk all-way. Other decision structures, however, are conceivable and should be statistically tested within the nested logit modeling structure.

Overall, the performance of parking supply and price variables in these models was somewhat disappointing. There are several reasons for this result. First, parking charges do not vary significantly from one Toronto Transit Commission lot to another. Thus, they can have little impact on the access station choice problem. Park-and-ride parking charges are likely to play a more significant role in explaining the choice of the subway with automobile access main mode in which these costs can be compared with the price of parking at the workplace for the drive-all-way mode [this is found to be the case by Miller and Cheah (*5*)].

Second, the role that parking supply plays within the choice process is likely to be rather complex. Parking supply probably acts as a constraint on access station choice; that is, a traveler cannot use a given station if he or she cannot find a parking space there. Exactly which trip makers are so constrained, however, is not easy to determine, either within a simple logit choice model formulation or within the static modeling process used in all current modeling systems. That is, parking lots fill up over the course of the morning. Early arrivers have their pick of parking spaces and hence stations. Travelers who arrive later face various constraints on their choices.

Such effects are likely to be more pronounced in the case of subway than for commuter rail, given the closer station spacing and higher service frequency of the former. This may explain why a statistically significant effect for parking supply was found for the GO-Rail case but not for the subway case. In any event, further exploration of this issue is warranted, given the importance typically placed on parking supply and pricing issues.

This study combined automobile drivers and automobile passengers into a combined automobile mode. It is unlikely that this assumption has had a major impact on the results obtained in this study. It is also clear from the subway access station analysis presented, however, that differences do exist between automobile driver and passenger access station choice behavior. As indicated by the findings of both Talvitie (*3*) and Mukundan et al. (*4*), however, extension of the model to deal explicitly with automobile passengers is likely to be difficult to accomplish.

Finally, it is important to note that conventional transportation network modeling software applications are typically not designed to deal with explicit models of rail access mode and station choice. Such packages are designed to assign vehicle origin-destination flows to a road network and transit passenger flows to a transit network. The applications are not typically suited to assigning mixed mode flows that have trip components on both the road and transit networks. It can also be argued that such packages may not always deal adequately with competition between commuter rail and subway modes, where such competition exists.

Mukundan et al. use their model to "post-process" Washington, D.C., Metro users previously determined by a conventional main mode choice model. This approach, however, can be criticized in that the main mode choice model may not properly reflect access mode and station choice effects. Miller and Cheah (*5*) discuss one approach to deal with this problem: Fortran programs are used to supplement network package calculation, with information flowing between the Fortran programs and the network package, as required. The net result is that main mode choices are determined simultaneously and consistently with access mode and station choices. Although this approach requires developing special-purpose software, once developed, this system operates fairly efficiently and provides nearly unlimited user control over the detail of the mode choice model calculations. Clearly, however, development of more flexible and powerful software in this area would be desirable.

SUMMARY AND CONCLUSIONS

On the basis of observed station choice behavior in the access mode and station choice model, rules for determining access station choice sets for both commuter rail and subway in the GTA were developed. A nested logit model of commuter rail access mode and station and a multinomial logit model of subway automobile access station choice were then developed. Consistent with the findings of other researchers, credible models of access mode and station choice were obtained. Directions for further work include (a) testing alternative overall main mode plus access choice structures, (b) properly capturing parking supply and price effects with these models, (c) developing improved representations of the auto passenger mode, and (d) developing improved network modeling software for dealing with mixed modes of travel.

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