USER PERCEPTION OF TRANSIT NETWORK CHARACTERISTICS FROM THE VIEWPOINT OF AN ASSIGNMENT MODEL

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(Abridged from the French version)

INTRODUCTION

Trip assignment models are important tools for the evaluation of network alternatives in urban transportation systems. The generation of the "best" transit network is usually achieved by heuristic search conducted with the aid of a typical planning package; many packages appropriate for large and complex environments are available: UTPS (1) from U.S.A., EMME/2 (2,3) from Canada, TRANSEPT (4) from England, NOPTS (5) from Switzerland, TRANSCOM (6) from Montreal, etc... These models, despite their own particularities and characteristics, use a similar methodology involving:

- a segmentation of the study territory into small geographic subareas, called zones, for which transport activities are supposed to be concentrated at the centroids;
- a very detailed coding of the network;
- a precise knowledge of transport demand, usually based on an Origin-Destination survey.

In this context, two delicate issues require special expertise from the planner: the explicit or implicit (i.e. modeled) coding of the access links, and the calibration of the impedance function representing user route choice behavior. For the transit case, experience with road traffic assignment models is not helpful in solving these problems; because of the nature of the walking and waiting phases of a transit trip, network loading is more sensitive to spatial aggregation and weighting factors related to the trip components. Furthermore, questions arise about the possible relevance of more sophisticated assignment methods than the all-or-nothing method, such as probabilistic multipath (7) or equilibrium (8) approaches.

To address these preoccupations, a very large empirical study was undertaken, based on the processing of two O/D surveys, each one dealing with some 15 000 individual transit trips made during an a.m. peak period. By making a systematic comparison between the declared route choice of interviewed persons, and the route simulated with a shortest path algorithm, we try to pin-point, in this paper, the sources of error usually connected with the modeling of urban transit trip assignment.

STUDY LABORATORY

A true "data laboratory" was made available by the Service Planning Department of the Montreal Urban Community Transit Commission. This consists essentially of a data bank based on extensive O/D surveys (9,10) executed at regular intervals of four years, coupled with related spatial data and software packages. The context is best described by the following figures and details.

a) Origin/Destination surveys: a population of near 3 000 000, distributed over a territory of 2 300 square kilometers (partitioned into some 1 284 zones), randomly sampled at a rate of 5 percent, the household being interviewed by telephone. In addition to information related to car ownwership, age and sex of individuals, each trip is described by its origin and destination zones, its departure or arrival time, its purpose (work, study, shopping, leisure, other or return to domicile) and its transport mode (car driver, car passenger, public transit, taxicab, rail, walk). Whenever the transit system is used, the traveler described his path through the network in terms of the bus and metro routes taken.

b) Public transit network: in 1978, the area served by the MUCTC network included 370 square kilometers that were served by 3 subway lines and 131 regular surface routes. Nearly 1 000 nodes must be coded to represent the transfer points, including 43 metro stations. About 5 000 directed links are needed to cover the total network length of 2 240 kilometers.

c) Assignment model: the software packages of the MADITUC-/TRANSCOM (11) suite of programsare used here to achieve automatic access (implicit generation of dummy links between zone centroids and network nodes), to validate the declared paths, to compute shortest paths and to load the passenger trips onto the transit network. Aggregate indicators, relative to the simulations, are then derived.

THE TRANSIT PATH CONCEPT

We focus our attention on the basic concept of a transit PATH --i.e. the path taken by a passenger on a transit network--. Strictly speaking, this is a TRIP made by an individual, described by the following sequence: centroid of an origin zone, access link to an entry node, sequence of lines and tranfer nodes used until an exit node is reached, access link to centroid of a destination zone. For the purposes of the experiment, certain concepts must be defined:

- the response: this is the path as described by the interviewed person at the time of survey, defining only the origin and destination zones with a sequence of transit lines (L1, L2, ..., Lk), where k is the number of lines used;

- the declared path: a complete path reconstituted from the response and a validation program which determines, from the available information, the most probable access nodes (entry/exit) and transfer nodes; this derived path is then fully compatible with network loading programs;

- the simulated path: a path computed using a shortest path algorithm with a certain impedance function which includes waiting, walking and travel times as well as transfer penalties. The tree-building process can be initiated from a network node as well as from a zone centroid; if desired, the algorithm can take into account combinations of bus routes on links; for this reason, a distinction must also be made between equal paths (same sets of lines), common paths (same sets of nodes but at least one different line) and different paths (at least one node and one line are different).

Two types of paths are distinguished in the basic data when considering a trip between two zones: the simple path, where a single sampled passenger is travelling and the multiple path, where more than one surveyed person travelled from the same origin to the same destination zones. In the last case, the users may or may not use the same line sets, and therefore, the paths are respectively qualified as identical multiple or different multiple.

An analysis was carried out on the 1974 O/D survey data, concerning this last classification. Less than 1% of the potential cells of the O/D matrix contained observations (non-null entries), most of them (85%) being of the simple path variety. These represented 68% of all the surveyed trips. The other O/D pairs with multiple paths behaved with a measured index of "multipathicity" of about 20%. So, from the data, only 6.5% of all the trips would necessitate an assignment model with diversion capabilities.

THE EXPERIMENT

With the help of the available study laboratory, some interesting questions can be explored:

- do the users of a public transit system behave approximately as hypotheses used in an all-or-nothing assignment suggest they should?
- are the reproduction errors due to the choice of used path between two points of the network, or to the choice of different access points? Do the problems depend on the choice of the algorithm, on the calibration of parameters in the impedance function, or on the level of spatial aggregation?

In an attempt to discriminate between the different causes of error, a series of experiments were carried out using the declared paths as references. A simulation model was developed which could generate an assignment of the network using a node to node O/D matrix as input and allowing different access strategies to be tried. Furthermore, different user behaviors were tested, using an impedance function taking into account many factors:

- in-vehicle travel time;
- waiting time, subject to a line mean headway, corrected by a regularity factor, limited by maximum and minimum values and to which a transfer penalty is added;
- access time or walk time, characterized by the average walking speed and the distance between the zone centroid and the network access point.

The general formula for the impedance function of a trip embedded in the assignment model is as follows:

$$a0*(TAo+TAd)+\sum_{j=1}^{k}(TVj+a4*\min(\max(a1,a2*Hj),a3)+a5*Pj)$$

where:

k : number of transit lines taken
TAo : access time at the origin
TAd : access time at the destination
TVj : in-vehicle travel time on line j
Hj : mean headway of line j
Pj : transfer penalty related to line j (typical value -tv- = 5 min.)
a0 : access time weighting factor (tv=2) in travel time units
a1 : minimum waiting time (tv= 2 min.)
a2 : conversion factor of headway in waiting time (if perfect regularity, tv = 0.5)
a3 : maximum waiting time (tv = 15 min.)
a4 : waiting time weighting factor (tv = 2)
a5 : perception factor of the transfer penalty (tv = 0.5 for the submode metro)

In this context, the analysis involved five different tests, each comparing the declared paths with a different series of simulated paths.

Test 1: Calibration of the impedance function

The first step involved finding the impedance function coefficients that gave the best results. Many simulations were carried out based on a node to node O/D matrix, as the access problem is excluded at this point.

The efficiency of reproduction of the declared paths can be measured as the maximum number of coincidences, or through the behavior of certain aggregate indices.

At this point, it must be said that the "H+5" simulations gave the best impedance function coefficients. A supplementary test was added, modelling an assignment of the nonreproduced paths with link access instead of node access, so as to better appreciate the error due to the resolution level of the network coding. For the "H+5" simulation with a shortest path algorithm, the % of reproduced paths increased from 80% to 88%. Therefore, the use of the all-or-nothing assignment is well justified when the access problem is short-circuited. Table 1 summarizes the most important results of this first test.

Simulation Variable	DECLARED	1 H/2	2 H	3 H/2+5	4 H+5	5 compl
lines/ trip	1.917 (100)	2.110 (110)	1.998 (104)	1.888 (98)	1.875 (98)	1.901 (99)
subway volumes	161k (100)	183k (114)	177k (110)	164k (102)	163k (101)	171k (106)
transfers mét-mét	51k (100)	53k (105)	50k (99)	43k (85)	43k (84)	48k (94)
surface links	419k (100)	458k (109)	430k (103)	414k (99)	411k (98)	407k (97)
%EQUAL paths	--	61.8	67.3	71.4	72.4	72.5
% COMMON	--	7.8	7.6	8.4	7.6	7.7
% DIFFERENT	--	30.4	25.1	20.2	20.0	19.8
r2 TOTAL T	--	.92	.92	.94	.92	.92
r2 OUT-VEH T	--	.59	.71	.83	.83	.83

Table 1. Impact of the impedance function, without access.

Test 2: User behavior study

The second step was an attempt to explain user behavior: do such variables as age, sex, address, trip purpose, travel modes, number of line links have an influence on path reproduction through the impedance function parameters? The sociological variables were found to be insignificant, whereas unimodal metro trips were evidently well reproduced. It was also found that the reproduction error increased with the complexity of a trip; whatever the impedance function tested, there is an almost perfect linear relation between the number of transfers and the percentage of different paths.

Test 3: Testing of a blind access method

As the resolution level of network definition is approximately the same as the zonal system (number of nodes almost equal to the number of centroids for the M.U.C.T.C. territory), it is interesting to test the effect of an assignment method implying totally blind automatic access. To do this, the shortest path algorithm is applied on the O/D pair of nodes which are the closest to the initial centroids.

Test 4: Conventional zone to zone assignment

Normally, trip assignment on a network is worked out from centroid to centroid; most of the time, this implies manual coding of some artificial links, which makes it difficult to standardize and control this activity. With the MADITUC-/TRANSCOM programs, automatic access is modeled and controled by global parameters (maximum distance, walking speed, maximum number of links,...) with possible punctual interventions. An access network having been generated, the shortest path algorithm is applied to find the best path from the origin zone to the destination zone, using the traditional all-or-nothing assignment method.

Test 5: Logit diversion assignment

After splitting the problem into three parts -- access to the origin, routing on the network and access to the destination--, the assignment algorithm is made more sophisticated by expanding the possibilities of origin and destination accesses (1 to 4 different nodes can correspond to one zone of origin or destination). Afterwards, the shortest path algorithm is applied to the No/Nd pairs to determine the different node to node travel times. Then, after regrouping the original paths, the assignment predicts a diversion between the possible alternatives for which the total travel times are now known. A Dial multipath assignment method (logistic function with diversion parameter Θ) is used on this small network.

Moreover, the following table contains the results of two tests: maximum diversion (Θ=0) and the best factor for fitting of the aggregate indicators (Θ=-1.5).

THE RESULTS

The following table contains aggregate indicators corresponding to the complete assignment of the 332 000 (17 000 surveyed paths) morning peak-period trips, on the M.U.C.T.C. network in 1978. The eight best and most typical simulations of each class of situation are given:

'DÉCLA': the declared paths loading on the network; "H+5" impedance function, unless otherwise stipulated.
'SIMUL': the simulated paths loading from the same origin and destination nodes; calculated by a shortest path algorithm, using the above-mentioned impedance function.
'S-H/2': the simulated paths loading from node to node, using the traditional H/2 impedance function.
'BLIAC': the simulated paths loading from node to node, using blind access assignment.
'C-Cal': the simulated paths loading from centroid to centroid, with access time weight factor equal to 1.0; here, the computed access time is proportional to the distance between the centroid and the access node.
'CCH/2': same as preceding but using the H/2 impedance

function.
'DIV-0': the paths loading with diversion at the access level; diversion factor Θ=0.0 was used here, expanding the 17 442 initial paths to 78 815 paths loading.
'D-1.5': same as preceding, but using a diversion factor Θ of -1.5.

The chosen indicators are of two classes. The first group measures coincidences between the simulated and declared paths. The second group shows the aggregate results of the simulations. The indicators are:

'EQPA': % of equal paths,
'COPA': % of common paths,
'DIPA': % of different paths,
'r2TOT': correlation between total travel times,
'r2OVT': correlation between out-of-vehicle times,
'a.t.t.': average travelling time on the network, in minutes, using the "H+5" impedance function,
'nllink': number of line links taken,
'waitt.': waiting time (minutes),
'dist. ': average distance travelled on the network (km),
'METRO' : total number of passengers using the metro, in thousands (k),
'p.C-MM': proportion of metro-metro transferring passengers,
'L1,L2,L4': number of users respectively using the metro lines 1, 2 and 4,
'i.v.t.': average "in-vehicle" travelling time (minutes),
'v.spe.': average speed of vehicles taken (kmph),
'wait-H': mean sum of headways of lines used (minutes).

variable	base DECLA	node*node SIMUL	S-H/2	BLIAC	zone*zone C-Cal	CCH/2	diversion DIV-0	D-1.5
EQPA	--	72.4	61.8	24.3	35.3	26.9	--	--
COPA	--	7.6	7.8	2.4	4.3	4.0	--	--
DIPA	--	20.0	30.4	73.3	60.4	69.1	--	--
r2TOT	--	.92	.92	.67	.74	.81	--	--
r2OVT	--	.83	.59	.29	.41	.26	--	--
a.t.t.	35.7	34.2	35.3	41.2	36.4	38.9	42.3	37.2
nllink	1.92	1.88	2.11	2.37	2.06	2.46	2.63	2.27
waitt.	16.2	15.7	17.6	21.0	17.4	20.7	22.6	18.8
dist.	7.21	7.06	7.07	7.47	7.22	7.25	7.55	7.19
METRO	161k	163k	183k	156k	161k	184k	178k	180k
p.C-MM	.314	.262	.291	.205	.248	.314	.271	.287
L1	95k	92k	107k	84k	88k	109k	99k	102k
L2	95k	91k	107k	84k	92k	112k	106k	109k
L4	22k	22k	22k	20k	21k	22k	21k	21k
i.v.t.	19.5	18.5	17.7	20.2	19.0	18.2	19.7	18.3
v.spe.	22.2	22.9	24.0	22.2	22.8	23.9	23.1	23.5
wait-H	6.64	6.31	7.06	9.16	7.09	8.38	9.46	7.48

Table 2. Comparison of simulations.

CONCLUSIONS

Different lessons can be drawn from these experiments. The mentioned statistics given above establish the respective merits of each of the simulations in this context. However certain points call for further discussion:

(1) It stands to reason that, because of the experiment's nature, the following conclusions are valid strictly for the Montreal case and can only be generalized with extreme caution. However, the comprehensiveness of the test ensures some "robustness and likelihood" to quite a few results; as a matter of fact, the conclusions remained very steady, in the analyses of 1974 and 1978 survey data.

(2) It is clear that, when the territory and transportation network are defined at the same level of resolution, the all-or-nothing assignment algorithm is very satisfying when applied to the part of the trip carried out on the network, i.e. excluding access; a well-calibrated impedance function allows the reproduction of 80% of the declared paths and this can be raised to 88% if the algorithm is initiated from a link instead of a node.

(3) The calibration of the impedance function is critical: the performance of the algorithm in terms of coincidences is improved by 30%, for a zone to zone assignment. In addition, one of the most commonly used functions seems to be one of the worst: the use of an impedance function of H/2 increases substantially the number of transfers, and in this way, results in an overloading of heavy transit modes. As a consequence, this algorithm overestimates by 12 to 15% the number of metro trips, encouraging the use of heavy substructures, or at least, overvaluing their required capacity.

(4) When access is inserted into an assignment method, the results deteriorate considerably: the number of coincidences regarding the declared paths drop from 80% to 40% of common or equal paths. However, in terms of aggregate indicators, it is possible to obtain global values that are very close to the observed values. This is disturbing as it shows that many compensation phenomena exist on a highly ramified network. The 'C-Cal' simulation is characteristic of this problem: it projects a perfect estimate of the total number of metro users but yields an error of more than 20% for the number of passengers transferring from metro to metro. What can be said of the H/2 simulation results?!... "Entropy at its maximum"!

(5) Thus, except for user behavior, the access phenomenon (due to the spatial aggregation problem) is the assignment model's principal source of error. In fact, it seems that only consideration for the imponderables related to the sampling conditions of demand estimation, and external reasons may justify the use of more "diffusing" methods. In some circumstances, a diversion model to soften the arbitrariness inherent in the spatial aggregation context, combined with the use of an all-or-nothing assignment method, may be considered, but unpredic-

table results may occur.

In summary, on the Montreal data base, our experiments show that, among the assignment methods that can be applied on a transit network, the all-or-nothing assignment seems entirely justified, specifically when the impedance function is previously well calibrated. Based on these results, we hope that future research on assignment models emphasizes spatial aggregation problems, an important factor that could justify the use of diversion models.

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REFERENCES

1. R. B. Dial, Urban Transportation Planning System: Philosophy and Function. TRB, Transportation Research Record 599, 1976, pp. 60-64.

2. M. Florian, R. Chapleau, S. Nguyen, C. Achim, L. James-Lefebvre, S. Galarneau, J. Lefebvre and C. Fisk. Validation and Application of an Equilibrium-Based Two-Mode Urban Transportation Planning Method (EMME). TRB, Transportation Research Record 728, 1979, pp. 14-23.

3. A. Babin, M.Florian, L. James-Lefebvre and H. Spiess. EMME/2, an Interactive Graphic Method for Road and Transit Planning. Public. 204, Centre de Recherche sur les Transports, Université de Montréal, 1982.

4. A. Last, S.E. Leak. TRANSEPT: A Bus Model. Traffic Engineering and Control, vol. 17, January 1976, pp. 14-20.

5. M. Rapp, P. Mattenberger. Planification opérationnelle des transports urbains en commun - approches et applications. Presented at the World Conference on Transportation Research, Rotterdam, April 1977.

6. R. Chapleau, P. Trottier. L'utilisation du modèle d'affectation TRANSCOM dans la planification opérationnelle d'un réseau de transport en commun. Routes et Transport, Association québecoise du transport et des routes, vol. 23, August 1979.

7. R. B. Dial. A Probabilistic Multipath Traffic Assignment Model which Obviates Path Enumeration. Transportation Research, Vol. 5, 1971, pp. 83-111.

8. S. Nguyen, L. James. TRAFFIC - An Equilibrium Traffic Assignment Program. Publ. 7, Centre de Recherche sur les Transports, Université de Montréal, 1975.

9. Commission de transport de la Communauté urbaine de Montréal. *Mobilité des Montréalais: 1978*. Service de la Planification, July 1979.

10. Commission de transport de la Communauté urbaine de Montréal. *Méthode d'enquête: enquête régionale O-D*. Service de la Planification, April 1981.

11. R. Chapleau, B. Allard, M. Canova. *MADITUC, un modèle de planification opérationnelle adapté aux entreprises de transport en commun de taille moyenne*. Presented at the Roads and Transportation Association of Canada annual meeting, Halifax, Sept. 1982, Publ. 265, Centre de Recherche sur les Transports, Université de Montréal.

Remark: more detailed information is available from the following research documents:

** J. de Cea, R. Chapleau, P. Trottier. *Calibration des coefficients d'impédance et étude du comportement des voyageurs par l'analyse désagrégée de leurs itinéraires sur le réseau de transport en commun*. Rapport préliminaire de recherche no. 3, Service de la Planification, C.T.C.U.M., January 1982.

** J. de Cea. *Modèles d'affectation de transport collectif urbain: traitement de l'accès et de la diversion entre les chemins*. Doctorate thesis, Section Génie des Transports, École Polytechnique de Montréal, Sept. 1982. Publ. 265 Centre de Recherche en Transport, Université de Montréal.