TRANSIT NETWORK ANALYSIS AND EVALUATION WITH A TOTALLY DISAGGREGATE APPROACH

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Introduction

It is worth recalling two statements by Manheim (1), defining the main challenges presently faced by transportation planners:

> "The substantive challenge of transportation systems analysis is to intervene, delicately and deliberately, in the complex fabric of a society to use transport effectively, in coordination with other public and private actions, to achieve the goals of that society..."

> "The methodological challenge of transportation systems analysis is to conduct a systematic analysis in a particular situation which is valid, practical, and relevant, and which assists in clarifying the issues to be debated... A key task for the analyst is to select a process of analysis, including a choice of model, that will help to..."

In the transit network analysis context, numerous tools have been made available to planners to undertake various studies of the apprehended impacts of possible interventions. In the 1970s, comprehensive planning packages were developed on the premises of new computing power and algorithms. The well-known UTPS --Urban Mass Transportation Administration's Transport Planning System (2)-- package attempts to integrate all the desired functions of the synthetic approach: crude statistical tools for trip generation and modal split, matrix manipulation modules for trip distribution and Origin-Destination data processing, file management, trip assignment on road and transit networks, report production, etc... The system works on an IBM mainframe, is a self-contained and almost closed system, and makes efficiently peak-hour network assignment of an O-D matrix.

Other simulation models have gained notoriety, especially EMME (3), a model integrating modal split and bi-modal (transit and road networks) equilibrium assignment. More interesting is the completely redesigned new model EMME/2 (4) which uses the same approach in a modern interactive graphics context; the multi-modal equilibrium package makes use of matrix, function and network editors to specify the conditions of the usual peak-hour network assignment of an O-D matrix.

For specific transit planning, the noteworthy concept of NOPTS (5) --for Network OPtimization of Transit Systems-- establishes well the main components of the operational planning for transit networks: a heuristic interactive approach with graphical presentation of results, computation of operational statistics, schedule production, transfer optimization (6), etc... The main objective of the system remains simulating the loading of the transit network subject to a peak-hour O-D trip matrix. To our knowledge, implementation has been mainly for small and medium scale networks.

The aforementioned planning models follow a well-defined common approach which focuses essentially on the network capacity analysis problem. This is the simulation approach, characterized by these elements:

- a study territory segmented by a zoning system which is a compromise between computing efficiency and level of resolution;
- a specification of demand in the form of an Origin-Destination trip matrix for a fixed period of time, derived from synthetic modeling --trip generation to trip distribution-- or, at best, from an O-D survey;
- a network description obtained by the coding of route geometry, the coding of service attributes --link travel times, headways-- and the explicit coding of access links between zone centroids and network nodes.

Moreover, rationality hypotheses are made about users' perception and behaviour, and this is translated into the use of a specific algorithm: equilibrium, probabilistic multipath or all-or-nothing assignment.

This approach has played a positive role in the evaluation of many projects, but has also generated arguments from detractors (7, 8). The most severe criticism that can be made concerns the absence of empirical validation of the accepted hypotheses and our corresponding ignorance of the importance of biases thus introduced.

With the aid of a unique set of survey data, collected by the Montreal Urban Community Transit Corporation's Planning Service Department (9), some investigations (10, 11) produced new evidence concerning transit users' behaviour from the viewpoint of an assignment model: the sufficiency of all-or-nothing (shortest path) trip assignment for the intra-network trip component, the large bias introduced by the access stage (zone aggregation), the importance of impedance function calibration on the quality of assignment results. These points have led to the necessity of developing a new transit planning package which incorporates analytical capabilities to deal with the transit network simulation model more adequately. The resulting model, MADITUC ("Modèle d'Analyse Désagrégée des Itinéraires en Transport Urbain Collectif" --Model for the Disaggregate Analysis of Trips on an Urban Transit Network--) was first presented in 1982 (12) and has been since implemented in two large-scale contexts. The main concepts and functions are described in the following paragraphs.

TRANSIT SERVICE PLANNING CONTEXT

In the context of continuous large scale urban planning process, the analysis of transportation systems, and especially of public transport, requires the availability of relevant databases and the use of related modeling tools. These databases provide two types of information: SUPPLY and DEMAND. Adequate planning instruments must enable the planner, first, to *model* appropriately the transport system with available data and, second, to give reasonable answers to a large subset of *problems* he has to deal with.

Aimed at a level of resolution compatible with the preoccupations of the transit planner dealing with a medium-term horizon (--network geometric design, basic level of service--), the computerized procedures of the MADITUC software (Model for the Analysis of Disaggregate Itineraries on an Urban Transit Network) provides the usual trip assignment capability, and in addition enables the planner to carry out an operational evaluation of the transit network and a detailed analysis of paths made by the transit riders. The MADITUC package was first developed in the Montreal context, around the database related to the MUCTC (Montreal Urban Community Transit Corporation) Origin-Destination regional surveys done in 1970, 1974, 1978 and 1982. All transit operators of the Metropolitan region have their network coded: MUCTC (rail, subway, bus), STL (Laval Transit Corporation), STRSM (South Shore Transit Corporation) and others; the corresponding framework includes 1500 zones, 250 transit lines and some 3000 nodes and 10000 links. Three large implementations are presently maintained: MUCTC --Service Planning Department--, Quebec Ministry of Transport --Personal Transportation Information Systems Service--, and Ecole Polytechnique -- Transportation Division-- for teaching transit planning techniques with a CAD (Computer Assisted Design) approach.

DATA DESCRIPTION

Urban transportation systems analysis is carried out with data coming from two main components:

- transportation SUPPLY --network--,
- transportation DEMAND --trips--.

Data requirements for the first kind of analysis come from the operational characteristics of the network; a transit NETWORK is formed by a paired set of NODES and LINES in the following fashion:

- a NODE is specified by a number, x-y coordinates, and an optional descriptor (station or street name); when a territorial code is added, operational statistics are estimated according to spatial area;

- a LINE --for any transit mode-- is characterized by three types of data:
    - general: number, descriptor, real length, commercial speed (inbound and outbound), and other optional informations (division, vehicle type)
    - geometric: route description defined as an ordered sequence of directed nodes (mixed one-way and two-way layout)
    - level of service: specification of up to five variable time periods and average headways.

These data are sufficient to completely define a transit network; LINK attributes (travel times, distances) are processed implicitly by the system; an UPDATE module enables the planner to input more precise data, if available.

The DEMAND aspect of the MADITUC system may be processed from two kinds of data: service counts (at maximum load points) or O-D trips (for, say, an a.m. peak period). In the first case, COUNT analysis is performed by functions belonging to the NETWORK module: firstly, multiple count data taken along a bus route (15-minute time intervals) are MERGED --submodule MERGE-- to produce a "demand envelope" at the line injection point (terminal); secondly, with the application of loading standards and other parameters (unit cost for a vehicle-hour and a passenger-hour) the submodule COUNT produces an "optimal" departure schedule and a vehicle assignment that minimizes the number of vehicles and, with this fleet, minimizes the combined (operator and riders) cost of operation. In the more conventional approach (demand specified by O-D trips), the processing is much more complex and involves numerous functions detailed in the following paragraphs.

CONCEPTS and TERMINOLOGY

Very standard notions and concepts are used for the transit network analysis part of MADITUC. In spite of many new features, such as headway determination with counts, vehicle scheduling, computing of operational statistics in a dynamic manner instead of the traditional steady-state approach, MADITUC's terminology is conventional, and essentially the same as other transit planning models such as UTPS, EMME or NOPTS. For the demand modules, when data come from an Origin-Destination survey, MADITUC uses a different approach to processing trip data.

The main feature of MADITUC is its disaggregate approach. The traditional models use an O-D trip matrix for a given period of time to be assigned on the transit network. A cell of the matrix contains the number of riders going from an origin zone O to a destination zone D; shortest paths on the network are computed and trips are loaded. With MADITUC, every observed trip (sampled) is processed individually and in addition to the number of riders (expansion factor) for the specific O-D pair, all other related "socio-economic" information (age, sex, purpose, other modes, fare, car availability, household revenue, dwelling zone, postal code, etc...) is kept available to the analysis context in addition to the path specification (entry and exit nodes, transfer nodes, lines taken) and travel attributes (access, waiting and travel times). The basic notions associated with an individual TRIP, also called ITINERARY, are as follows (figure 1):

- Zo : origin zone
- Zd : destination zone
- FLOW : expansion factor of the observed O-D trip
- INDEX : index generated internally by MADITUC to link the socio-economic variables of the trip
- L1,..,L6 : transit lines taken or simulated
- No : entry node on the transit network
- Nd : exit node on the transit network
- N2,..,N5 : transfer nodes
- TA : access time (walk)
- TW : waiting time depending of
  * transfer penalty
  * mode factor
  * headway
  * regularity factor
  * min and max values
- TT : travel time (in-vehicle)

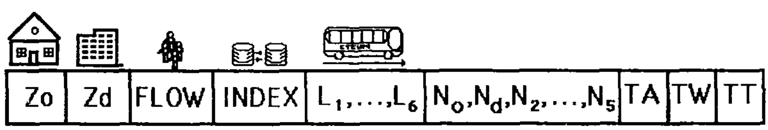

Figure 1: ITINERARY (O-D trip) description

Depending on the kind of trip FILE dealt with, a specification is necessary to distinguish between observed and simulated "features". When analysing an ITINERARY, the term OBSERVED is used for a PATH (sequence of nodes and lines) derived from the ANSWER (lines taken as told to the survey interviewer) and the application of an "intelligent" program which searches for the most probable access and transfer nodes (conditionally to the answer) -- the figure 2 illustrated the different components relevant to the VALIDATION procedure--; the term SIMULATED is related to the use of a simulation MODEL. The last term applies to the ACCESS components of the trip (choice of entry and exit nodes) and to the PATH description (lines and transfer nodes) obtained by a shortest path computation --zone to zone or node to node--. This means that many processing alternatives are available such as, say, extraction of OBSERVED ACCESS from OBSERVED ITINERARY file to be coupled with SIMULATED shortest PATHS.

The use of these fundamental concepts --OBSERVED AND SIMULATED-- is illustrated in figure 3, for the general MADITUC trip assignment. O-D TRIPS, ZONES and NETWORK (survey reference network) files become input to the VALIDATION module which outputs an OBSERVED ACCESS TABLE and an OBSERVED ITINERARIES file, ready for network LOADING. In contrast, a normal SIMULATION needs an ACCESS step (automatic generation of dummy links between zone centroid and network nodes) to build the ACCESS TABLE and a shortest PATH calculation to produce a SIMULATED ITINERARIES file perfectly compatible with the first one. The same LOADING program is used. Summary reporting or one-to-one comparisons make calibration easier and provide in-depth knowledge of any simulation bias.

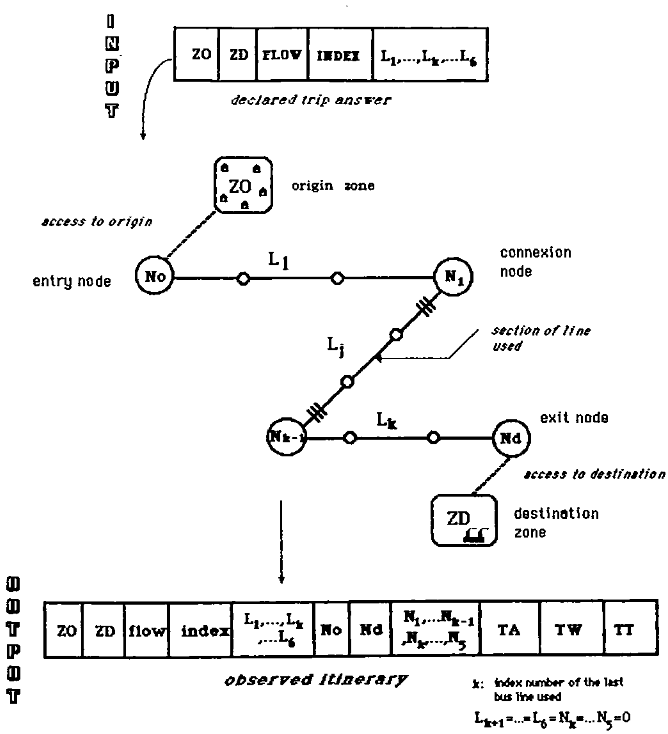

Figure 2. TRIP VALIDATION (from a surveyed answer)

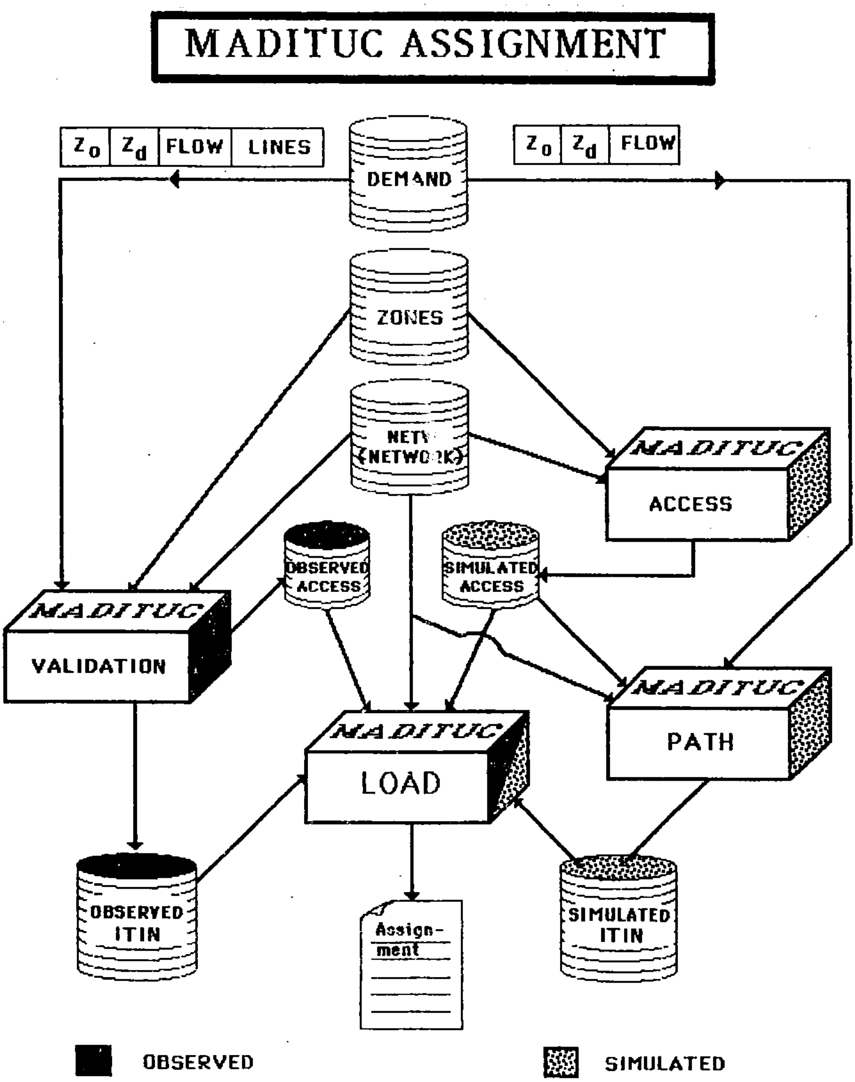

Figure 3: OBSERVED/SIMULATED TRIP ASSIGNMENT

GENERAL TRANSIT TRIP ASSIGNMENT PROCEDURE

Numerous options and analysis features are built into the MADITUC system. Some understanding of the overall planning exercise is necessary to grasp the usefulness of FILES (data, results), COMMANDS and MODULES in different contexts. These concepts are illustrated further with diagrams.

In general, three types of activities are undertaken with the aid of the system: SUPPLY modeling, DEMAND modeling and performance (DEMAND/SUPPLY) analysis. Figure 4 illustrates functional blocks and related modules; demand may be processed indifferently in a SIMULATED or an OBSERVED way.

It should be recalled that, when looking at a specific procedure, the data are mostly maintained in an external format. This feature, called MADITUC "openness", enables the planner to carry out upstream and downstream file manipulation with other "ad hoc" programs (FORTRAN, SAS --Statistical Analysis System(-13)--); updating, modification, conversion, data extraction, scenario comparison, calibration, statistical analysis, clustering, graphical reporting, data transfer to microcomputer (word processor, spreadsheet) are possible operations in any analysis step; in doing so, however, caution must be exercised by the planner to always ensure complete validity.

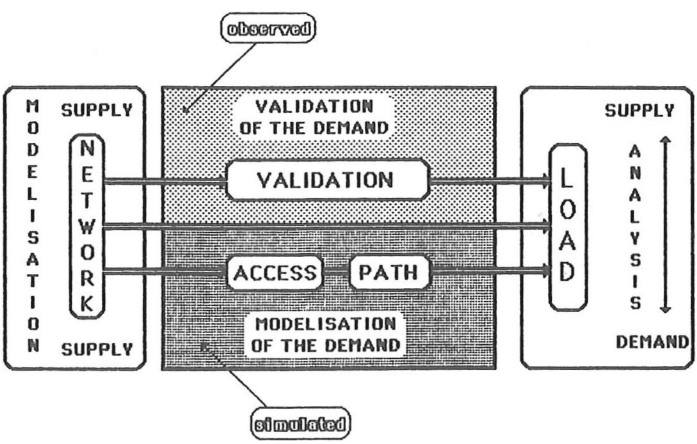

Figure 4: SUPPLY-DEMAND-ANALYSIS components

LIST OF MADITUC PROCEDURES

When transit network evaluation is considered, trip assignment is the core activity undertaken by the planner. For instance, comparative analysis of observed and simulated trips facilitates calibration of the impedance function --determination of time weights (access, waiting and travel) -- on the reference network. For a new network, many types of simulation are available. The following paragraphs provide a succinct summary of the numerous modules available:

***NETWORK module:

- defines the geometry of the transit network with NODES, LINES (allowing one-ways, loops, symmetrical express service, variation of route in the day) and LEVEL OF SERVICE (headways, layover rules). This set-up permits, in addition to trip assignment and network loading for a typical peak period, computation of operational statistics (fleet, vehicle hours, vehicle kilometres) for a (week)day according to different contexts : steady-state regime, dynamic simulation of vehicle movements from an injection point, on a territorial basis. Schedule determination and vehicle assignment are also derived from the processing of input data.
- as an accessory --submodule using the NETWORK database facilities--, a submodule COUNT realizes the MERGEing of different standing counts along a route to produce a maximum load point envelope translated to the vehicle injection point, and then, makes an optimal (minimization of a combination of operator´s and users´ costs) determination of headways, according to peak and off-peak loading standards;
- another accessory submodule computes operational statistics from the input of a detailed (irregular) timetable;
- for coding verification, a submodule produces a graphical representation of the network on a CALCOMP plotter (see figure 5); zone centroids, zone perimeters and access links may be optionally added to the plot.

***TRIP ASSIGNMENT module: four available procedures:

- OBSERVED trip assignment
- SIMULATED trip assignment (ZONE to ZONE)
- SIMULATED trip assignment (NODE to NODE)
- OBSERVED/SIMULATED trip assignment

****OBSERVED TRIP ASSIGNMENT

OBJECTIVE: generate an observed itinerary file and make a trip assignment on the reference transit network

DATA:
- NETWORK description (nodes and lines)
- ZONE data (centroids)
- declared trip data (Zo, Zd, FLOW, LINES)

RESULTS:
- network file (NETW)
- observed access file (TACCESS)
- observed trip file
- network loading file

MODULES:
- NETWORK

- VALIDATION
- LOAD

****<u>SIMULATED TRIP ASSIGNMENT (ZONE to ZONE)</u>

OBJECTIVE: generate a simulated itinerary file and make a trip assignment on the transit network (reference network used for calibration purpose), impact evaluation of a new network)

DATA:
- NETWORK description (nodes and lines)
- ZONE data (centroids)
- declared trip data (Zo, Zd, FLOW)

RESULTS:
- network file (NETW)
- simulated access file (TACCESS)
- simulated trip file
- network loading file (from simulation)

MODULES:
- NETWORK
- ACCESS
- PATH
- LOAD

****<u>SIMULATED TRIP ASSIGNMENT (NODE to NODE)</u>

OBJECTIVE: generate a simulated itinerary file and make a trip assignment on the transit network (with probabilistic diversion at the access level)

DATA:
- NETWORK description (nodes and lines)
- ZONE data (centroids)
- declared trip data (Zo, Zd, FLOW)

RESULTS:
- network file (NETW)
- expanded/simulated partial trip file
- simulated trip file
- network loading file (from simulation)

MODULES:
- NETWORK
- ACCESS
- PATH
- DIVERSION
- LOAD

****<u>OBSERVED/SIMULATED TRIP ASSIGNMENT (Figure 6)</u>

OBJECTIVE: generate a simulated itinerary file to be compared with an observed itinerary file (permits calibration of the impedance function without the bias introduced by the access)

DATA:
- NETWORK description (nodes and lines)
- ZONE data (centroids)
- declared trip data (Zo, Zd, FLOW)

RESULTS:
- network file (NETW)
- observed partial trip file
- observed/simulated trip file
- network loading file (observation/simulation)

MODULES:
- NETWORK
- VALIDATION
- PATH
- LOAD

***PERIPHERAL PROCEDURES

Other immediate procedures are available for executing accessory functions. For instance, some special demand data preparation programs, network analysis accessories, systematic output comparison procedures are introduced to serve as planning aids. A brief description follows:

****in the NETWORK module

NETWORKA : network analysis (headway determination with counts); uses submodules MERGE and COUNT

NETWORKC : systematic comparison of operational statistics coming from two networks

****JUNCTION module

PURPOSE: demand data processing; program doing zone substitution for multimodal (car-transit) trips

PROCEDURE: SJUNCT

****TRIP program

PURPOSE: data extraction from O-D survey file, copy and conversion to a MADITUC file format

PROCEDURE: TRIP (written in SAS)

****SELECT-COMPAR programs

PURPOSE: comparison of two or more network loading output files (report selection) and performance factors

note: a FORTRAN program (SELECT) decodes loading output files and then a SAS program computes indicators

PROCEDURES: - numerous SELECTi programs

****PLOT module

PURPOSE: network graphical representation on a CALCOMP plotter

DATA:
- NODES
- transit LINES
- zone CENTROIDS
- ACCESS links
- ZONE perimeters

PROCEDURE: PLOT

****SAS/GRAPH programs

PURPOSE: plot numerous MADITUC results (PATH and LOAD modules) with SAS/GRAPH (GMAP proc) facilities

PROCEDURES:
- STATSYNT: statistics by origin zone
- ACSTAT: metro station accessibility by walk
- PROLINE: passenger load profile of a line
- ISOCRO: isochronous areas plotting (Figure 7)
- ISOCOMP : time differential plot

****AGGREGATION facilities

Zone dictionaries are maintained for automatic summary reports; example: 1500 zones, 65 sectors, 10 districts.

FUNCTIONS FOR TRANSIT NETWORK ANALYSIS

The disaggregate approach related to the conceptual framework of MADITUC enables the transit planner to carry out innovative analyses, which are not possible with a conventional O-D matrix approach. To realize the full spectrum of analytical possibilities, it is worth recalling the list of *variables* defined in a trip record (from a typical O-D survey):

```
TRIP (disaggregate approach)

     - DEPARTURE TIME (or arrival)

     - PURPOSE        * WORK
                      * STUDY
                      * SHOPPING
                      * LEISURE
                      * OTHER
                      * HOME RETURN

     - MODES          * AUTO-DRIVER
                      * AUTO-PASSENGER
                      * TRANSIT      > METRO
                                     > BUS       > MUCTC
                                                 > STL
                                                 > STRSM
                                                 > OTHER
                                                 > SCHOOL
                                     > TRAIN
                      * ....
           (with or without priority)

     - SOCIO-ECONOMIC CHARACTERISTICS
                      * SEX
                      * AGE
                      * CAR OWNERSHIP
                      * RESIDENTIAL ZONE
                      * HOUSEHOLD REVENUE
                      * etc...

     - TRAVEL INFORMATION
                      * ORIGIN ZONE
                      * DESTINATION ZONE
                            ...if multimode --> JUNCTION ZONE
                            ...if TRANSIT   --> LINES taken
                                            --> fare mode (82)
```

MADITUC processing adds travel attributes to these trip characteristics. Functionaly, the extended trip record combines any information derived from the transit network database with the user´s (or household´s, or zone´s, or subregion´s,...) variables. For analysis purposes, the planner may select, extract and process a trip file on any kind of specification of variables; in fact, using a generic software package such SAS as a pre-, intermediate- or post-processor, MADITUC may be considered as a kind of *specialized* --transit-- statistical analysis system. Specific studies may illustrate interesting capabilities.

Transit network spreadsheet

Exclusive use of the NETWORK module of MADITUC --without any trip data-- provides the planner with a series of transit functions similar to the conceptual framework of a spreadsheet. Resource evaluation constitutes the core operation in the prediction of impacts related to different service policy alternatives, as for examples: change of off-peak headway, change of the geometry of the route, introduction of short lines, change of commercial speed (by some priority measure), subnetwork reconfiguration, change of service periods, etc... At this stage, MADITUC acts as a network scale model, carrying out relevant information on departures, runs, vehicle assignments, layover times, temporal graph of number of vehicles in service, vehicle entry/exit times, etc...

Detailed analysis of riders of a transit line

When dealing with trip files, the planner may select and extract records corresponding to any specific condition. Observed or simulated itineraries may be considered. For instance, extraction of trips using a specific bus route in the a.m. peak period may be followed by these procedures: network loading to obtain the load profile of the line and utilization ratios (passenger-hours and passenger-kilometres on seat-hr and seat-km), origin and destination statistics (flow, access / waiting / in-vehicle times, metro usage), other lines usage, boarding / alighting and transfer volumes, time and distance distribution of the riders. Moreover, rider characteristics may be analyzed: age and sex distribution, car ownership, etc...

Metro station accessibility study

Trips passing by a specific network node may be extracted and thoroughly examined. Data segmentation is done according to access mode (bus, car driver, car passenger, walk, etc...) and all imaginable statistics are computed. Figure 8 illustrates walking access distribution to a subway station.

Impact of fare modification

If a fare structure is applied according to the user's origin or residential zone (with, for example, monthly passes), it is easy, with the disaggregate approach, to simulate path selection on the network for different types of users by segmenting them and by applying different impedance functions (including intermodal fare matrix). If the network geometry remains the same, combined trip loading is carried out easily.

Transit financing analysis

Issues in public transportation financing are challenged with great difficulty by transit planners. The usual planning models are not suitable for identifying beneficiaries of specific transport services. In this context, the following approach is suggested: when carrying out an observed or simulated trip assignment, computation is done, for each O-D trip, on the relative usage (- in terms of passengers, passenger-hours and passenger-kilometres-) of numerous selected modes for which a costing model exists (- train, subway, bus-). Secondly, transit trips, according to their *residential* zone, are summed up on larger areas, like municipalities. These statistics constitute a good measure of the relative usage of the network facilities by all residents of a specific sector. Revenues provided by the sector´s residents are estimated easily --adult and reduced fare ridership--. Even, financial contributions based on land taxes may be taken into account. Then, a complete balance-sheet is produced including direct and indirect revenues, and transit benefits; if costs are allocated proportionally to received benefits, deficits may be distributed on a territorial basis.

Modal split model

The disaggregate approach offers also interesting opportunities for processing non-transit trip data. Predicting the impact of a transit network modification can be considered with the following method:

a) computation of travel times on the reference transit network for transit and non-transit (car driver and passenger) users; for instance, we do know the true modal choice of these users and the attributes of the "transit choice";

b) computation of travel times on the newly modified transit network for all users;

c) according to the travel time differences, a modal shift model is applied: for example a former car user may become a transit user if the time differential is greater than some threshold value, depending on other user characteristics. Other cases are to be carried out on a similar fashion.

Modelling modal choice becomes a discrete procedure which may integrate category analysis (-age, sex, car ownership, destination, trip purpose- and corresponding threshold times). The method estimates also the user benefits (consumers´ surplus) to be allocated to the network change.

CONCLUSION

This paper has presented the main concepts and functions of the existing MADITUC software package insofar as it addresses the evaluation and analysis of a transit network. The system acts as a scale model, integrates main databases relevant to service planning environment, provides open interfaces with graphical and statistical analysis tools, and produces standard economic evaluation and performance reports. Moreover, the disaggregate approach capabilities offer mind-expanding analytical opportunities, enabling transit planners to fully exploit limited and expensive O-D survey data.

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