ROUTE CHOICE AND ASSIGNMENT MODELS FOR "ITS" TRANSIT NETWORKS

AGOSTINO NUZZOLO

"Tor Vergata" University of Rome - Department of Civil Engineering
via di Tor Vergata 110 - 00133 ROME, ITALY

FRANCESCO RUSSO

University of Reggio Calabria – D.I.M.E.T. Faculty of Engineering
Feo di Vito – 89100 REGGIO CALABRIA, ITALY

UMBERTO CRISALLI

"Tor Vergata" University of Rome - Department of Civil Engineering
via di Tor Vergata 110 - 00133 ROME, ITALY

FRANCESCA GANGEMI

"Tor Vergata" University of Rome - Department of Civil Engineering
via di Tor Vergata 110 - 00133 ROME, ITALY

Abstract

This paper deals with route choice and assignment models for transit networks. The presented dynamic approach allows to consider the within-day time-dependencies of demand and supplied services for high frequency transit systems with different levels of punctuality/regularity and information to users obtained through different types of ITS systems.

INTRODUCTION

Nowadays much effort is made in order to improve through ITS (Federal Transit Administration, 1998) the performances of transit services. Special attention has been given to increase time reliability through APTS - Advanced Public Transportation Systems - (Knoppers and Muller 1995, Vance and Balcombe 1997) and pre-trip and en-route information on the available service through ATIS - Advanced Traveller Information System - (Balogh and Smith, 1992; Atkins, 1994; Kirchoff, 1995; Hickman and Wilson, 1995; Golledge, 1997). For the analysis and assessment of specific ITS levels, simulation models consistent with these new service characteristics and underlying user behaviour assumptions have to be used.

With high-frequency and not regular services with real time information at stop, the user behaviour can be "clever" (intelligent) adaptive (Newell in Chriqui and Robillard, 1975), i.e. the choice of the run at stop, in the attractive choice set, is carried out considering the residual waiting time and travel time of the other runs, so the real timetables have to be taken into account.

With high-frequency and not regular services without user information, the user behaviour is mainly indifferent adaptive, i.e. the user gets on the first arriving/departing attractive run. In this case the use of the runs depends on the arrival law of the bus, that in general differs, at least in the parameters, from one line to the other.

Traditionally, the simulation of transit systems have been developed through a static approach and use the concept of hyperpath or optimal strategy (Dial, 1971; Nguyen and Pallottino, 1988; Spiess and Florian, 1989; Cascetta and Nuzzolo, 1988; Ortuzar and Williamsen, 1990; De Cea and Fernandez, 1993; Wu *et al*, 1994). The use of the static approach, in particular if based on hypotheses relative to different system characteristics and users' behaviour, is not the best simulation tool, because it does not let us take into account the degree of regular functioning of services and the users' information, producing errors in the prediction of on-board flows, waiting times, interchange times and transfer stops.

A dynamic approach, using path choice models that take into account time-dependent demand and services, allows to obtain on-board flows of each run and not only the average load of run sets having the same path, obtained by a static approach.

In this paper an assignment model that uses dynamic path choice models of stochastic type is presented; the models allow to consider the within day time-dependencies of demand and supplied services for high frequency transit systems with different levels of punctuality/regularity and information to users; they allow to simulate transit services with different types of ITS systems. The used approach can be considered a general extension of the spatio-temporal (diachronic) approach proposed by the authors for extraurban transit services (Nuzzolo and Russo, 1996). Even if obtained in a different way, the proposed path choice model can be also considered an extension and a generalisation of the Hickman and Wilson (1995) model. The main differences concern the use of random utility models to simulate users behaviour, the simulation of stop choice as well as the run one and a more precise definition of the choice set; moreover a stochastic spatio-temporal network model for services, that allows the application of consolidated graph algorithms, is used.

The paper includes: the analysis of the network models used in the approach; the proposed time-dependent path choice models and the behavioural hypotheses on which they are based, developed in different contexts of service punctuality/regularity and of information to the user; the calibration of a path choice model; a dynamic network loading model as well as the results of a comparative test among different hypothesised level of ITS in a real urban network.

NETWORK MODELS

In the following the run diachronic service network model, which could be used in dynamic assignment, is examined; for further details on network models see Nuzzolo and Russo (1997).

With reference to a period T (e.g. 7.30-8.30 a.m.) the whole graph is made of a combination of three subgraph (see figure 1):

- the first one concerning services;
- the second one relative to the demand temporal structure;
- the third one concerning access/egress (A/E) networks to the transit system.

For the construction of the diachronic subgraph representing runs, ideal temporal axes at stops are defined; the link representing the generic run r, from stop j to stop i, is placed with initial and final nodes respectively in departure (n_j^r) and arrival (n_i^r) times.

The subgraph relative to demand temporal structure is composed by different subgraphs, at least one for zone. Generally time distribution of demand can be discretised according to a certain number of time intervals in which the demand distribution, connected to the departure time, may be thought to be constant and located in the interval middle point. These points, called *temporal centroids*, belong to a set, defined for each spatial centroid, that constitutes the temporal demand subgraph.

For A/E representation a complete graph, representing the pedestrian (A/E) system, can be used.

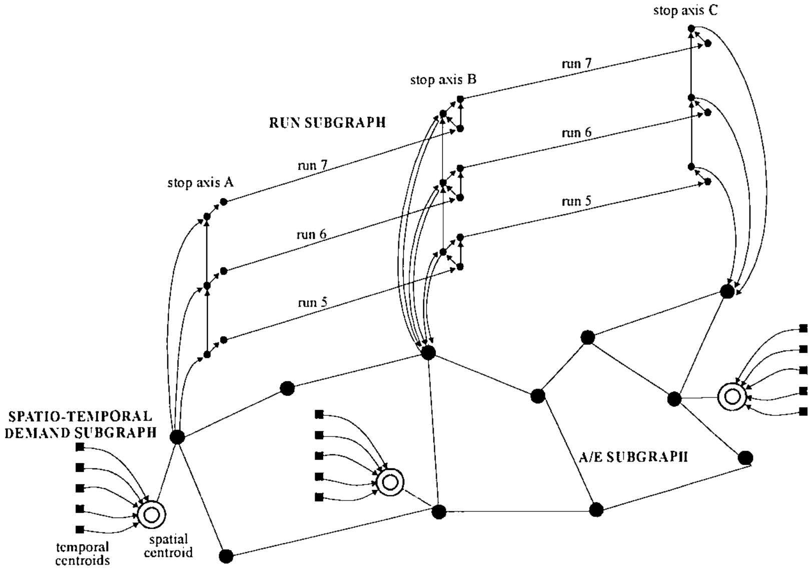

Figure 1 - The diachronic service network.

The used network model is of stochastic type (Nuzzolo and Russo, 1998) because the distribution of random terms of variables t_{crs} *(run time)* and t_{hrs} *(stop time)* is taken into account.

Considering a period T_k, the service network configuration k, relative to the period T_k, is defined as the set of the runs with their real arrival and departure times at stops that happen in the period T_k and that can differ from the scheduled ones due to the non regularity of the services.

With regard to path choice mechanism between a given O/D pair, we can define some general behavioural hypotheses for all types of services, that must be integrated with specific hypotheses in relation to the characteristics of service (frequency, regularity/punctuality, information to users) and of the user (e.g. habitual traveller for commuting or repetitive shopping).

User behaviour

General hypotheses on user behaviour, assumed in the following, are those formalised in the sphere of random utility theory (Ben-Akiva and Lerman, 1985): the user is a rational decision-maker, i.e. he considers all paths linking O/D pair and chooses the minimum disutility one.

Relatively to attributes appearing in disutility U_p associated to a path p, the user considers a set of components as access and egress time (t_a, t_e), on-board time (t_b), transfer time (t_t), number of transfers (N_t), waiting time (t_w) and so on.

In the following *frequency* stands for cumulated frequency φ_{Iods} of runs belonging to the set I_{ods}, named set of "useful" runs for users on O/D pair at stop s. This set is made of runs connecting directly or indirectly the stop s with the destination, leaving after the user arrival time at stop and not being dominated, that is to say two runs of which one, leaving before and arriving after do not exist. The set I_{ods} will be classified at high frequency if its frequency is greater than a given φ_{min} (e.g. 5 runs/hour).

Moreover in the following the hypothesis of *regular user*, i.e. who knows the real system functioning based on previous experiences, is made.

Specific hypotheses concern the stop and run (or sequence of runs) choice mechanism and the user arrival pattern at stops.

In relation to *stop and run choice mechanism*, we can refer to two types of behaviour:

- *preventive choices*, those using, before leaving, available information on different paths, e.g. scheduled times and real ones experimented in previous trips, or forecasted by ITS;
- *adaptive choices*, those which, in addition to previous information, take into account service variations that happen during the trip and eventual further available information.

Considering the *user arrival* at stops, it can be hypothesised as random inside a given interval. The interval width and the probability law of the arrival time t at stops s depend on service characteristics and particularly on frequency and punctuality/regularity.

In the case of medium-high frequency services, we can assume that:

- due to frequency services, the user has an average origin departure time t_D (not related to specific scheduled runs) and leaves around t_D in an interval $\Delta_D=[t_D-\Delta,t_D+\Delta]$;
- given the average access time t_{as} from origin to stop s, the user will arrive at stop in a temporal interval $\Delta_{Ds}=[t_{Ds}-\Delta,t_{Ds}+\Delta]$, with t_{Ds} equal to t_D plus t_{as}.

An example of probability law $f(t|t_{Ds})$ of user arrival time t in the interval Δ_{Ds} is one of the type reported in figure 2.

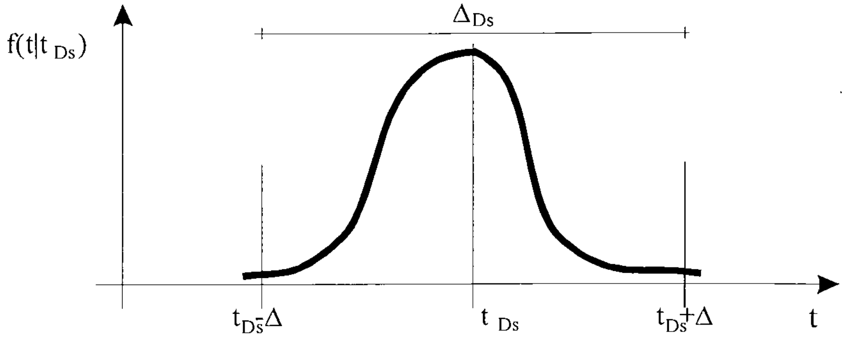

Figure 2 - Example of user arrival distribution law: high frequency services

Reference services

For medium-high frequency systems we can identify two situations of greater operative interest, with strictly connected behaviour hypotheses:

- high frequency irregular services with user information at stop (a), for which we suppose a preventive access stop choice at origin and an adaptive run choice within I_{ods} at stop. The adaptive choice is of *intelligent* type, i.e. at the arrival of a run r included in the choice set, the user gets on the vehicle if the perceived disutility connected to that run is smaller than disutilities, including waiting time, due to the use of runs which have not arrived yet;
- high frequency irregular services without user information at stop (b), for which we assume a preventive access stop choice and a preventive generation of the attractive set at origin, while we suppose an adaptive run choice in A_{ods} at stop. The adaptive choice is of *indifferent* type, i.e. the user gets on the first arriving run, if included in A_{ods}.

Each situation requires a different specification of the path choice model in relation to user and service characteristics.

As the models can take into account different levels of service irregularity and information to users, we can simulate different types of ITS systems.

In the following sections, path choice models for high frequency irregular systems with (a case) and without (b case) user information are proposed. The formulation is relative to an o/d pair, so for simplicity we omit the index "od".

High frequency irregular systems with user information

As regards stop and run choice, we assume the user at origin chooses the stop and then, arriving at stop, chooses the run according to available information, which must be made up of waiting times of arrival runs or also of the remaining travel time components until destination stop.

Stop choice model

We assume the perceived utility U_s associated to stop s is function of:

- a vector of specific stop attributes $\underline{X}_s$, as access time from origin, shops and/or news-stands presence and so on;

- an utility $H_{\Delta_{Ds}}$ (named "run inclusive utility") relative to accessible runs from the stop in relation to time t_{Ds} (see below);
- a random term η_s

and so

$$U_s(\Delta_D) = V_s(\Delta_D) + \eta_s = \underline{\beta}_a' \cdot \underline{X}_s + \beta_H \cdot H_{\Delta_{Ds}} + \eta_s \tag{1}$$

in the case that the η_s relative to the different accessible stops are Gumbel i.i.d., the stop s choice probability can be calculated through a multinomial logit model as

$$p(s \mid \Delta_D) = \frac{\exp(V_s(\Delta_D))}{\sum_{s' \in S_{od}} \exp(V_{s'}(\Delta_D))} \tag{2}$$

where $V_s(\Delta_D)$ is the systematic utility of stop s, in relation to the origin departure time interval Δ_D, and S_{od} is the accessible stop set to reach d from o.

Run choice model

Referring to the arrival time t of the user u at the stop s and to irregular services, the user has at his disposal a set of "useful" runs $I_s(t, k)$, where k is a possible supply configuration which can happen.

We assume the user, arriving at stop at the time $t \in \Delta_{Ds} = [t_{Ds} - \Delta, t_{Ds} + \Delta]$, considers an attractive set $I_s^u(t,k) \subseteq I_s(t, k)$ inside which he chooses with intelligent adaptive behaviour. In the strict sense the set $I_s^u(t, k)$ should be obtained with a specific choice set generation model (Mansky, 1977), nevertheless for simplicity in the following we will consider $I_s^u(t, k) \equiv I_s(t, k)$.

The perceived utility of the generic run r, conditioned to user arrival time t and transit service configuration k, $U_r(t, k)$, can be expressed as:

$$U_r(t,k) = \alpha_w \cdot T_{wr}(t,k) + \alpha_b \cdot T_{br} + \alpha_t \cdot T_{tr} + \alpha_{nt} \cdot N_{tr} + \eta_r \tag{3}$$

where: T_{br} is the on-board time, T_{tr} is the transfer time, N_{tr} is the number of transfers, $T_{wr}(t, k)$ represents the waiting time from arrival time t at stop to the run r departure time in the supply configuration k and η_r is the random term.

We observe that if the user is also informed at stops about forecasted on-board time and transfer time, in eqn (3) appear $T_{br}(t, k)$, $T_{tr}(t, k)$ and $N_{tr}(t, k)$ values relative to configuration k and arrival time t.

In the case that η_r relative to different runs are Gumbel i.i.d., the choice probability of run r, conditioned to arrival time t and to supply configuration k, can be calculated through a multinomial logit model as

$$p(r \mid t, k) = \frac{\exp(V_r(t,k))}{\sum_{r' \in I_s(t,k)} \exp(V_{r'}(t,k))} \tag{4}$$

where $V_r(t,k)$ is the systematic utility of run r conditioned to user arrival time t and transit service configuration k.

Given $p(r|t, k)$, the probability $p(r|\Delta_{Ds}, k)$ to use run r considering all possible arrival time t in the interval $\Delta_{Ds} = [t_{Ds} - \Delta, t_{Ds} + \Delta]$ can be written as:

$$p(r \mid \Delta_{Ds}, k) = \int_{t_{Ds}-\Delta}^{t_{Ds}+\Delta} p(r \mid t, k) \cdot f(t)dt \qquad (5)$$

where f(t) is the probability law of user arrival.

If a discrete number of configuration can happen, we can define p(k) as the probability that configuration k may realise, so the global probability $p(r|\Delta_{Ds})$ to use run r, conditioned to the interval Δ_{Ds}, can be expressed through

$$p(r \mid \Delta_{Ds}) = \sum_k p(r \mid \Delta_{Ds}, k) \cdot p(k) \qquad (6)$$

We observe that run choice is of *adaptive* type, because $I_s(t, k)$ and each alternative perceived utility $U_r(t, k)$ are function of the time t and of the supply configuration k, and that the behaviour is *intelligent* adaptive, because the user uses at least information about waiting times of arrival runs.

Run inclusive utility

The average utility (satisfaction) $H_s(t, k)$ that user with arrival time t associates to choice set $I_s(t, k)$ is given by

$$H_s(t,k) = E[W^u(t,k)] = \int_{-\infty}^{+\infty} W^u(t,k) \cdot g_\omega d\omega \qquad (7)$$

where $W^u(t, k)$ represents the maximum perceived utility for user u who has the choice set $I_s(t, k)$ and g_ω represents the distribution of random terms of the greatest utilities $W^u(t, k)$. As known, if the ω are distributed according to i.i.d. Gumbel variables, we have:

$$H_s(t,k) = \log \sum_{r \in I_s(t,k)} \exp(V_r(t,k)) \qquad (8)$$

The average utility of users with origin departure time t_D that arrive at stop s in the interval Δ_{Ds} is given by

$$H_{\Delta_{Ds}}(k) = \underset{t}{E}[H_s(t,k)] = \int_{t_{Ds}-\Delta}^{t_{Ds}+\Delta} H_s(t,k) \cdot f(t)dt \qquad (9)$$

so the average utility $H_{\Delta_{Ds}}$ of users arriving in Δ_{Ds}, respect to the possible supply configurations, is expressed through

$$H_{\Delta_{Ds}} = \underset{k}{E}[H_{\Delta_{Ds}}(k)] = \sum_k H_{\Delta_{Ds}}(k) \cdot p(k) \qquad (10)$$

and finally

$$H_{\Delta_{Ds}} = \sum_k [\int_{t_{Ds}-\Delta}^{t_{Ds}+\Delta} \int_{-\infty}^{+\infty} W_r^u(t,k) \cdot g_\omega d\omega \cdot f(t)dt] \cdot p(k) \qquad (11)$$

Stop and run probability

Hence the choice probability of stop s and run r, conditioned to the origin reference departure time interval Δ_D, can be expressed in the following way:

$$p(r, s|\Delta_D) = p(s| \Delta_D) \cdot p(r \mid \Delta_{Ds}) \qquad (12)$$

where:

$p(s|\Delta_D)$ is the probability of choosing stop s conditioned to the origin reference departure time interval Δ_D;

$p(r|\Delta_{Ds})$ is the probability of choosing run r conditioned to the use of stop s and to the arrival time at this stop in Δ_{Ds}.

This formulation can be used to calculate path and link flows into a procedure of network loading that in the case of non-congested network allows to set up a Dynamic Assignment Model. As regards the operative aspects of run choice probability computation, see Nuzzolo and Russo (1998) and Crisalli (1998).

High frequency irregular systems without user information

This section deals with the behavioural assumptions and with the specification of stop and run choice models for irregular systems without user information.

User behavioural hypotheses

In this case, as previously reported, we hypothesise a preventive stop choice as well as a preventive generation of an attractive set of runs at origin, stated as $A_s(\Delta_{Ds})$, while we hypothesise an indifferent adaptive choice of the run in $A_s(\Delta_{Ds})$ at the stop.

Referring to the user arrival law at stop with reference time t_{Ds}, since we consider high frequency services, we assume that user arrives at stop in a random way within $\Delta_{Ds}=[t_{Ds}-\Delta, t_{Ds}+\Delta]$, with probability law $f(t|t_{Ds})$ which in the following is indicated with f(t).

Stop choice model

As concern the stop choice, we assume the same mechanism previously described with a different specification of $H_{\Delta_{Ds}}$ that is reported below.

The attractive run set

For simplicity we can overlap the attractive run set $A_s(\Delta_{Ds})$ with the useful run set which can be seen in the interval Δ_{Ds}, assuming the user will insert in the set $A_s(\Delta_{Ds})$ the useful runs which he has previously experimented at the stop s during the interval Δ_{Ds}; therefore $A_s(\Delta_{Ds})$ does not depend on t and k (while previously $I_s(\Delta_{Ds})$ does).

With a greater degree of precision we could hypothesise a user optimisation strategy, identifying $A^u_s(\Delta_{Ds}) \subseteq A_s(\Delta_{Ds})$ as the subset of useful runs which, with an indifferent adaptive choice, minimises the (perceived) disutility of the trip, analogously to the optimal strategy used in the static approach of the "hyperpath model"

Run use model

On the basis of an indifferent adaptive behaviour and given the arrival time t of user u at stop s and the transit service configuration k, the probability $p(r|t,k)$ to use run $r \in A_s(\Delta_{Ds})$ can be expressed as:

$$p(r \mid t,k) = 1 \qquad \text{for the first arriving run} \tag{13}$$

$$p(r' \mid t,k) = 0 \qquad \text{for the other runs} \qquad r' \neq r;\ r' \in A_s(\Delta_{Ds}) \tag{14}$$

The probabilities $p(r|\Delta_{Ds}, k)$ and $p(r|\Delta_{Ds})$ can be calculated through eqns (5) and (6).

Stop utility

Defining with $V(r|t, k)$ the average systematic "a posteriory" (dis)utility that users associate to the use of run r, we have:

$$V(r|t,k) = \gamma_w \cdot T_{wr}(t,k) + \gamma_b \cdot T_{br} + \gamma_{tr} \cdot T_{tr} + \gamma_{nt} \cdot N_{tr} \quad (15)$$

where: T_{br} is the on-board time, T_{tr} is the transfer time, N_{tr} is the number of transfers, $T_{wr}(t, k)$ represents the waiting time from arrival time t at stop to the run r departure time in the supply configuration k.

So given the configuration k, the average (dis)utility of stop $H_{\Delta_{Ds}}(k)$ can obtained as:

$$H_{\Delta_{Ds}}(k) = \int_{t_{Ds-\Delta}}^{t_{Ds+\Delta}} V(r|t,k) \cdot p(r|t,k) \cdot f(t)dt \quad (16)$$

and finally $H_{\Delta_{Ds}}$ through eqn (10).

AN EXAMPLE OF PATH CHOICE MODEL

The coefficients of attributes used in the run systematic disutility, even if under the same user behavioural characteristics, depend strongly on service characteristics. For example the coefficient relative to waiting time should be lower for transit systems with user information than for transit systems without. In addition, the presence of information about waiting time (or on the other travel time components) can modify the values of error term variance and so the model parameters can change.

Therefore different situations of service characteristics, even if under the same user behavioural characteristics, need models with specific parameters that should be ad-hoc calibrated.

In the following an example of path choice, that can be used for an ATIS system with user information about travel time components (waiting time, on-board time, transfer time, etc) is reported.

The calibration has been carried out using the maximum likelihood method (Ben-Akiva and Lerman, 1985) on the basis of a stated preferences (SP) survey on a sample of university students in Rome. The survey field (see figure 3) is characterised by the head station of the underground where people interchange with bus service to reach the university campus. Two different bus stops can be chosen and for each stop two alternative paths are available. The considered attributes for the SP survey project are access time, waiting time, on-board time and transfer one.

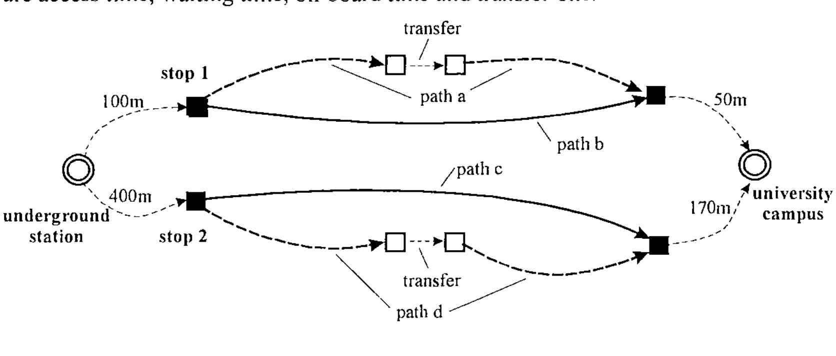

Figure 3 - The survey field.

The used calibration is the well-known "partial information" approach in which the whole stop and run choice model is divided into two submodels: the first simulating the run choice, the second simulating the stop choice considering the behavioural congruence with the run choice model. It can be done introducing in the systematic utility the run logsum (that is proportional to the run inclusive utility).

The specification of run and stop systematic utilities is reported in the following:

$$V_r = \alpha_w \cdot T_{wr} + \alpha_b \cdot T_{br} + \alpha_t \cdot T_{tr} + \alpha_e \cdot T_e \tag{17}$$

where T_{wr} is the waiting time, T_{br} is the on-board time, T_{tr} is the transfer time and T_{egr} is the egress one.

$$V_s = \beta_a \cdot T_a + \beta_H \cdot H_s \tag{18}$$

where T_a is the access time and $H_s = \ln \sum_{r \in I_s} \exp(V_r)$ is the run logsum.

The calibration has been obtained on a sample of 144 interviews using the HieLoW (Bierlaire, 1995) software package and the results are reported in Table 1.

Table 1 - Calibration results.

	run				stop	
ρ^2=0.51	α_w	α_b	α_t	α_e	β_a	β_H
Values	-0.85	-0.46	-0.70	-0.39	-0.57	0.86
(t-st)	*(-4.44)*	*(-3.43)*	*(-2.81)*	*(-1.83)*	*(-5.15)*	*(5.62)*

As we can see all coefficients have correct signs and most are statistically significant. In particular, the parameter of waiting time is about the double of on-board one and is comparable with transfer one (LaPST, 1998).

A DYNAMIC NETWORK LOADING MODEL

The presented path choice model can be used in transit assignment models in order to calculate the path flow $F(r,s \mid \Delta_D)$, defined through the run r and the stop s and generated by demand $d_{t_D}^{OD}$ relative to the O/D pair and to origin reference departure time interval Δ_D, as

$$F(r,s \mid \Delta_D) = d_{t_D}^{OD} \cdot p(s \mid \Delta_D) \cdot p(r \mid \Delta_{Ds}) \tag{19}$$

Indicating with A_{RS} the link-path incidence matrix, relative to the set R of on-board links and to the set S of access and egress ones, we can obtain link flows f_{rs}, relative to on-board, access and egress links, as

$$f_{rs} = A_{RS} \cdot F(r,s \mid \Delta_D) \tag{20}$$

If we assume that link costs are not flow-dependent, we can refer to Dynamic Network Loading model. A computation procedure for such a model is reported in Nuzzolo and Russo (1998) and Crisalli (1998).

AN APPLICATION ON A REAL URBAN TRANSIT NETWORK

The assignment model has been applied to a real urban transit network in order to test the goodness of the proposed approach. The transit network of a medium-size town in the south Italy (Salerno) has been considered. It is made of 58 service lines with 735 runs in the referring period (7.30-8.30 a.m.). The study area, characterised by 160,000 inhabitants and about 7,200 transit users in the peak hour, has been divided in 62 traffic zones. The considered supplied services allow to hypothesise high frequency services and random user arrival at stops. For the application test we hypothesise regular users and, through the introduction of ITS systems, we also assume three different types of service characteristics:

(a_1) regular service and presence of information to users at stops;

(a_2) irregular service and presence of information to users at stops;

(b) irregular service without information to users at stops.

The (a_1) case can be seen as particular case of (a_2) when the transit services respect the scheduled timetable.

In (a_1) and (a_2) cases we can refer to a preventive stop choice at origin and an intelligent adaptive run choice at stop, while in (b) we consider again a preventive stop choice but an indifferent adaptive run choice at stop within an attractive run set built at origin.

The Dynamic Network Loading model uses stop and run choice models of logit type and a spatio-temporal (diachronic) network model, which is made of 44,846 nodes and 81,654 links. As regards the stop and run choice, the utility functions are those reported in eqns (17) and (18). The model parameters have been assumed according to preliminary results of a research currently in-progress (LaPST, 1998), including the calibrated model reported above.

The demand has been divided in time slices of 1 minute each and its level has been considered constant during the simulated period in order to avoid the influence of the time-dependent demand.

As previously described, the assignment model allows to obtain on-board flows for each run of each service line. In the case of regular services, figure 4 shows the on-board flows of each run belonging to a service line on a generic section between two stops and the average value. As we can see, the values of each run are quite different from the average value, showing the great variability of the run flow inside the same line that can be taken into account only using a dynamic approach. In the same way it is possible to obtain the same results for irregular services.

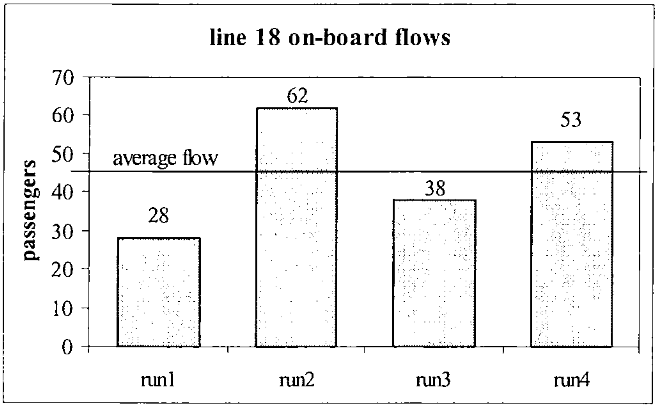

Figure 4 - Example of assignment model results.

In the following the comparison among results carried out through the simulation of transit services with different service characteristics is reported. It has been obtained calculating some aggregate indexes that regard the average values of travel time components, in particular waiting time, on-board time and transfer one. As we can see in Table 2, the total travel time increases passing from regular services to irregular ones as well as the waiting time does, while the presence of information allows to obtain an on-board time close to the regular case, as expected. Focusing on irregular services, the absence of information brings to a decrease of the waiting time (respect to the presence of information) and to and increase of on-board time and transfer one, due to the indifferent adaptive behaviour in run choice at stop.

The results show the goodness of the approach to give suitable outputs for different type of system functioning.

Table 2 - Values of variation coefficients.

	Service characteristics		
Time (min)	**Regular INFO (a_1)**	**Irregular INFO (a_2)**	**Irregular NO INFO (a_3)**
Waiting	6.2	6.8	6.4
on-board	13.0	13.1	14.4
Transfer	1.2	1.3	1.7
Total	20.4	21.2	22.5

CONCLUSIONS

In this paper a new approach for transit assignment has been presented. Different users' behavioural hypotheses and path choice models have been presented according to different service characteristics. The assignment model has been applied to a real transit system in order to test the goodness of the proposed approach to simulate different types of ITS systems.

The used dynamic approach is more complex and time-consuming than the traditional static one, but allows to obtain more precise and detailed outputs, in particular the time-dependent run loads and the relative travel times. The approach is suitable to be used as an assessment tool for operative planning or for tactical one when it is necessary to evaluate the modifications on transit system due to service characteristics changes (e.g. the introduction of ITS systems).

Further developments are in progress; they mainly regard the treatment of congestion and the improvement of users' behaviour simulation (partially informed users, more advanced choice model, choice set generation model) considering mixed punctuality/regularity of the system and different levels of information to users.

REFERENCES

Atkins, S. (1994) Passenger information at bus stop (PIBS). **Report on monitoring studies of Route 18 demonstration**. London Transport Report.

Balogh, S. and Smith, R. (1992) Real-time bus information – the London Transport Route 18 demonstration. **Proceedings of PTRC Conference**, London.

Ben-Akiva, M. and Lerman, S. (1985) **Discrete choice analysis.** MIT Press, Cambridge, Massachusetts.

Bierlaire, M. (1995) HieLoW: Estimation of hierarchical logit models. **Technical Report 94/23**, Dept of Mathematics, FUNDP, Namur, Belgium.

Cascetta, E. and Nuzzolo, A. (1988) Uno schema comportamentale per la modellizzazione delle scelte di percorso nelle reti di trasporto pubblico urbano. **Internal Report**, Dipartimento di Ingegneria dei Trasporti, University of Naples, Naples, Italy.

Chriqui, C. and Robillard, P. (1975) Common Bus Lines. **Transportation Science 9**, 110-121.

Crisalli, U. (1998) A Stochastic Network Loading model for ITS urban transit networks. **Proceedings of 4th International Conference on Urban Transport and the Environment**, Lisbon, Portugal.

De Cea, J. and Fernandez, E. (1993) Transit assignment for congested public transport system: an equilibrium model. **Transportation Science 27(2),** 133-147.

Dial, R. B. (1971) A probability multipath assignment which obviates path enumeration. **Transportation Science, 5**.

Federal Transit Administration, (1998) **Advanced Public Transportation System: The State of the Art. Update '98.** U.S. Department of Transportation.

Golledge, R.G. (1997) Dynamics and ITS: Behavioural Responses to Information Available from ATIS. **Resource papers, Conference preprint IATBR-97**, Austin, Texas.

Hickman, M.D. and Wilson, N.H.M. (1995) Passenger travel time and path choice implications of real-time transit information. **Transportation Research C3, 4**, 211-226.

Kirchoff, P. (1995) Public transit research and development in Germany. **Transportation Research 29**, 1-7.

Knoppers, R. and Muller, T. (1995) Optimized transfer opportunities in Public Transport. **Transportation Science, 29**, 101-105.

LaPST - Transportation System Laboratory, (1998) Stop and run choice models. **Internal Report**, Dept Civil Engineering, "Tor Vergata" University of Rome, Rome, Italy.

Mansky, C. (1977) The structure of random utility models. **Theory and Decision 8**.

Nguyen, S. and Pallottino, S. (1988) Equilibration Traffic Assignment for Large Scale Transit Networks. **European Journal of Operational Research 37**, 176-186.

Nuzzolo, A. and Russo, F. (1996) Stochastic assignment models for transit low frequency services. Some theoretical and operative aspects. In Bianco, L. and Toth, P. (eds.), **Advanced Methods in Transportation Analysis**. Springer-Verlag, Berlin, 321-340.

Nuzzolo, A. and Russo, F. (1997) **Modelli per l'analisi e la simulazione dei sistemi di trasporto collettivo.** Franco Angeli, Milano.

Nuzzolo, A. and Russo, F. (1998) A Dynamic Network Loading model for transit services. **Proceedings of TRISTAN III Conference**, San Juan, Puerto Rico.

Ortuzar, J. and Williamsen, L.G. (1990) **Modelling Transport.** Whiley, England.

Spiess, H. and Florian, M. (1989) Optimal strategies: a new assignment model for transit networks. **Transportation Research, 23B**, pp. 83-102.

Vance, C. and Balcombe, R.J. (1997) How to tell bus what they need to Know. **Proceeding of 25° ETF-PTRC**, London.

Wu, J.H., Florian, M. and Marcotte, P. (1994) Transit equilibrium assignment: a model and solution algorithms. **Transportation Science 28**, 193-203.