Short-term Prediction of Transit On-board Loads Using a Schedule-based Dynamic Approach

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1 Introduction

The application of new telecommunication and informatics technologies to public transport systems allows the implementation of Transit Information Systems (TIS), which represent the branch of ITS (Intelligent Transport Systems) for public transport. The use of TIS allows the real-time knowledge of system functioning, in order to enhance network performances for both the company and the users' point of view.

Application in this field are well known and mainly regard ATIS (Advanced Travellers Information Systems), aiming at improving user knowledge in path choice, and APTS (Advanced Public Transportation Systems), aiming at optimising transit performances through the fleet control. A TIS can provide users with information before the trip departure (pre-trip choices) as well as during trip (en-route choices). Pre-trip information systems allow to reduce uncertainty about transit timetable and routes. By providing accurate real-time information before the trip, transit users are able to take more aware decisions about routes and departure times. En-route information systems offer a wide variety of information to transit users that are already on the way of travel; the main provided information concern real-time bus arrival and departure times, aiming at reducing waiting anxiety and increasing customer satisfaction.

In this paper we focus on TIS, which provides en-route information about: real-time waiting times of arriving runs at stops, and on-board loads (or occupancy degrees) of arriving runs at the stops. The first information plays a key role to reduce user uncertain in path choice; the latter information can influence en-route choices, especially in congested transit systems, where users may choose to skip overloaded runs and wait for less crowded ones by trading off between longer waiting-time, higher on-board comfort, and time already spent at stop.

In order to provide information on real-time waiting times, it is necessary to develop models and algorithms able to predict real-time link travel time on the network, based on current vehicle location and historical data, while the information concerning the on-board loads of arriving runs requires the setup of a modelling framework in which within-day dynamics, both on demand and supply side, are explicitly simulated.

This paper presents an overview on the modelling framework and its implementation in order to give the above described real-time information. Section 2 reports the modelling framework, which is based on the schedule-based dynamic approach briefly described in section 3. Section 4 presents some possible implementation and an idea of future perspectives of the presented research.

2 The overall modeling framework

The core of the modelling system is the Operation Control Centre (OCC), where information on current vehicles location and passenger boarded and alighted at stops are received by means of monitoring and communication devices (e.g. DGPS, radio modem, etc.). This information is real-time analysed by the OCC in order to predict arrival times and on-board loads of runs arriving at stops, which are successively sent to users by means of stop displays, mobile phones, www, and so on.

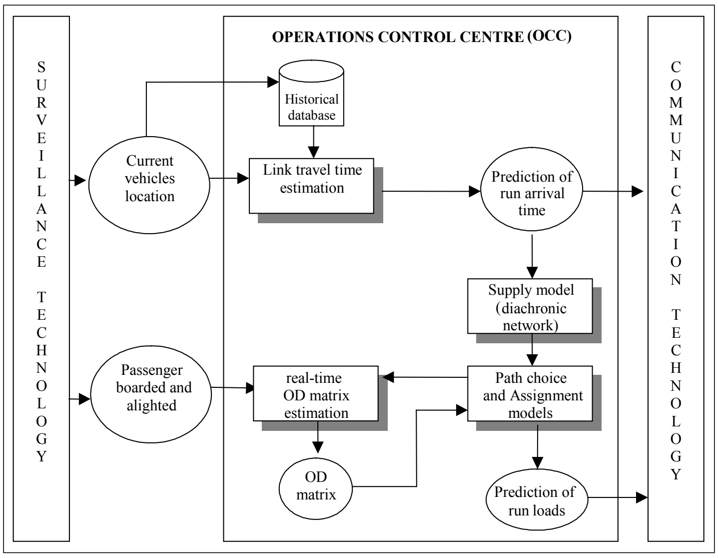

Figure 1: Overall framework: components and models

Run arrival times and on-board loads predictions are based on the modelling framework of Figure 1. The prediction of arrival times is simpler than run occupancy prediction because it does not require the simulation of user behaviour with respect to current network condition and to information provided. Examples of algorithms to predict link travel times and hence arrival times at stops can be deepened on Miyata et al. (1997).

On the other hand, on-board loads prediction requires the specification of a comprehensive modelling framework, as described in the following.

Traditional models for transit networks have usually been developed using a static approach on the basis of the concept of hyperpath (Nguyen and Pallottino, 1988) or optimal strategy (Spiess and Florian, 1989). Assumptions made in this approach are adequate for services with high frequency, very low punctuality and low user information; they generate relevant approximations when used in different contexts, as that of the presence of ITS technologies. In such cases the schedule-based approach (Nuzzolo et al., 2001, 2004) is suitable to be used, as it allows the system configuration to be obtained in terms of flows and travel times for each run of each line. These detailed results require different treatment for: demand definition, as we must also know the time distribution of transit users; supply modelling, which must represent time variations of system characteristics; ad-hoc time-dependent path choice models, based on specific hypotheses on user behaviour and service characteristics.

Hence, the overall modelling framework built up to forecast run on-board loads of transit services is made of:

- a time-varying O-D matrix estimation procedure based on real-time counts of passengers boarded and alighted from vehicles at stops;
- a supply model aiming at representing explicitly time-dependent transit network, in relation to the real-time information on vehicle location;
- a sequential RUM (Random Utility Model) model, simulating user behaviour in path choice;
- a within-day dynamic assignment model, which allows to estimate the loads on each run of the transit system at any time of the reference period.

3 The schedule-based dynamic modelling approach

In the following we describe a class of schedule-based dynamic path choice and assignment models proposed by Nuzzolo et al. (2001) in order to obtain on-board loads for transit networks. They can be specified in different ways to be coherent with service and user characteristics of the simulated transit system.

Urban transit services are characterised by different boarding stops and runs, which allow to reach the destination for the same *od* pair and origin departure time τ_{Di}. Hence choice dimensions regard the choice of access stop *s* and that of run *r* (or sequence of runs) leading users to destination.

It is assumed that users do not have full information before starting their trip and they follow a mixed pre-trip/en-route choice behaviour. The choice of boarding stops is considered to be made before starting the trip (pre-trip) at origin, since it is not influenced by unknown events. En-route choices occur at stops and are relative to the decision to board a particular run or to wait for another run of the run choice set. Furthermore, in relation to the high frequency of services, typical of urban areas, we can assume that the origin departure time coincides with the desired origin departure time, so user arrival at the stop is not related to run departure scheduled times.

Given a stop choice set S_{od} (e.g. considering all stops within a maximum distance from origin), the probability $p[s|\tau_{Di}]$ of choosing the boarding stop *s* can be expressed as:

$$p[s|\tau_{Di}] = prob(U_s > U_{s'}) = prob(V_s + \varepsilon_s > V_{s'} + \varepsilon_{s'}) \qquad (1)$$

where U_s is the perceived utility, sum of the systematic utility V_s and a random residual ε_s. The systematic utility V_s is usually a function of access time and run inclusive utility, which expresses the average utility associated with all runs available at stop *s*. Different random utility models can be specified according to the hypotheses on random residuals ε_s.

The en-route run choice at the stop can be differently specified according to user type. In the following, as we consider frequent users, the en-route choice at stop is assumed intelligent adaptive and is simulated through the sequential choice mechanism described in the following. When a run r of the path choice set K^s arrives at stop s, the user chooses to board r if the perceived utility U_r is greater than the utility $U_{r'}$ of all other runs $r' \in K^s$ yet to arrive. If users do not choose run r, the choice is reconsidered when the next run arrives and so on (*sequential run choice behaviour*).

For high-frequency transit services, in addition to the traditional attributes (access time, on-board time, transfer time, number of transfers, monetary cost, comfort), a key role is played by the waiting time (equal to the difference between the arrival time of run r' and the arrival time of run r, supplied by the information system) and by the time already spent at stop (equal to the difference between arrival time of run r and the user arrival time τ_{Dis} at stop s, simulating a possible "impatience effect"). The probability $\pi_{\tau_r}[r]$ of choosing the arriving run r at time τ_r, conditional upon not choosing previous runs belonging to the choice set K^s, can be expressed by:

$$\pi_{\tau_r}[r] = prob(U_r > U_{r'}) = prob(V_r + \varepsilon_r > V_{r'} + \varepsilon_{r'}) \qquad \forall r \neq r' \qquad (2)$$

where U_r and $U_{r'}$ are perceived run utilities, sum of systematic utilities V_r and $V_{r'}$ and random terms ε_r and $\varepsilon_{r'}$. Different random utility models can be specified according to the hypotheses on random residuals ε_r. Eqn (2) expresses only the probability of boarding or otherwise for each arriving run with respect to runs still to arrive, i.e. provided the users did not board previous runs. In order to obtain the total probability we need to consider eqn (2) in relation to choices made by the user with respect to runs which have already passed. If τ_1, τ_2, ... τ_n, ... is the run arrival time sequence and r_1, r_2, ... r_n, ... the relative run sequence, the total unconditional probability $p_{\tau_n}^{\tau_{Di}}[r_n \mid s]$ of choosing run r_n arriving at τ_n is defined through the probability of boarding run r_n and the probability that users did not board the previous r_1, …, r_{n-1} arrived runs, that is:

$$p_{\tau_n}^{\tau_{Di}}[r_n \mid s] = \pi_{\tau_n}[r_n \mid s]\left(1 - \prod_{i=1}^{n-1} p_{\tau_i}^{\tau_{Di}}[r_i \mid s]\right) \qquad (3)$$

Finally the probability $p_{od}[s,r \mid \tau_{Di}]$ of choosing a path including run r at boarding stop s, given the *od* pair and the origin departure time τ_{Di}, can be obtained by multiplying the probability of choosing stop s, given the origin departure time τ_{Di}, eqn (1), by the probability of choosing run r at stop s, eqn (3).

On board loads of transit services can be estimated by using a within-day dynamic assignment model. For each time τ of the day, it allows the estimation of the load on links representing services operating at time τ, according to the supply system configuration $\underline{b}_\tau$ (run and stop times) at that time, and to the demand configuration $\underline{d[\tau_D]}$ (time segmentation).

The path load $h_\tau^{od,\tau_{Di}}[s,r]$, relative to run (or to the sequence of runs) r and stop s, generated through demand $d^{od,\tau_{Di}}$ on the *od* pair with origin departure time τ_{Di}, and relative to the arrival time $\tau(=\tau_r)$ of run r at stop s, can be written as:

$$h_\tau^{od,\tau_{Di}}[s,r] = d^{od,\tau_{Di}} \cdot p_\tau^{\tau_{Di}}[s,r] \tag{4}$$

where $p_\tau^{\tau_{Di}}[s,r]$ is the path choice probability calculated through eqns (1,3).

4 Conclusions

This paper describes a system of models developed to be used for the short-term forecasting of waiting times and on-board loads of arriving runs at stops of transit systems where a TIS is operating. Predictions are based on a schedule-based dynamic modelling approach, which uses real-time data on the position of operating vehicles on the network and on counts of travellers boarded and alighted at a number of predefined stops.

The modelling framework presented above could be implemented in a Decision Support System of the Operation Control Centre in order to support operative strategies for transit systems. From an operator perspective, short-term prediction of run occupancy can be seen as a tool to optimise trips schedules and to adapt trip timetable to the modification of service configuration due to irregularity. On the other hand, from the user perspective, on-board run load (or run occupancy) is another source of information, in addition to real-time waiting times of arriving runs, to optimise travel choices.

The core of the simulation is: when an event occurs the input variables of the schedule-based transit assignment models are updated, that is:

- the service configuration $\underline{b}$ (supply model) is updated, based on the current vehicles location and on the link travel times estimates;
- the OD matrix $\underline{d[\tau_D]}$ is simultaneously estimated, according to boarded and alighted passenger counts.

Then, users path choice is simulated and the loads on the runs for the remaining time of the whole reference period (i.e. the period of time from the time τ in which the event has occurred to the end of the reference period) are estimated.

More details on application examples of this system of models can be deepened on Nuzzolo et al. (2002).

Future research perspectives mainly regard the further development of the modelling framework through the validation of models and algorithms, and eventually the development of new ones (especially for the real-time link travel time prediction and the O/D estimation), as well as the specification and calibration of path choice model parameters based on real data given by Transit Information Systems (TIS).

References

E. Cascetta, *Transportation Systems Engineering: theory and methods*, Kluwer (2001).

A. Miyata, K. Muroaka, T. Akiyama and A. Abe, ”The Correction of the Forecasting Travel Time by Using AVI Data”, Proceedings of 4th ITS World Congress, Berlin (Germany), 1997.

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

A. Nuzzolo, F. Russo and U. Crisalli, ”A doubly dynamic schedule-based assignment model for transit networks”, *Transportation Science* 35, 268-285 (2001).

A. Nuzzolo and U. Crisalli, ”Estimation of transit origin/destination matrices from traffic counts using a schedule-based approach”, Proceedings of the ETF, Cambridge, UK, 2001.

A. Nuzzolo, U. Crisalli, P. Coppola and L. Rosati, ”Short-term prediction of run-occupancy in transit information system (TIS)”, Proceedings of the ETF, Cambridge, UK, 2002.

A. Nuzzolo and U. Crisalli, ”The schedule-based approach in dynamic transit modelling: a general overview”, in *Schedule-based dynamic transit modeling*, A. Nuzzolo and N.H.M. Wilson (eds), 1-24, Kluwer Academic Publisher, 2004.

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