A DAY-TO-DAY DYNAMIC MODEL OF DEPARTURE TIME AND PRE-TRIP ROUTE CHOICE IN PRESENCE OF ADVANCED TRAVELLERS INFORMATION SYSTEMS

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SUMMARY

In this paper we present a doubly dynamic models system aiming at simulating the impacts of Advanced Traveller Information Systems (ATIS) on pre-trip users’ travel choices such as route and departure time and on network performances. The overall framework consists of three main sub-models. The travel behaviour simulator models the day-to-day choice updating model for different user classes (e.g. informed and non-informed). The within-day dynamic traffic simulator simulates the propagation of flows on the network and estimate network performances allowing for non-stationary conditions within the simulation period and random fluctuation of supply characteristics. Finally, the ATIS model aiming at generating real-time traffic information based on current network conditions. Supply/Demand interactions are simulated within a day-to-day dynamic process framework.

Keywords: ATIS, pre-trip information, day-to-day dynamics, choice updating process

INTRODUCTION

Transportation Telematics is the usual term to identify innovative technologies applied to transportation such as ATIS (Advanced Travellers Information Systems), DRGS (Dynamic Route Guidance Systems), ATMS (Advanced Traffic Management Systems) and so on. The main issue of such technologies is that of providing travellers with travel guidance in order to enhance traffic network performances. However, while ATMS aim at optimising traffic conditions at system level (system optimum), ATIS aim at improving individual decision-making process by mean of information (user’s optimum). Furthermore, while ATMS measures are in many case compulsories, compliance with ATIS measures remains optional. Here travel Guidance refers to information provided to drivers in the attempt to facilitate their travel choice (mode, departure time, route,…). Some of these choices are only effective prior to trip departure (pre-trip choices), some others during trip (while trip or en-route choices). Information can be either descriptive (travellers are provided with description of network
conditions) which aims mainly to improve travellers’ knowledge and awareness of the actual state of the network, or *prescriptive* that is actual recommendations about travel choice (departure time, route choice, …) which travellers can comply with or not.

According to temporal nature of information, we can distinguish information in three categories (Ben Akiva et al., 1991):

- historical information, based on the state of the network during the previous day;
- real-time information, which describe the current state of the network and
- predictive information, which concerns the future conditions on the network.

It is clear that the best information to provide should be a reliable predictive information. On the other hand, it is extremely difficult to provide this kind of information in case of congestion. In congested network, in fact, future traffic performance (that is, what information should tell) depends on future path flows which in turn depend on information provided, since drivers who receive guidance may change their path as a result of information. Guidance generation is therefore a fixed-point problem (Ben Akiva et al., 1997).

The solution of such a problem is out of the scope of this paper, we rather focus on the behavioural issues concerning information provision. It is crucial, in fact, to any procedure aiming at generating travel guidance, to model how users respond to information, in order to avoid the potential adverse impacts, known in literature as overreaction and concentration (Ben Akiva et al., 1991). Concentration occurs when information reduces the variations among drivers and increases the uniformity of perception of network conditions. Overreaction occurs when drivers’ reaction to information shifts congestion from one road to another because too many drivers react in the same way to information.

In order to avoid these adverse effects, information should thus take into account the behavioural response of travellers. In doing so, different classes of users must be taken into account according to knowledge of the network, degree of compliance with information and so on. Besides there are other two key aspects that a model aiming to simulate drivers’ response to ATIS has to accomplish: the dynamic temporal dimension and the stochasticity of the behavioural models adopted. The former is essential to explicitly simulate the updating process of the perception of alternatives (and eventually of the choice set) due to historical knowledge, experience and information. The latter is needed since no dynamic learning process could be simulated when a deterministic model is used as deterministic models assume that users have a perfect knowledge.

Different approaches have been proposed in literature in order to cope with simulation of ATIS. Al-Deek and Kanafani (1993), for instance, propose a model to compute the saving time due to the introduction of ATIS in case of accident on corridors. The simple case of a two-link network is studied: users propagate on the network according to user’ equilibrium; in case of accident on a link, users equipped with ATIS switch on the other link until a new equilibrium is achieved. Using a deterministic queue model the authors compute a 25%-total travel time reduction on the network with respect to the scenario without ATIS. A behavioural model for simulation of ATIS, based on bounded rationality (Mahamassani et al., 1987) is embedded in DYNASMART (Jayakrishnan et al., 1994), a comprehensive models system developed in order to assess the impacts of real-time information strategies and traffic control. To authors knowledge the only model dealing with predictive information in DYNAMIT (Ben Akiva et al., 1987). The fixed-point problem of consistency between information provided and actual network condition is here solved by means of an algorithm
similar to the MSA method for Stochastic User Equilibrium Assignment. At a given instant, according to actual network performance, drivers are provided with information; a pre-trip demand simulator, then, allow to predict users’ (first step) choice of mode, path and departure time. A traffic meso-simulator propagates O-D flows on the network allowing the calculation of the resulting network performance (Path performances). The latter are compared to those predicted by ATIS and are updated until consistency is achieved.

In DYNAMIT day-to-day dynamics are not explicitly taken into account, the OD matrices are estimated dynamically using a Kalman’s filter which allow to update historical OD’s with current traffic counts. Different behavioural models have been proposed, on the other hand, to cope with day-to-day dynamics in presence of ATIS (Emmerink, 1996; Jakarishan et al., 1994; Van Berkum and van der Mede, 1994). These models simulate the learning and adjustment process due to information by exponential smoothing (Ben Akiva et al., 1986; Cantarella e Cascetta, 1995) or bayesian filters (Jha et al., 1998).

In the following the learning and adjustment approach proposed by Cantarella and Cascetta (1995) is extended into a comprehensive models system aiming to simulate the impacts of traffic information on day–to-day drivers pre-trip behaviour.

**THE MODELS SYSTEM**

As it is shown in figure 1, the overall framework of the models system consists of:

- Travel Behaviour Simulator (the Demand Model), simulating, at a given day \( t \), users’ knowledge-updating process, based on past experience and real-time information (if any);
- Pre-Trip Information System (the ATIS Model), which based on the current network condition provide information;
- Traffic Simulator (the Supply Model) which embeds a Dynamic Network Model and a Network Flow Propagation Model allowing real-time estimation of network performances.

In this paper we do not deal with en-route guidance, the model system proposed is in fact a doubly dynamic (within-day + day-to-day dynamic) models system aiming at simulating how real-time information can affect pre-trip choice dimension such as departure time and path ones. Within-day dynamics are here considered in order to better estimate network performances provided that within a given simulation period \( t \) network performances largely vary due to over-saturation sub-period of supply characteristics.

**Notation**

The following notation will be adopted:

- \( X^t_{kj,past} \) is the generic performance attribute \( X \) related to path “\( k \)” starting at time-interval “\( j \)” at day \( t \), due to past experience, for user class \( i \);
- \( X^t_{past} \) is the above performance attribute vector \((n_{KJ} \times 1)\), being \( n_{KJ} \) the number of path-departure time pairs available;
- \( X^t_{kj,info} \) is the performance attribute \( X \) related to path “\( k \)” and departure time ”\( j \)” provided by the ATIS at day \( t \);
- \( X^t_{info} \) is the vector \((n_{KJ} \times 1)\) of the performance attributes \( X^t_{kj,info} \);
- \( X^t_{kj,exp} \) is the performance attribute \( X \) related to path “\( k \)” and interval “\( j \)” expected by user class \( i \) at day \( t \);
- $X^{t,i}_{kj,\text{exp}}$ is the vector $(n_{kj} \times 1)$ of performance attributes $X^{t,i}_{kj,\text{exp}}$;
- $X^{t,i}_{kj,\text{act}}$ is the actual value of performance attribute $X$ related to path “k” actually experienced by user class $i$ leaving at “j”;
- $X^{t,i}_{act}$ is the vector $(n_{kj} \times 1)$ of attribute $X^{t,i}_{kj,act}$;
- $g^{t,i}_{kj,\text{exp}}$ is the generalised path cost for user class $i$, at day $t$, related to path “k” and departure time interval “j”;
- $g^{t,i}_{\text{exp}}$ is the vector $(n_{kj} \times 1)$ of the generalised costs $g^{t,i}_{kj,\text{exp}}$;

Figure 1 – The overall framework of the models system proposed

Note that in any time period it results that the performance attribute provided by the ATIS is the same for any user class $i$:

$$X^{t,i}_{kj,\text{info}} = X^{t,i}_{kj,\text{info}} \quad \forall i$$

The generalised expected is a linear combination of the expected performance attribute cost, $X^{t,i}_{kj,\text{exp}}$ (e.g. travel time and travel cost, number of congested links,...) through $\gamma^i$ parameters depending on user class $i$:
\[ g^{t,i}_{kj,\text{exp}} = \sum_x \gamma^t_x \cdot X^{t,i}_{kj,\text{exp}} \]

In our model we assume:

\[ g^{t,i}_{kj,\text{exp}} = TT^{t,i}_{kj,\text{exp}} + CF_k \]

being:

- \( TT^{t,i}_{kj,\text{exp}} \), the travel time expected at day \( t \) on path “\( k \)” leaving during time interval “\( j \)”;
- \( CF_k \), the commonality factor related to path “\( k \)” of C-Logit model (Cascetta et al., 1998) introduced to overtake the IIA properties of Logit models (Ben Akiva Lerman, 1985) by reducing the probabilities of choosing each path according to the degree of overlapping (i.e. number of links in common). It is specified as:

\[ CF_k = \ln \left( 1 + \sum_{h \neq k} \frac{TT^o_{hk}}{(TT^o_h \cdot TT^o_k)^{1/2}} \right) \]

being:

- \( TT^o_{hk} \) travel time of links common to path “\( h \)” ad “\( k \)” resulting of a Stochastic User Equilibrium Assignment;
- \( TT^o_h \) e \( TT^o_k \) path travel time respectively of path “\( h \)” and “\( k \)” resulting of a Stochastic User Equilibrium Assignment.

Users are here grouped into four classes defined according to the degree of knowledge of the network (habitual and occasional users) and to availability of information (informed and non-informed users), as reported in tab. 1.

<table>
<thead>
<tr>
<th></th>
<th>Informed users (I)</th>
<th>Non informed users (NI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Habitual users (A)</strong></td>
<td>IA</td>
<td>NIA</td>
</tr>
<tr>
<td><strong>Non-Habitual users (NA)</strong></td>
<td>INA</td>
<td>NINA</td>
</tr>
</tbody>
</table>

Tab. 1 – User classes considered in the proposed model.

**The Travel Behaviour Simulator (TBS)**

The Travel Behaviour Simulator consists of:
- Experience updating models simulating how users’ perception changes day-to-day according to what they expected and what the actually experienced in the previous days;
- Information acquiring models simulating how information provision modifies users’ expectation of network performance;
- Path/departure time choice updating models simulating day-to-day choice adjustment process.

**Experience updating models**

Experience at a given day \( t \) is the result of what users expected and actually experienced at any previous day \( t-1, t-2, \ldots \):

\[ X^{t,i}_{past} = G( X^{t-1,i}_{act}, X^{t-1,i}_{exp}, X^{t-2,i}_{act}, X^{t-2,i}_{exp}, \ldots) \]
where $X^{t,i}_{past}$ is the generic performance attribute $X$. In the proposed framework, on the one hand, we assume that the performance attribute which is considered in the day-to-day updating process is the path travel time starting at a given time (interval) “j”, $TT^{t,i}_{kj, past}$, on the other hand, we assume that this travel time depends on the expected and actually travel time on the same path “k” leaving at the same time interval “j” of only the previous day $t-1$:

$$TT^{t,i}_{kj, past} = G(TT^{t-1,i}_{kj, act}, TT^{t-1,i}_{kj, exp})$$

The function $G$ is an exponential smoothing filter (Horowitz, 1984; Ben Akiva et al., 1986):

$$TT^{t,i}_{kj, past} = \beta^i \cdot TT^{t-1,i}_{kj, act} + (1 - \beta^i) \cdot TT^{t-1,i}_{kj, exp}$$

being $\beta^i$ a parameter between 0 and 1 representing the weight of previous day actual experience for user class $i$.

The experience updating process can be individual or aggregated: in the former case (individual memory), the updating process is based on the performances, i.e. in our case the path travel times, that users have individually experienced in the previous days; in the latter case (aggregate memory), the updating process is based on a average performance attribute (i.e. the average travel time on path k leaving at time j) equal for all the users. In the proposed model we adopt an aggregated choice updating model: at a given day $t$ for each path $k$ and for each departure time interval an average path travel time is calculated through:

$$\overline{TT}^{i}_{kj, act} = \frac{\sum_{i=1}^{N_{k,l}} TT^{i,i}_{kj, act}}{N^{i}_{k,l}} \quad \forall i$$

being $N^{i}_{k,l}$ the number of users leaving at time “j” on path “k”, at day $t$.

**Information acquiring models**

The information acquiring models simulate how information provided by the ATIS modifies users’ perception of the performance attributes (i.e. in our case path travel time). At given day $t$, we assume that:

$$TT^{t,i}_{kj, exp} = \lambda^i \cdot TT^{t,i}_{kj, info} + (1 - \lambda^i) \cdot TT^{t,i}_{kj, past}$$

where $\lambda^i$ is a parameter between 0 and 1, representing the weight given by user $i$ to the information received. Different values of $\lambda^i$ are specified according to the availability of the information and to the reliability of the ATIS. It is reasonable to assume that $\lambda^i$ increases with the reliability of the information System: 0 for non-informed (NI) users (which have no access at all to the information system); 1 for Informed-Non habitual (INA) users (which have totally rely on information received since they have a coarse knowledge of network).

$$\lambda^{NI} = 0 \rightarrow X^{t,NI}_{att} = X^{t,NI}_{exp}$$

$$\lambda^{INA} = 1 \rightarrow X^{t,INA}_{att} = X^{t,INA}_{info}$$

**Path/Departure time choice updating models**

Path and departure time choices are modelled through random utility theory: a systematic utility consisting of path generalised cost and early-departure/late-arrival penalties (Abkowitz, 1981; Small, 1982; Hendrickson e Plank, 1984) is associated to each pair (k,j), with “k” being one of the K-shortest paths (computed off-line) between the given O-D pair, and “j” being one
of the departure time intervals available (i.e. the interval in which the users is choosing plus all the subsequent until the end of the simulation period).

At day $t$, the probabilities of the generic pair $(k,j)$ changes as time pass over, on due to modification of the choice set: for instance, at time interval $j=3$, it is evident that all the pairs $(k,1)$ and $(k,2)$ are not available since it is no more possible leaving at time $j=1$ and $j=2$. In the hypotheses of random residuals distributed as a i.d.d. Gumble variable (Ben-Akiva Lerman, 1985) the probability of pair $(k,j)$ at time $j^*$ results:

$$p_{kj}^{i,j}(j^*) = \begin{cases} \frac{\exp(V_{kj}^{i,j} / \theta)}{\sum_{k',j':j'*} \exp(V_{k'j'}^{i,j} / \theta)} & \text{if } j \geq j^* \\ 0 & \text{altrimenti} \end{cases}$$

$\theta$ being a parameter proportional to the variance of random residuals. In the following for sake of simplicity, we shall omit to explicitly indicate explicitly the dependence of $p_{kj}^{i,j}$ on time interval $j^*$.

To take into account that, due to habit and inertia with respect to change, some users would not modify their choices but repeat day by day the same choices, we introduce the probability $p_{kj}^{i,j}(t-1)$, that user $i$ chooses path $k$ and time interval $j$ at day $t$, conditional to having chosen $k'$ and $j'$ al day $t-1$. If $\alpha$ is the probability of reconsidering the choice, assumed for sake of simplicity independent on day $t$, it results that:

$$p_{kj}^{i,j} = \alpha \cdot p_{kj}^{i,j-1} + (1-\alpha)$$

Then the flow on path “$k$” in time interval “$j$”, $h_{kj}^{i,j}$,will be given by:

$$h_{kj}^{i,j} = \sum_{k'} p_{kj}^{i,j} \cdot h_{kj}^{i,j}$$

and thus (Cantarella and Cascetta, 1995) it is easy to prove that:

$$h_{kj}^{i,j} = \alpha \cdot p_{kj}^{i,j} \cdot d_{OD}^{i,j} + (1-\alpha) \cdot h_{kj}^{i,j-1}$$

being $d_{OD}^{i,j}$ the number of users $i$ between origin O and destination D.

The Pre-Trip Information System

According to the classification of ATIS introduced in the first paragraph, the Information System simulated in the proposed framework is a Pre-Trip-Descriptive-Real-time-Drivers Information System. It is pre-trip since information are available only before starting the trip; descriptive because information are provided through network performance indicators (i.e. path travel time) and not through explicit guidance on what to do; real-time since users are provided with information based on the current state of the network.

Let us consider, for instance, a simple case of non-recurrent congestion (e.g. an accident, or whatever can reduce temporary the capacity of a given link). Provided that the accident occurs at the time interval $j-1$, the model starts a parallel simulation of the system, starting from network condition at time $j$, supposing that no users knows about the accident. Path travel time computed in this hypothetical situation (i.e. with no information available), will be then transmit to the informed users in the “real-world” simulation (previously stopped at time $j$).
Since consistency between information provided and actual network performance is not guaranteed (in fact the actual behaviour of informed drivers can give rise to different traffic conditions with respect to those provided by the system), the information system implemented is not predictive. Anyway, it is possible to show that should the number of informed users be negligible, the model goes toward a “consistent” configuration.

**The Traffic Simulator (TS)**

In order to take into account that network performances are not stationary but they largely vary within the simulation period, a dynamic traffic simulator is embedded in the models system to better estimate actual network performances.

The traffic simulator consists of

- a *Dynamic Network Model*;
- a *Dynamic Network Flow Propagation Model*.

**The Dynamic Network Model**

A traditional network model, consisting of links and nodes, where the topology and the performance of each link are not stationary over time. Dynamic Network performances are introduced by subdividing the simulation period into time slices, and by supposing that at each time slice $j$, link condition could vary depending on a number of factor such as link characteristics, presence of accident, weather condition and of the flow at time slice $j-1$.

Thus, the network at day $t$ and time interval $j, N_j'$, could be seen as a realisation of a random variable:

$$N_j' \sim N(\Delta, N_{j-1}', f_{j-1}')$$

being:

- $N_j'$ Network configuration at time interval $j$;
- $\Delta$ the link-path incidence matrix;
- $f_{j-1}'$ link flow vector at day $t$ and time interval $j$.

It is easy to see that from this definition the network condition at day $t$ and time slice $j$ depends on all the time slices $1, \ldots, j-1$ preceding $j$ at the same day.

**The Dynamic Network Flow Propagation Model**

The movement simulation of users on the network at each day $t$ is due by a meso-simulator called MICE (Cantarella et al, 1999). It is based on a discretization of the traffic network into links and nodes and an aggregation of users into “packets” or platoons (at least a packet can embed only one user).

Each packet is represented on the network by a single point giving its position over time (i.e. the so-called “point packets” approach). The network loading model can deal with both link and node flow propagation models ensuring the respect of the FIFO rule (with a duly defined adjusting rule) also in the cases when the functional form of the link travel time could fails, due to high inflow rate, for example.

The link and node model in MICE are designed to simulate the spill-back of queues when users on link exceed storage capacity. The node model used is suited to implement a kind of traffic light-actuated intersection, but also a fixed phase plan could be chosen.
APPLICATIONS

Preliminary applications of the models system proposed showed the importance of the control parameters (i.e. the parameters alpha’s, beta’s and lambda’s, the parameters of the departure time/path choice model and so on) and the duration of the time slice in which the simulation period (day t) is subdivided. Therefore, an analysis of the proposed framework sensitivity to the model parameters has been carried on by means of very simple test networks. The results of such analysis are presented in the following of the paper. Application to real-world case studies evaluating the impacts of the ATIS on drivers’ choices will be subject of future studies.

The first experiment has been carried on in order to duly define the duration of each time slice in which day t has to be split and to verify the elasticity of the departure time sub-model. A single-path test network is considered. The simulation period is assumed of 30 minutes long and has been split in 10 time-slices of 180 seconds each. An accident (i.e. a 66% reduction of link capacity of 360 seconds) is supposed to occur at the beginning of day 4. All the users are supposed to be Informed-Habitual (IA), they react to the information by adjusting their departure time. In fact, as shown in figure 3, at day 4 after the first time slice (TS0) in which the accident occurs, the number of users departing in the subsequent time slices vary with respect to the previous days. It can be observed a decrease of users departing at time slices TS1, TS2 and TS3 in which the delay due to the accident is still relevant, and an increase in TS4 when the queue due to the accident is over.

As it can be seen, in the days before the accident occurs the departures distribution among the time slice is uniform, meaning that time slices from TS0 to TS4 are perceived as equivalent equal in terms of utility. The accident induces a shock in this uniform distribution that after few days goes over.

To test the elasticity with respect to path choices, the test network considered is a single O-D pair network consisting of two path from origin O to destination D (see figure 2). The capacity of the links belonging to the two paths are all the same and have been maintained fixed throughout the following experiments. Different levels of congestion have been achieved by modifying the number of user moving on the network. In this case the departure time has been considered not flexible (rigid demand profile): all the user have been constrained to depart at time slice TS2.
Two different user classes have been considered: Informed Habitual (class 1) and Not-Informed Habitual (class 0). We have firstly considered the case in which no accident occurs. As it can be seen from figure 4, after few days of simulation the system converges to a fixed-point attractor in which cost are consistent with flow for both paths considered.

It can be noted that that while class 0 converges smoothly to the attractor, class 1 goes through a little number of oscillations around the fixed-point. This is due to the fact that Informed-Habitual users are assumed to reconsider their choices at each day, on the basis of what the ATIS suggests. The frequency of the oscillation highly increases with the level of congestion of the network, as proved by the simulation results reported in figure 5.
Finally the case of non recurrent congestion (i.e. accident) occurring at a given day has been tested. As expected in case of accident on one of the two alternative paths, the informed users divert to the alternative path improving their travel time with respect to not-informed drivers, as reported in the table 1.

<table>
<thead>
<tr>
<th>No Accident (min)</th>
<th>Accident (min)</th>
<th>Benefits of Informed users w.r.t not-Informed users</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>25</td>
<td>Mean path cost experienced by Not-Informed users</td>
</tr>
<tr>
<td>21</td>
<td>22</td>
<td>Mean path cost experienced by Informed users</td>
</tr>
<tr>
<td></td>
<td>11%</td>
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</tr>
</tbody>
</table>

Table 1 –Path travel times with and without accident.

CONCLUSIONS

A doubly dynamic models system aiming at simulating the impacts of Advanced Traveller Information Systems (ATIS) on pre-trip users’ travel choices such as route and departure time and on network performances has been presented. The overall framework consists of three main sub-models. The travel behaviour simulator models the day-to-day choice updating model for different user classes (e.g. informed and non-informed). The within-day dynamic traffic simulator simulates the propagation of flows on the network and estimate network performances allowing for non-stationary conditions within the simulation period and random fluctuation of supply characteristics. Finally, a module generating real-time traffic information based on current network conditions simulate the presence of an Advanced Traveller Information System (ATIS) in the transport system. Supply/Demand interactions are simulated within a day-to-day dynamic process framework. Preliminary applications of the models system proposed showed the importance of the control parameters of the models. An analysis of sensitivity to the model parameters has been carried on by means of very simple test networks, in order to test the elasticity of path and departure time choices under different condition of congestion (i.e. recurrent and non-recurrent).

REFERENCES


