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Problems of Modelling of ITS Services in Transportation Models

G. KAROŃ[a], J. MIKULSKI[b]
[a] SILESIAN UNIVERSITY OF TECHNOLOGY, Faculty of Transport, Krasinskiego 8, Katowice, Poland
[b] KATOWICE SCHOOL OF TECHNOLOGY, Rolna 43, Katowice, Poland
EMAIL: grzegorz.karon@polsl.pl

ABSTRACT

Paper presents important issues related to macroscopic/strategic transportation modelling for ITS projects – utility function and perceived travel time for mode choice in macroscopic model.

KEYWORDS: ITS, Dynamic modeling, transportation modelling

1. Introduction

Development of ITS systems is presented in practical aspects – in systems engineering – mainly in [1-3, 4]. The main problems of the transportation modelling is taking into account impact of ITS configuration on the users and their preferences in the choice of transportation system – mode choice [10, 11, 13-17]. Mapping macroscopic transportation model with ITS in specific variant of configuration requires the determination of the impact of these systems on the so-called utility functions. In four stage transportation model (macroscopic model) the utility of ITS [10, 11, 18] may be included in all stages of the modelling of transportation demand and supply transportation model – a model of the transportation network.

The **generalized cost of travel time** and weights – coefficients – of components of this measure **may be used to take account the impact of the functional and operational configuration of ITS on the users and their preferences in the choice of transportation system** – mode choice.

2. Services of ITS in urban transportation modelling

The expected results of prepared technical variant of ITS configuration can be specified as [7, 8, 9]:

- short-term results on operational level of traffic management – related to the current decisions of transport users (e.g. driver's choice of traffic lane at the approach of the intersections, decision on overtake on the section of the road etc),
- medium-term results on tactical level of traffic management – related to the choice of path in the network and to the search for free parking places,
- long-term results on strategic level of traffic management – related to decisions of network users on travelling and on choice of means of transport and transportation modes.

Assuming a specific configuration of ITS, acting within the framework of logical architecture, implementing certain ITS services, can be expected that the result will be changes in the traffic flows in the transport network. These changes are caused by changes in the transport behaviour of users including [10, 11, 12]:

- changes in the travel generation,
- changes in the spatial distribution of travel,
- changes in selection of the transport mode while travelling,
- changes in path choice in the transport network while travelling in selected mode.

Changes in travel behaviour under the influence of ITS services are dependent, among others, from [10, 11]:

- the nature of the transport needs – nature of the activities and purposes of trips: absolutely obligatory (e.g. work, education); relatively obligatory (social and living e.g. shopping, offices, health etc.); optional (such as leisure, recreation, entertainment),
- the type of user activity (working, studying, learning, retired etc.),
- preferences in mode choice of transport users,
- kind of transport mode,

- active availability of transport (the ability to travel from a specific source/object to other destinations/objects) and passive availability of transport (the ability to travel to a specific destination/object from other sources/objects),
- utility function describing the decision-making processes of users.

In transportation demand the number of trips between a pair of TAZ's – traffic analysis zones *i* and *j* can be expressed generally as a function dependent on the following factors [10, 11]:

- socio-economic variables, describing the activity (area development) and the decisions taken by users,
- quantitative and qualitative attributes of the transport system,
- characteristics describing users carrying out trips:
- category *k* of the user,
- purpose *z* of trip,
- the period *h* of analysis,
- transport mode *m*,
- path *s* in the network,
- vector $\hat{a}$ of coefficients and parameters.

User of category *k*, making a decision [10, 11] about the trip and its stages (this is determined alternative *p*), is concerning a set of mutually independent, alternative trips, and for different categories *k* of users there may be different sets of alternatives P^k. The user assigns each alternative in the set P^k utility function U_p^k [2]:

$$U_p^k = V_p^k + \varepsilon_p^k \qquad \forall p \in P^k \tag{1}$$

where:

V_p^k – the expected value of utility function defined by travellers *k*-th category,

ε_p^k – random part of utility function – deviation from the expected value (average value) of utility.

The utility function V_p^k is a function of attributes X_{lp}^k, related to the alternative *p* and users of *k*-th category, who are considering a range of alternatives in the decision-making process [10, 11]:

$$V_p^k = \sum_l \beta_l X_{lp}^k \qquad \forall p \in \mathrm{P}^k \tag{2}$$

where:

β_l – *l*-th linear regression coefficient,

X_{lp}^k – *l*-th attribute of:

- attributes of transportation systems – attributes can be divided into quantitative and qualitative: e.g. travel time, travel cost, frequency of public transport, delays, comfort etc.,
- attributes of spatial management (activity attributes in the area) - attributes describe the spatial development of land in terms of movement creation, among others, the number of facilities that generate travel/traffic and their parameters, such as: the number of factories and workplaces, the number of schools, universities and the number of learners, number of stores and service outlets with the number of people using them, etc.,
- socioeconomic attributes of the demand for transport relate to individual users or households and these are e.g: gender, age, income level, the position of the person in the family, the status of holding a driving license, the number of cars, bicycles, motorcycles on the farm etc.

The user of *k*-th category selects from the set P^k such an alternative *p*, that maximizes the usefulness of the decision. The choice of alternatives *p* is given with a certain probability $\mathrm{Pr}^k(p)$. This probability is determined taking into account the usability U_r^k concerning the other alternative *r*:

$$\mathrm{Pr}^k(p) = \mathrm{Pr}^k\left(U_p^k > U_r^k\right) \qquad \forall p \neq r, \quad p, r \in \mathrm{P}^k \tag{3}$$

Perceived travel time and so-called generalized cost of travel can be shown as [10, 11]:

$$c_p^k = \sum_{skł} a_{p_{skł}}^k \cdot w_{p_{skł}}^k \qquad \forall p \in \mathrm{P}_{ij}^k \tag{4}$$

where:

$w_{p_{skł}}^k$ – values of the variables corresponding the component attribute *skł* in *p*-th travel alternative (treated as a chain of movements); for example, for the journey by tram, attributes are the elements of travel time and additional components, including fare (ticket), and for car journeys - additional component will be such as parking charge,

$a_{p_{skł}}^k$ – weights (equivalent coefficients) related to the attributes of the individual components *skł* of *p*-th alternative (chain of movements);

Weights $a_{p_{skł}}^k$ consider perceived disutility of the subsequent stages of displacement within a specific chain, representing the *m*-th mode of journey, along a specified path *s*, for trip in origin-destination (i, j), by the users of category *k*. It should be noted that the nuisance of the same section in the chain, as e.g. described in-vehicle time, it may indeed be perceived differently by different categories of users. For example, the lack of a seat in a vehicle of public transport will be less burdensome for young people than for older people with reduced mobility, although both will spend the same in-vehicle time standing next to each other.

Similarly perceived travel time by car in terms of congestion may be different for different groups of users. For example driving during peak hours by road with the local traffic jams caused congestion will be perhaps less burdensome for those implementing short trip from work to home, than for people from outside the town, running on the same road but in transit, while travelling absolutely obligatory eg. to work or very important meeting. In this second case, greater burdensome of transit journey due to the risk of not achieving the destination at the scheduled time, that is, the risk of being late and the consequences of this event.

Weights are coefficients that may be used to take account the impact of the functional and operational configuration of ITS on the users and their preferences in the choice of transportation system – mode choice (see Fig. 1).

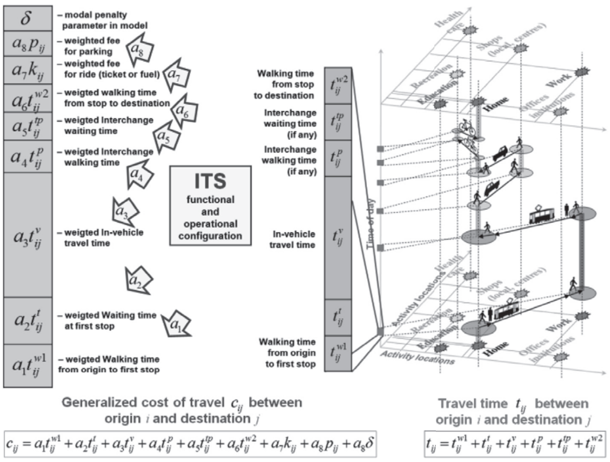

Fig. 1. Generalized cost of travel with travel time as a result of the ITS operation in functional and operational configuration [own study]

3. Discussion on the detail of transportation models in the context of mapping the effects of ITS systems

Using ITS services, in addition to influencing the distribution of traffic flows in the transportation network (among others by traffic control subsystems and VMS signs) may also affect user decisions on making certain types of travel. Decisions of users concerning their travelling may be considered in at least three aspects:

- the aspect of the journey: travel or resignation from travel,
- time aspect of travel: travel during peak hours or off-peak hours,
- spatial aspect of the journey: the most popular routes (the shortest, but also the most traffic-laden) or less popular routes (longer, but less burdened by traffic).

Development of the **macroscopic/strategic** transportation **model requires gathering a wide variety of data,** derived from different sources: surveys and traffic measurements [10, 11, 19]. The scope and **level of detail of data** collected in the survey results from at least two aspects. The **first one** is the structure of the four-stage transportation model and the basic scope of the necessary data. The **second one** is the scope of the project—investment project, study, transport development strategy, etc.—especially the assumptions, components and results of the project in terms of the impact on the transportation system and its users. For example the article [28] presents the issues related to the use of the **macroscopic/strategic transport model for evaluation ex-ante of ITS** configuration. The structure of the transport model on strategic level of traffic management has been presented in the context of the following impact of ITS configuration:

- changes in the use of paths in network,
- changes in the use of transport system modes,
- changes in the destinations of trips,
- changes in the number of trips for various purposes and activities.

The development of the **macroscopic/strategic** transportation model requires the collection of data on travel and traffic flows [12, 13], taking into account the following characteristics [20-25]:

- internal travel and internal traffic – generated by residents and vehicles originating in the research area,
- internal source travels and traffic – the source of the journey is inside of the research area and the destination is outside of this area,
- external source travels and traffic – the source of the journey is outside of the research area and the destination is inside of this area,
- travel and traffic with source and destination are outside the study area, but passing through the study area,
- external travel and traffic – source and destination are outside the study area and not passing through the area, but passing through its neighborhood.

For example, the article [29] presents the **macroscopic/strategic** transportation model development for ITS project with carrying out the household interview survey for determining the travel behavior of transport users – related to the following decision problems:

- determination of population and sample size,
- selection of the characteristics of the sample unit, which are important from the point of view of the representativeness of the study,
- determination of the observation unit and the sampling scheme,
- preparation of a plan for testing the process of survey implementation.

Moreover if the **macroscopic/strategic** transportation model is developed to **evaluate technical variants of the ITS configuration** defined in the concept or in the feasibility study of the ITS, then in the process of delimitation urban area into TAZ's (traffic analysis zones) it is important to consider the **functional and technical aspects of the ITS** project. For example, in the methodology [25] the TAZ's of urban agglomeration take into account:

- Zonal Traffic Control System and Public Transport Management System.
- Passenger Information System and Drivers Information System,
- Video Surveillance and Monitoring of Public Space System.

These **decision problems** are conditioned by the methodology of delimitation of the study area, by the methodology of description of transportation systems and by the methodology of identification of traffic flows in transportation systems – described in next article [30]. Presented methodology in [30] takes into account three types of area delimitation criteria: administrative, structural, functional-technical criterion with respect to the ITS project. Verification of this methodology was made during preparation tender documentation (including specification of the essential terms of the contract as well as description of the subject of the order). The scope and the algorithm of traffic flows surveys and measurements – necessary for the construction of an urban agglomeration transportation model for ITS projects – has been presented in the article [31]. This algorithm has been presented with their formal description and following tasks:

- development of a detailed schedule,
- obtaining the necessary permits and agreements for the implementation,
- development of information and promotion plans,
- preparation of a description of the ITS project for the contractor.

4. Conclusion

The structure of **transportation model presented in article is suitable for long-term results – for strategic level of transport systems development in urban area.** While transportation models for **tactical level** of traffic management with **medium-term results**, and for **operational level** of traffic management with **short-term results** are used to determine the characteristics, describing traffic conditions in a transport network, for example expected smoothness of traffic flows [7, 8], and to determine dynamic characteristics describing for example information spread processes in dynamic traffic networks.

In the case of ITS systems, these are defined ITS subsystems, represented in the form of ITS services or the manner of using specific ITS services in the form of strategies for specific activities using ITS services. One of the basic models of this type are models including ITS services providing transport system users with **information on traffic conditions and modes of movement.** In this case, the possibility of using this information is distinguished: **pre-trip information** – at the stage of travel planning, and **en-route information** – during the travel. Models that map the use of information at the pre-trip information stage use models **of analysis of this information in terms of their impact on user decisions** regarding the selection of the destination and the transport system (mode). However, models using information during travel [en-route information] use **models describing user decisions made at network nodes – when changing routes**.

Therefore the better modelling of ITS services requires dynamic transport models e.g. Dynamic Traffic Assignment models (DTA) also called models with dynamics during the day (within-day dynamics models) [10]. This is due to the fact that static transport models do not take into account changes in traffic flow distribution, changes in travel demand, changes in transportation supply – in short-term. These changes result from the impact of ITS services on users and traffic conditions as well as on the operation of transport systems. This is a fundamental issue, because such changes can be expected as the results of ITS systems in a specific configuration – including results of activities related to the creation, propagation, and dissipation of vehicle queues, and temporary reductions in link capacity, and changes in the demand for transport during peak hours.

The dynamic transportation models require a more detailed representation of users' behavior than static transport models. **Dynamic modeling requires description** of two users' phenomena:

- **choice updating behavior** – description how present choices are influenced by the choices from previous days,
- **learning and forecasting mechanisms** – description how experience and information from previous transport efficiency influence present choices.

The basic components of the DTA model are:

- **dynamic propagation of the flow along a link**,
- **dynamic model of network flow propagation**,
- **travel time on link depends on** two distinct link types: **running links** represent the real movement of the vehicle and **queuing or waiting links** represent waiting vehicles at intersections, toll barriers etc.,
- **link performance** and **travel time functions** – the functions that express link travel time according to link flows; this functions measure link travel time against the number of users on the link,
- travel times – **expected travel time and current travel time**, which **users expect and experience while traveling** at a particular moment.

Dynamic Traffic Assignment models (DTAs) are treated as dual dynamic models because they include the following two major sub-models:

- model of supply system update, including in the field of dynamic update of their functional features – link and path performance model,
- model for updating transport demand, including in the field of dynamic update of transport behavior and preferences (among others, models of choice of transport systems and routes in the transport network) – utility updating model.

These issues of system mapping using dynamic models are the subject of further research by the authors of the article.

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