IVAN BOŠNJAK, D. Sc.
Fakultet prometnih znanosti
Odsjek za inteligentne transportne sustave
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska
e-mail: bosnjaki@fpz.hr
IBRAHIM JUSUFRANIĆ, D. Sc.
Fakultet saobraćaja i komunikacija
Zmaja od Bosne 8, 71000 Sarajevo, Bosna i Hercegovina
VINKO VIŠNJIĆ, D. Sc.
Fakultet prometnih znanosti
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska

Traffic Engineering
Preliminary Communication
U. D. C.: 656.05
Accepted: Sep. 29, 2003
Approved: Mar. 2, 2004

MODELLING FRAMEWORK FOR DYNAMIC MULTICLASS TRAFFIC ASSIGNMENT IN ITS ENVIRONMENT

ABSTRACT

Deployment of flexible traffic control, pre-trip, on-trip, guidance and other ITS services require considerable research toward the development of appropriate methodological framework and tools. In this paper, adapted modelling framework for dynamic multiclass traffic assignment (DMTA) in ITS environment is proposed and elaborated. DMTA system uses traffic data associated with three backdrops: time, space and defined "user classes". The proposed structure of DMTA system includes modules for O-D estimation and prediction, real-time network state simulation, consistency checking, updating functions, resetting functions. The methodological tools for solving DMTA problems include combination of mathematical programming, simulation and heuristic methods.

KEY WORDS

traffic networks, Intelligent Transport Systems, dynamic modelling, drivers' information

1. INTRODUCTION

The real benefits of ITS technologies deployment have motivated considerable research toward the development of holistic framework, methodologies and algorithms for real-time traffic and transport operations [1], [2]. The majority of classical methods and algorithms address steady-state flow conditions in the network and therefore they are not suitable for several real-time ITS applications such as flexible traffic control, pre-trip, on-trip, guidance services, etc.

To make better decisions drivers, travellers and guidance systems have to utilise different real-time data sources and information about:

- traffic flow, speeds and travel times on roads,
- locations and causes of delays,
- new constructions and events not yet causing delays but which could cause delays by the time drivers reach them.

Most of the existing real-time traffic information is referred to as "incident information" which includes accidents, lane obstructions, road works, animals on roadways, road weather, damaged pavement, sporting events, police actions etc. The traffic database files that describe incident situations consist of incident and so forth. The incident information comes from mobile-phone callers, fleet operators, police, emergency dispatch centers, toll operators and a variety of other sources.

In our research we want to systematically consider the problems of dynamic traffic modelling and drivers information services to develop framework for dynamic multiclass traffic assignment in new ITS environment. The basic feature of new dynamic models is that they depart from the static assignment assumptions to deal with time-varying flows and incident events.

2. BACKGROUND RESEARCH RELATED TO DTA

Dynamic Traffic Assignment (DTA) theory and models have evolved substantially since the first works [5] to more appropriate formulations including link performance functions [3] and "cell transmission model" [4]. The basic feature of these dynamic models is that they deport from the static assignment assumptions to deal with time-varying flows and adaptable control actions.

Daganzo proposes the *cell transmission model* to simulate the traffic behaviour on a single highway link where basic relationship between traffic flow (φ) and density (k) defined in the form:

$$\varphi = \min\{v, k, \varphi_{\max}, w(k_j - k)\} \quad \text{for } 0 \le k \le k_j$$

can be approximated by a set of difference equations (with system state adapted at every time interval). In the above relationship the defined quantities are:

$\varphi_{\max}$ – maximum flow or capacity of the link,

v – free flow speed,

w – the backward propagation speed,

k_j – jam density.

The basic idea of cell transmission model is discretization of the assignment period (time period of interest) into small homogenous *cells* where length of each cell is equal to the distance travelled by the free-flow moving vehicles in the time interval. Some authors extended the basic model to represent freeway and arterial street networks and Ziliaskopoulos [8] proposes that the traffic flow propagation relationships could be captured by a set of linear constrains in linear programming DTA models.

3. MODELLING DYNAMIC EQUILIBRIUM AND CLASSIFYING THE DRIVERS' BEHAVIOUR

The equilibrium between the demand for travel and the supply of the road network can be considered at several levels with different quantities and attributes. The demand is described as the number of trips or O-D pair and mode that would be made for a given level of service i. e. travel time, monetary costs (fares, fuel) and other features (comfort, etc.). The supply is described as traffic network represented by links (and their associated nodes) and their costs. The costs (C) are the function of the attributes associated to the links and nodes: distance, capacity, free-flow speed and speed-flow relationship. If the actual level of service turns out to be lower than required, then a route changes or shift in modes or times of day can be activated.

In the simplest model of road network the equilibrium takes place where travellers (drivers) from a fixed trip matrix seek routes to minimise their travel times or costs. After some trial and error this allocation of trips to routes gives a pattern of path and link flows which could be defined as the user equilibrium (UE) when travellers can no longer find better routes for the desired destinations.

The corresponding "marginal cost" or marginal addition of a vehicle to the total operating cost (or travel time) can be calculated as:

$$C_{\mathrm{ma}} = C_a(\phi_a) + \frac{\partial C_a(\phi_a)}{\partial \phi_a}$$

where

$C_a(\phi_a)$ – corresponds to the average cost on the link or nodes and

$\frac{\partial C_a(\phi_a)}{\partial \phi_a}$ – corresponds to the contribution to delay made by the additional (marginal) vehicle.

A number of authors suggested different functional forms for time(cost)–flow relationships and methods for capacity–restrained traffic assignment [6]. According to the defined user equilibrium (UE) or Wardrop's first principle, the equilibrium means that all routes between any O-D pair have equal and minimum cost while all the unused routes have greater or equal costs. Wardrop proposes an alternative way of assigning traffic onto a network from the view of planners and engineers who consider broader system optimum (SO). Wardrop's second principle defines that under equilibrium conditions traffic should be arranged in such a way that the average (or total) travel cost in congested network is minimised. The basic premise in traffic assignment is the assumption of a rational and informed traveller, i. e. one choosing the route with the least perceived and anticipated costs.

One applicable way to define equilibrium on traffic networks with time-dependent demand is extrapolation of Wardrop's static conditions. In the adapted approach the *user equilibrium* (UE) conditions mean that ITS-drivers follow time dependent least travel time paths, while *system optimum* (SO) conditions result from drivers following the least marginal travel time paths. Specific driver/user behaviour governing trip-making mode split and route-choice decisions can be incorporated as specific user classes [3].

In ITS environment it is reasonable to consider four basic user classes related to dynamic traffic assignment problems where each class is associated with typical driver behaviour. These are:

- class 1: ITS equipped drivers who follow system-optimal (SO) paths;
- class 2: ITS equipped drivers who follow user optimum routes;
- class 3: ITS equipped drivers who follow specific behavioural rules (different from class 1 and class 2);
- class 4: drivers in vehicles without ITS equipment for pre-trip, on-trip and route guidance services.

Advanced guidance system with pre-trip and on-trip traveller/driver information service requires structure and functional processes shown in Fig. 2. The predictive guidance takes into account drivers' responses to information, and it is consistent and

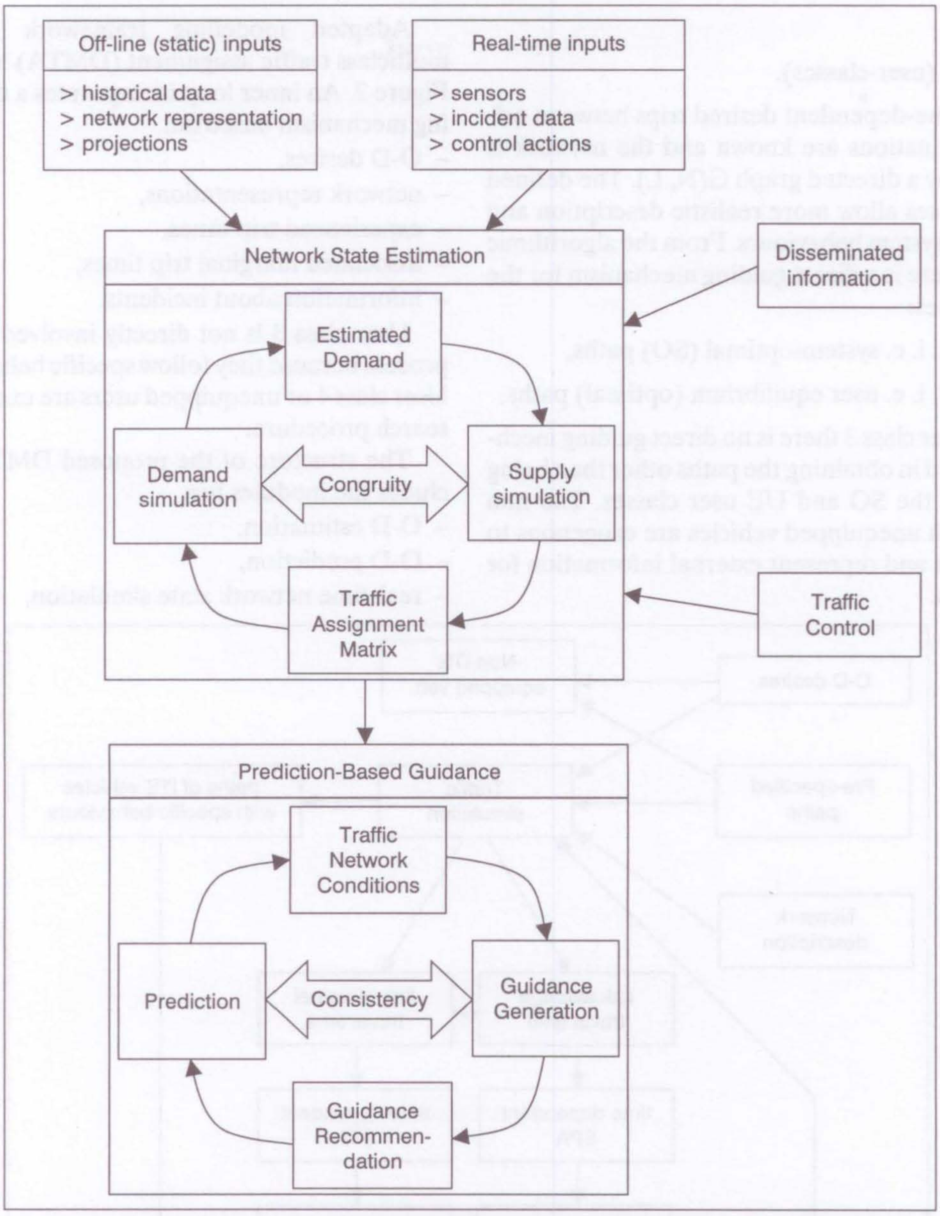

Figure 1 - Structure and processes in anticipatory real-time guidance system

user-optimal. Quality of anticipation means that the system estimates and predicts the current and future traffic conditions on the existing network at the time when the links and nodes are actually traversed.

The guidance generation is an iterative process between prediction and alternative guidance strategies. Drivers who receive guidance information may change their paths according to recommendations, or follow the specific behaviours related with aversion to switching routes, perceptual factors, etc. Guidance information has the quality of consistency if the traffic conditions which result from drivers' reactions to it are the same or very similar (within the limits of modelling accuracy) as those which had been anticipated when generating it.

4. PROPOSED MODELLING FRAMEWORK FOR ITS-DMTA SYSTEM

Deployment of ITS technologies for network traffic management and the new pre-trip, on-trip and guidance ITS services require defined ITS architecture and systemic problem solver framework. A hybrid mathematical and simulation based modelling framework can be a starting point. Dynamic traffic assignment methodology has the central role in supporting advanced traffic management and traveller/driver information services. The proposed DTA system has to describe how traffic flow patterns develop according to three *backdrops*:

– time,

– space,

– population (user-classes).

Cost or time-dependent desired trips between origins and destinations are known and the network is represented by a directed graph G(N, L). The defined four user classes allow more realistic description and prediction of system behaviours. From the algorithmic standpoint there is a direct guiding mechanism for the two user classes:

– user class 1, i. e. system-optimal (SO) paths,

– user class 2, i. e. user equilibrium (optimal) paths.

For the user class 3 there is no direct guiding mechanism involved in obtaining the paths other than being predicted for the SO and UE user classes. The non ITS-users with unequipped vehicles are exogenous to the procedure and represent external information for each iteration.

Adapted modelling framework for dynamic multiclass traffic assignment (DMTA) is presented in Figure 2. An inner loop incorporates a direction-finding mechanism based on:

– O-D desires,

– network representations,

– experienced trip times,

– associated marginal trip times,

– information about incidents.

User class 3 is not directly involved in the search process because they follow specific behavioural rules. User class 4 or unequipped users are exogenous to the search procedure.

The structure of the proposed DMTA system includes the modules for:

– O-D estimation,

– O-D prediction,

– real-time network state simulation,

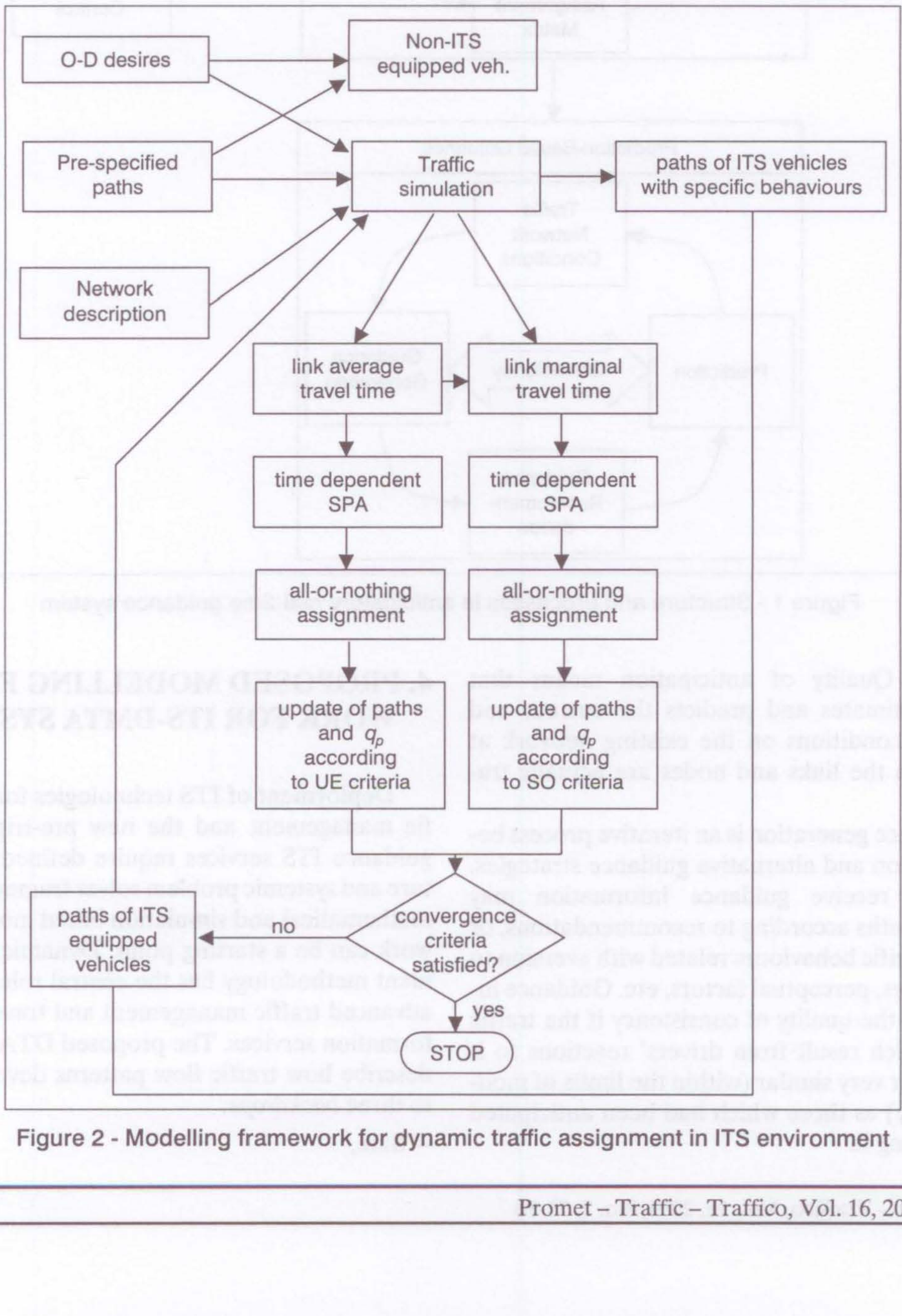

Figure 2 - Modelling framework for dynamic traffic assignment in ITS environment

- consistency checking,
- updating functions,
- resetting functions.

These modules can be integrated using COBRA standards with multiple rolling horizon framework. The DMTA system has to interact with multiple data sources such as:

- loop detectors,
- roadside sensors,
- vehicle probes,
- information service providers,
- police (incident) actions, etc.

5. CONCLUSIONS

While there are various approaches and several models and algorithms for dynamic traffic assignment problems, there is no analytical/mathematical formulation that can solve the actual size networks, i. e. there is no equivalent to the Frank-Wolfe solution algorithm for static problems.

Mathematical programming and optimal control DTA approaches have significant limitations in developing usable models for general networks and ITS applications. The basic requirement is trade between mathematical tractability and traffic realism.

The primary focus of current efforts in dynamic modelling has to be the development of robust and holistic methodological constructs suitable for real-time ITS-oriented problems including time-dependent O-D demand and incidents. Complete a priori knowledge about O-D demand and incidents with system-wide coordination are desirable, but they form obstacles to real-time operability. Effective solution has to be the development of holistic architecture with robust and computationally efficient on-line procedures for generalised traffic network. Local control rules using artificial intelligence techniques and currently available partial information can be used to determine the user routes within the defined area.

Simulation-based dynamic models with traffic simulators (such as DYNASMART) can be used as a part of the search process in holistic ITS problem-solving framework. The choice of spatio-temporal level has significant implications for the real-time computational tractability.

In the future researches the described modelling framework can be associated with general system problem-solving (GSPS) methodological tools. The role of GSPS is essentially the same in the various system sub-problems where systems problem-solving knowledge is used in combination with the traditional disciplines.

IVAN BOŠNJAK, D. Sc.
Fakultet prometnih znanosti
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska
e-mail: bosnjaki@fpz.hr
IBRAHIM JUSUFRANIĆ, D. Sc.
Fakultet saobraćaja i komunikacija
Zmaja od Bosne 8, 71000 Sarajevo, Bosna i Hercegovina
VINKO VIŠNJIĆ, D. Sc.
Fakultet prometnih znanosti
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska

SAŽETAK

PREDLOŽAK MODELIRANJA DINAMIČKE VIŠEKLASNE ASIGNACIJE PROMETA U ITS OKRUŽENJU

Primjena fleksibilnog vođenja prometa, pred-putnih, putnih, rutirajućih i drugih ITS usluga zahtjeva znatna istraživanja prema uspostavljanju cjelovitih metodoloških okvira i pomagala. U ovom radu predložen je i elaboriran predložak modeliranja dinamičke višeklasne asignacije prometa (DMTA) u ITS okruženju. DMTA sustav koristi prometne podatke asocirane s tri "backdrop" varijable: vrijeme, prostor i definirane "klase korisnika". Predložena struktura DMTA sustava uključuje module za procjenu i predikciju izvorišta-odredišta, simulacija realnog stanja, provjeru konzistentnosti, funkcije ažuriranja, funkcije resetiranja. Metodološka pomagala za rješavanje DMTA problema uključuju kombinaciju matematičkog programiranja, simulacije i heurističkih metoda.

KLJUČNE RIJEČI

prometne mreže, inteligentni transportni sustavi, dinamičko modeliranje, informacije vozačima

ABBREVIATIONS

COBRA	(Common Object Request Broker Architecture)
DMTA	(Dynamic Multiclass Traffic Assignment)
DTA	(Dynamic Traffic Assignment)
FIFO	(First-In-First-Out)
GSPS	(General Systems Problem Solver)
ITS	(Intelligent Transport Systems)
O-D	(Origin-Destination)
SPA	(Shortest Path Algorithm)
SO	(System-Optimal)
TCC	(Traffic Control Centre)
TMC	(Traffic Management Center)
UE	(User Equilibrium)
UML	(Unified Modelling Language)

LITERATURE

[1] **Ben-Akiva, M. E.** et al. (1997.). *Development of a Route Guidance Generation System for Real-Time Application*. Proceedings of 8th Int. Symposium on Automatic Control on Transportation Systems. Chania, pp. 433-438.

[2] **Bošnjak, I.** (2003.). *Intelligent Transport systems and Services* (Readings for Postgraduate studies). Faculty of Transport and Traffic Engineering, Zagreb.

[3] **Carey, M.** (1992.). *Nonconvexity of the Dynamic Traffic Assignment Problem*. Transportation Science, Vol. 26, pp. 127-133.

[4] **Daganzo, C. F.** (1995.). *The Cell Transmission Model: A Simple Dynamic Representation of Highway Traffic*. Transportation Research 28 B, No. 4, pp. 269-287.

[5] **Merchant, D. K.** and **G. L. Nemhauser** (1978.). *A Model and an Algorithm for the Dynamic Traffic Assignment Problems*. Transportation Science, Vol. 12, No. 3, pp. 183-199.

[6] **Ran, B.** and **D. Boyce** (1996.). *Modelling Dynamic Transportation Networks*. Springer-Verlag, Berlin.

[7] **Sweeney, L.** and **J. Ravier** (2002.). *Real-Time Traffic Information for Dynamic Route Guidance*. IEEE Vehicular Technology and Society News, Vol. 49, No. 3, pp. 9-13.

[8] **Ziliaskopoulos, A. K.** and **H. S. Mahmassani** (1993.). *A Time-Dependent Shortest Path Algorithm for Real-Time Intelligent Vehicle/Highway Systems*. Transportation Research Record 1408, pp. 94-104.