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Innovative Applications of O.R.

Estimation of urban traffic conditions using an Automatic Vehicle Location (AVL) System

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ABSTRACT

The aim of this paper is to develop an *Information Extension Model* (IEM) which uses location data of bus fleets (AVL data) to estimate road traffic conditions and provide input for implementing control strategies. The IEM consists of three sub-models: the *Link Traffic Condition Model* (LTCM), the *AVL Adaptation Model* (AVLAM) and the *Network Traffic Condition Model* (NTCM). The first provides road traffic conditions as a function of mass-transit traffic conditions in the case of shared lanes, the second provides mass-transit traffic conditions as a function of AVL data, and the last provides road traffic conditions over the whole road network as a function of mass-transit traffic conditions.

The IEM (and its sub-models) were developed and calibrated in the case of real dimension networks and some tests were performed on a trial network. Numerical results show the effectiveness of the proposed method since it allows a reduction in travel demand estimation errors.

1. Introduction

The aim of this paper is to develop a method that uses location data of bus fleets to estimate road traffic conditions and hence provide input data for implementing control strategies. It is widely believed (for instance Shen, 1997; Nozick et al., 1998; Papageorgiou, 2003; Loukopoulos et al., 2005) that in recent decades increased travel demand has led to a rise in congestion especially in urban contexts and that there is a growing need to implement suitable measures to improve traffic conditions. Some of the measures to improve transportation system conditions (see, for instance, Wootton et al., 1995; Dia, 2002; Vianna et al., 2004; Gao and Chabini, 2006) are based on optimal resource management by means of the application of *Intelligent Transportation Systems* (ITS). In this context, amongst others, two groups of tools have been developed to tackle the above problems: *Advanced Traveller Information Systems* (ATIS) and *Advanced Traffic Management Systems* (ATMS).

The purpose of ATIS policies (widely described by Yang and Meng, 2001; Lo and Szeto, 2002) is to provide travellers with system condition information to modify their choices. In this direction, some studies (such as Adbel-Aty et al., 1995) have shown that the variability (uncertainty) of some attributes, such as travel time, can change some user choices. Instead, the ATMS approach (analysed, for instance, by Barceló et al., 1996, 2005; Ioannou, 1997; Hourdakis and Michalopoulos, 2002) is based on optimal management of the transportation (supply) systems through knowledge of the network conditions.

Application of both ITS applications can be schematised by means of an automatic control system (as shown in Fig. 1).

The process is the technical or physical phenomenon to be modelled, such as traffic conditions in urban areas; disturbances are external quantities (such as traffic demand, accidents, etc.) whose values cannot be manipulated but in some cases may be directly measurable via appropriate devices; measurements are provided by sensors that are tools (TV cameras, probe vehicles, loop detectors, etc.) that measure some performances of the system; data processing is the elaboration of the sensor data for generating transportation information that is the control strategy input; the control strategy is a task that, by analysing sensor data and process goals (such as minimisation of total travel time), yields inputs for achieving the pre-specified goals; inputs are information that influence the analysed process by means of some devices indicated as actuators (such as traffic lights, variable message signs, etc); finally, outputs are the process performances generated by control strategy application.

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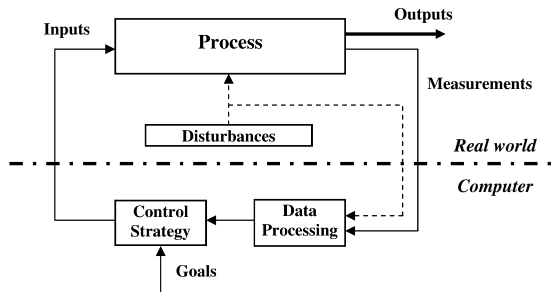

Fig. 1. Basic elements of an automatic control system (Papageorgiou, 1998).

Importantly, application of an automatic control system in a transportation context has to take into account that the information is not always available anywhere and any time, and a simple cause-effect connection (such as a closed-form formula) between actuator inputs and network performance responses cannot be developed as widely shown in the literature (see, for instance, Cantarella, 1997; Cascetta, 2001). Hence it is necessary to develop an *Information Extension Model* (IEM) for estimating the non-available information and a *System Simulation Model* (SSM) for modelling the complex cause-effect connection.

The aim of this paper is to develop an Information Extender Model, which can be adopted for extending sensor information. Generally, as asserted by Kirk and Fagan (2007), these devices can be classified into *Infrastructure Based Systems* (IBS) and *Non-infrastructure Based Systems* (NBS). In the first class there are TV cameras, loop detectors, etc. In general, these systems are located at one or more points of road segments and provide traffic information only in the neighbourhoods (for instance road segments) of those points. The other class contains probe vehicles, mobile devices, etc. In this case, the survey systems are located on vehicles and provide their location at each moment. Variation in the position of each monitored vehicle can be used to estimate vehicle performances and hence traffic conditions.

The first American and European studies on NBS applications were developed in the 1990s (König et al., 1997; Larima, 1997; Jochem et al., 1998; Gorys and Keen, 1999): the SOCRATES project (1988–1994), the EUROSCOUT project (1989–1991), the ADVANCE project (1992–1994) and the VERDI project (1996–1997).

The main advantage of using NBS is the direct survey of traffic conditions, such as vehicle speed at any time or monitored vehicle travel time. In this case, information can be estimated by position variation without using any models or formulas; instead, IBS nearly always require the use of formulas or models. Moreover, NBS could provide their information in an extended area (the area where probe vehicles travel), while the other systems provide them only at the points of road segments where they are located.

A major disadvantage of NBS is the required size of the fleet in order to obtain sufficiently precise estimates of traffic conditions: a large number of probe vehicles are necessary to achieve good statistical reliability of network information (Srinivasan and Jovanis, 1996). For fleet size requirements, these survey systems could entail high investment and management costs. Moreover, although greater quality in parameter estimation is supplied by a large number of probe vehicles, such vehicles, which are not present in usual traffic conditions, could modify the values of the surveyed variables.

The use of bus or taxi fleets can help to solve the above problems: fleet size is large where bus or taxi services are widely used, for instance in urban contexts. Indeed, in this case many investment and management costs are supported by performing bus or taxi services that are independent of survey tasks. Moreover, if the fleet is provided with an AVL system for giving user information, such as waiting time at bus stops, the only cost incurred is data elaboration for estimating traffic conditions. Finally, as fleet services are independent of survey tasks, the use of bus or taxi fleets does not modify traffic conditions.

At present, in many cities there are fleets provided with an AVL system used only for monitoring (and sometimes improving) services. However, the usefulness of the proposed approach is linked to the fact that surveyed AVL data also contain traffic condition information implicitly. Hence there have been several studies based on taxis or buses (for instance, Horbury, 1999, Hall and Vyas, 2000; Cathey and Dailey, 2002, 2003; Bertini and Tantiyanugulchai, 2004 ; Yoo et al., 2005). Obviously, AVL data are useful for our purpose only if these vehicles do not travel in exclusive lanes; hence if, for instance, a bus has a mixed path (with part in exclusive lanes and part in shared lanes), only shared-lane data can be utilised for estimating road traffic conditions. Thus, the IEM proposed in this paper is developed to process (mass-transit) AVL data in the case of shared lanes and provide a spatial extension of surveyed information provided by NBS systems.

The paper is organised as follows: in Section 2 the notation and terminology adopted in the paper are summarised; Section 3 describes the proposed IEM that can be adopted to estimate road traffic conditions by means of bus AVL data; the first application of the proposed model is reported in Section 4; Section 5 summarises conclusions and research prospects. Finally, Appendices A and B give a detailed description, respectively, of the virtual laboratory approach used for increasing the number of surveyed data and the proposed solution algorithm.

2. Notation and terminology

In this section we report in alphabetical order the notation and terminology adopted in the paper. In particular, bold terms represent vectors or matrices.

a_{acc} and a_{dec} are the maximum acceleration and deceleration coefficients of the buses considered;
$alight_i$ and $board_i$ are the numbers of alighting and boarding passengers for each run at the ith bus stop;
Cap_l is the capacity of link l;
Ch_l is the level of circulation hindrance due to pedestrian and parking movements on a scale [0,1];
$\mathbf{d}^b$ and $\mathbf{d}^c$ are respectively the mass-transit and the road travel demand vectors;