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Multi-period location of flow intercepting portable facilities of an intelligent transportation system

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A B S T R A C T

Intelligent transportation systems are of great importance in urban traffic management. In this context variable message signs (VMS) play a major role in providing drivers with useful information during their trips.

In this paper we consider the problem of finding the optimal location of a set of portable VMS on an urban network where flow patterns change during a time horizon.

We propose two original solving approaches based on flow intercepting facility location ILP models.

The paper presents an application of the proposed approaches to real-like test networks and discusses the results obtained providing some indications on their practical applications.

1. Introduction

In recent years intelligent transportation systems (ITS) based on innovative information and communication technologies have been increasingly used in traffic management and control, environmental protection, city logistics and urban security. In this context advanced traveler information systems play a major role and a significant contribution to this role is made by variable message signs (VMS) which constitute one of the most important components of an ITS ([28,35], ERTICO – ITS Europe: www.ertico.com).

Different classifications of VMS have been proposed, depending on their technology, activation mechanism and kind of information displayed. Generally speaking they are devices able to display real-time messages for network users with the aim of providing drivers with useful information and instructions during their trips. Most VMS consist of two elements, a graphic image (pictogram) and an alphanumeric text to be displayed. They can be managed both remotely and on field. The messages must be intelligible, incisive and concise so that they can be easily understood without being a source of distraction. They may be either pre-recorded or created in real time, if necessary.

VMS messages convey different kinds of information to road users related to: driving suggestions and speed recommendation; advisable paths and time needed to reach a certain destination; congestion levels at nodes that are critical during rush hours; timing and location of special events; services available on the network (i.e. refueling stations, parking areas and number of available lots); state of the network (road closures and road construction/maintenance activity or work-in-progress); unusual or unexpected events (i.e. incidents, accidentdisruptions or public demonstrations); modal choices (recommended park and ride areas and/or public transport in the vicinity); urban area protection (restricted zones, pedestrian areas, limited traffic zones or limited parking zones); route diversion (whether voluntary or mandatory) with instructions about alternative routes which allow the flow equilibrium on the network to be re-established; weather conditions; law enforcement; incident management; public safety and security.

Over the years, VMS have been explored in several areas of interest and from different viewpoints. Here we have cited only a few of the most recent contributions. The important issue of route guidance and route choice is discussed in Refs. [9,11]. Readability and comprehension of displayed messages are treated in Refs. [8,32]. Contributions about evaluation of VMS benefits and economic impact on travel times and other cost categories may be found in Refs. [23,26]. The issue of driver response is dealt with in Refs. [19,24,31,36]. Finally lane use balancing is examined in Ref. [30].

From the list of potential applications and theoretical/empirical contributions, the usefulness of VMS is evident: they are conceived to impact on the behavior of drivers in order to improve traffic

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dynamics. For this reason they constitute a remarkable tool for collective route guidance, providing drivers with instructions and suggestions aimed at reducing the traffic congestion level and preserving user safety and awareness; for example in the case of unexpected events that alter the normal state of the network, with evident social and economic benefits. Indeed, the main impact of the VMS is on traffic efficiency, achieved as a result of speed recommendations and congestion reduction, and environmental benefits, achieved as a result of reduced fuel consumption and emissions.

Until now they have been widely used on highways and have recently also found many applications on urban networks. This is confirmed by many real-life applications. For example, during the Winter Olympics in Turin 2006, VMS were a key element in the traffic management strategy. In Barcelona VMS are used for lane multi-usage over different time periods of the day, with the aim of reducing the congestion in the commercial city center, leading to a travel time reduction of 12%–15%. In Paris, SIRIUS (Information System for an Understandable Network for the User) uses more than 150 VMS, located before highway junctions or road network exits.

ITS technologies play a remarkable role in local government, for both technicians and policy decision makers, as witnessed by the specific actions undertaken by many road traffic authorities. Here we have provided just a few examples. The New York State Thruway Authority defines the guidelines for effective VMS usage, with the purpose of providing directions to assist Authority personnel, contractors, concessionaires and regional traffic management centers, who are responsible for VMS operation and message design. In the UK, in response to the European Union Directive 2010/40/EU, the Department for Transport published a report on “Intelligent Transport Systems in the UK”, describing the current situation in the country: a large number of VMS are placed across the road network (about 2800 VMS on the Strategic Road Network in England) and a plan for future installations across the UK is outlined. In 2009 the Conference of European Directors of Roads (CEDR) published a report entitled “VMS harmonization in Europe”, aimed at monitoring the main developments across Europe as well as understanding the issues arising from and the obstacles to VMS harmonization and interoperability.

Taking into account what has been said so far in terms of advantages provided by the VMS for the traffic network management, great attention has to be paid to effective VMS location on a road network.

This problem has been widely dealt with in literature. The approaches used are generally based on empirical evidence and/or experimental tests, but there are also many methodological contributions to the problem modeling and algorithmic solutions. We have cited the most recent among them here. In Ref. [22] the authors use a method, based on driving simulation experiments, to determine VMS locations for safe exiting at freeway off-ramp; in Ref. [12] a natural algorithm for VMS location is proposed; in Ref. [37] the authors develop a study on the optimization of VMS location, based on drivers' guidance compliance behaviors; in Ref. [16] the evaluation of a VMS location scheme effectiveness, in parking guidance system, is discussed; in Ref. [21] the authors present an incremental assignment model for VMS parking location problems; and finally, in Ref. [18] an algorithm for VMS location on an urban network, considering road attributions, is proposed.

For an effective VMS location it is also important to take into account flow pattern changes that may occur on urban networks during the day, in terms of flow values (peak or off-peak periods) and/or in terms of origin/destination travel demands, for trips towards and away from the city center. In other words the VMS location must be adapted to the flow variation in the areas that are candidate sites for their placement.

To this end it is necessary to take into account the differences between fixed and mobile VMS. Fixed VMS are huge gantries installed on network links that require a considerable economic investment. Once deployed they cannot be moved to other points of the network. They may not be in keeping with a city's image, especially in areas with historic buildings and monuments. They are therefore generally installed along highways or at the entrance to urban areas, or at least outside city centers. By contrast, portable VMS, which are the focus of this paper, are relatively small, designed to be moved from one location to another, and are used for a certain period of time. This makes them environmental-friendly, easy to handle and very flexible. For the above reasons they can be located on a highway or on the main roads of an urban area.

Due to their characteristics, fixed VMS have to be placed in points of the network where the flow level and the need to inform users do not change during the day. Portable VMS seem to be more suitable in all those cases where the flow pattern may vary during the day. Thanks to their features, they can be used in all situations caused by unusual traffic variations or by accidents and other special events, adapting their placement to the flow pattern variation induced by these events.

Their placement can therefore be performed as a multi-period operation or, if necessary in the case of unusual and significant events that change the network conditions, in a strictly dynamic way.

An intuitive and effective criterion for the portable VMS location is their capability to intercept drivers who have to be informed. For this reason the formulation of the flow intercepting facility location problem (*FIFLP*) can be used, aimed at either maximizing the intercepted flow with a pre-fixed number of VMS or minimizing the number of VMS required to intercept a pre-fixed amount of flow. As the reader will see in the following section, the literature about *FIFLP* is well established, but, to the best of authors' knowledge, all the contributions concern the single-period case (referred to in the following as *SP-FIFLP*), whereas the multi-period case (*MP-FIFLP*) has never been dealt with in literature. This work is aimed at filling this gap.

Indeed in the following we will define a tactical and operational decision problem, which could be expressed as multi-period flow intercepting facility location problem (*MP-FIFLP*). We will tackle it by two different integer linear programming (*ILP*) based approaches, a *sequential* and an *integrated* one.

Being k the number of periods taken into account, the sequential approach is based on the decomposition of the *MP-FIFLP* in k single-period *FIFLP* and $k-1$ assignment problems of *facilities* to *places*, devoted to minimizing the facility re-location cost.

Original *ILP* formulations are presented for the integrated approach, where the previous two problems are solved at the same time, with several kind of objective functions, taking into account all the information about path flows in the different periods of the time horizon under investigation.

The paper is structured as follows: in Section 2 we recall the *FIFLP*, its basic assumptions and related ILP models; in Section 3 we focus on the *MP-FIFLP* and on the two proposed approaches; and finally, in Section 4 we test the proposed formulations on real-like test networks and discuss the results obtained providing indications about their practical applications.

2. Flow intercepting facility location problems (FIFLP)

As discussed above, in this work the problem of dynamically locating portable VMS on a network is approached as a *MP-FIFLP*. In