Transportation Research Part C 64 (2016) 164–182

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Personalized real-time traffic information provision: Agent-based optimization model and solution framework

Jiaqi Ma [a], Brian L. Smith [b], Xuesong Zhou [c,*]

[a] Leidos, Inc., 11251 Roger Bacon Drive, Reston, VA 20190, USA
[b] Department of Civil and Environmental Engineering, University of Virginia, Thornton Hall, 351 McCormick Road, Charlottesville, VA 22904, USA
[c] School of Sustainable Engineering and the Built Environment, Arizona State University, Tempe, AZ 85287, USA

A R T I C L E I N F O

Article history:
Received 16 May 2014
Received in revised form 3 March 2015
Accepted 3 March 2015
Available online 21 March 2015

Keywords:
Agent-based modeling
Network modeling
Traveler information provision
Dynamic traffic management

A B S T R A C T

The advancement of information and communication technology allows the use of more sophisticated information provision strategies for real-time congested traffic management in a congested network. This paper proposes an agent-based optimization modeling framework to provide personalized traffic information for heterogeneous travelers. Based on a space–time network, a time-dependent link flow based integer programming model is first formulated to optimize various information strategies, including elements of where and when to provide the information, to whom the information is given, and what alternative route information should be suggested. The analytical model can be solved efficiently using off-the-shelf commercial solvers for small-scale network. A Lagrangian Relaxation-based heuristic solution approach is developed for medium to large networks via the use of a mesoscopic dynamic traffic simulator.

1. Introduction

Advanced Traveler Information Systems (ATIS) aim to enable drivers and commuters to adapt to changing traffic conditions and make informed routing decisions. In particular, Dynamic Message signs (DMS/VMS) and Highway Advisory Radio (HAR), as well as 511 systems and emerging social media such as twitter, are widely used to deliver information on major traffic events (e.g., incidents, congestion) by public agencies, however, they are usually spatially and/or temporally limited, and constrained in the amount of information delivered. Meanwhile, private-sector information provision vendors can provide the user optimal but uncoordinated routes, through in-vehicle route guidance system, to equipped drivers.

Many empirical studies (e.g., Peeta et al., 2000) reveal that drivers prefer detailed traffic information, including incident/congestion location, expected delay and available alternative routes, and more detailed information can yield higher diversion rates. The proliferation of mobile communication technology and devices such as smartphones and on-board units of connected vehicles provide an accessible and cost-effective platform for public-sector Traffic Operation Centers to deliver location-based and personalized traveler information that is timelier and seamlessly integrated with system-wide transportation management goals (e.g., Williams, 2010). The emergence of social networks has enabled direct access to people's mobility patterns and the ability to interact with them, thus presenting an opportunity to incentivize behavior change (either through a social group or the social network). Under major incident or severe weather conditions, a systematical integration of (1)

* Corresponding author. Tel.: +1 480 9655827.
E-mail addresses: Jiaqi.ma@leidos.com (J. Ma), briansmith@virginia.edu (B.L. Smith), xzhou74@asu.edu (X. Zhou).

http://dx.doi.org/10.1016/j.trc.2015.03.004
0968-090X/

publishing area-wide or corridor-level information through DMS and HAR and (2) delivering personalized guidance to individual drivers can greatly help transportation system operators not only reduce the cost and complexity of maintaining ATIS infrastructure but also effectively use bi-directional communications to manage vehicular networks.

All of these advances have created the need for new modeling approaches (in particular to encompass the new data), new estimation, inference and filtering methods and are leading to the development of new paradigms for control. This paper aims to develop an agent based optimization framework to use personalized information provision (PIP) to reduce system-wide delay. We are interested in addressing many practically important but theoretically challenging questions regarding a successful PIP deployment under non-recurring congestion conditions such as: when and where to inform travelers, which drivers to be informed and what alternative route to be suggested for different drivers.

2. Literature review

2.1. Modeling of traveler information provision

As the most common approach of traffic management, the use of VMS to manage real-time traffic have been studied by many researchers from different aspects. Peeta et al. (2000) conducted a stated preference survey along a freeway corridor and examined various driver diversion behavior with different VMS messages contents, including location of accident, expected delay, detour strategy and various combinations of the above. Their study shows that the maximum of willingness to divert occurs when all three information contents are provided. A later study (Peeta and Gedela, 2001) incorporated the driver response in a three-step VMS control heuristic, including activation, message display and update. The required diversion rate is determined by the different system-optimal assignment proportions (prepared offline using mean OD demand) and multiple user class situation (no-information user and real-time information user). Xu et al. (2012) incorporated an aggregated driver behavior model with attributes that can be obtained on-line (traffic message, traffic flow, weather and incident). The behavior model is calibrated on-line and was used in a feedback control to decide optimal traffic information. These studies focused on "optimal" VMS contents considering entire passing vehicles as a whole, while not explicitly considering which drivers or what proportion of them need to or should receive real time information.

The VMS location problem is closely related to the information provision problem in this paper. Since VMS is a fixed asset requiring a large amount of capital investment, most of the studies were to determine where to install the VMS so that the long-term system performance was optimal. A study by Abbas and McCoy (1999) sought to determine the locations for VMS to maximize potential benefits, defined as the sum of changes in delay and accidents on the freeway upstream and downstream of the incident and those on the alternative routes. The reduction in delay as a result of diversion was computed by the demand-capacity analysis procedure in the Highway Capacity Manual. Huynh et al. (2003) and Chiu and Huynh (2007) proposed novel dynamic network flow optimization models in which a set of the VMS locations are selected in the planning stage to minimize the expected network travel time given possible random incident realizations. Based on a simulation based Dynamic Traffic Assignment (DTA) framework, greedy heuristics and Tabu search algorithms are developed to find a near-optimal solution from a limited number of candidate links due to the exponentially increasing amount of combinations.

In the broad field of real-time traffic management modeling there are multiple subcategories that focus on vehicular flow management, for example simulation-based traffic assignment models, reactive feedback control, mathematical programming and dynamic programming. A dynamic programming approach (e.g., Charbonnier et al., 1991) produces optimal solutions and many insights because of its analytical nature, while it can only be applied to small size problems due to the huge computational burden associated with the large number of required modeling states in the formulation. The simulation-based approach can better describe complex traffic flow dynamics required for real-world traffic flow control applications. A number of studies along this line (Mahmassani and Jayakrishnan, 1999; Paz and Peeta, 2009; Bolelli et al., 1991; Hawas and Mahmassani, 1995; Hawas, 2012) strike to seamlessly integrate DTA simulators into general optimization or feedback control frameworks. The mathematical programming approach has received continuous attention from the research community, as its analytical nature offers many insights into the problem. Various optimization models have been proposed in the literature to produce simple and compact formulations, such as linear programming, so that the resulting problems are easy to solve by standard optimization solvers. On the other hand, dynamic network structures introduced by DTA optimization models are still quite complex and most of the existing models targets only simple test networks, such as single destination cell transition model based formulation by Ziliaskopoulos (2000). It should be also remarked that most of the optimization models in the literature are based on time-dependent origin–destination flow, with a typical departure time interval of 5 or 15 min. This flow-based modeling paradigm is adequate for finding the optimal dynamic system through flow-based traffic management strategies such as signal controls or aggregated information provision. In contrast, the PIP represents a fundamentally new approach for real-time ATIS system modeling under ubiquitous communication. This allows traffic system operators to fully optimize and coordinate individuals' trip plans according to the personal value of time, allowable budgets for congestion tolling and willingness to taking detours.

2.2. Agent-based modeling and optimization

Closely related to the PIP problem under consideration in this paper, the agent-based modeling approach has received increasing attention by transportation researchers to capture personal characteristics in traveler's daily activities, such as