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An optimization method for sustainable traffic control in urban areas

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ABSTRACT

The optimization of traffic signalization in urban areas is formulated as a problem of finding the cycle length, the green times and the offset of traffic signals that minimize an objective function of performance indices. Typical approaches to this optimization problem include the maximization of traffic throughput or the minimization of vehicles' delays, number of stops, fuel consumption, etc. Dynamic Traffic Assignment (DTA) models are widely used for online and offline applications for efficient deployment of traffic control strategies and the evaluation of traffic management schemes and policies. We propose an optimization method for combining dynamic traffic assignment and network control by minimizing the risk of potential loss induced to travelers by exceeding their budgeted travel time as a result of deployed traffic signal settings, using the Conditional Value-at-Risk model. The proposed methodology can be easily implemented by researchers or practitioners to evaluate their alternative strategies and aid them to choose the alternative with less potential risk. The traffic signal optimization procedure is implemented in TRANSYT-7F and the dynamic propagation and route choice of vehicles is simulated with a mesoscopic dynamic traffic assignment tool (DTALite) with fixed temporal demand and network characteristics. The proposed approach is applied to a reference test network used by many researchers for verification purposes. Numerical experiments provide evidence of the advantages of this optimization method with respect to conventional optimization techniques. The overall benefit to the performance of the network is evaluated with a Conditional Value-at-Risk Analysis where the optimal solution is the one presenting the least risk for 'guaranteed' total travel times.

1. Introduction

The evolution of Intelligence Transportation Systems (ITS) and Advanced Traveler Information Systems (ATIS) has led to the increasing use of Dynamic Traffic Assignment (DTA) models in a variety of on-line, off-line applications and incorporated in transportation planning studies (TRB, 2011). DTA modelling, introduced in the early 1970s (Yagar, 1971; Robillard, 1974; Merchant and Nemhauser, 1978), is the temporal extension and disaggregation of the classical static assignment problem, which assumes steady traffic conditions over the study period, in order to better capture realistic traffic conditions. Therefore, the aim of a DTA model is to determine the network flow patterns given Origin–Destination (O–D) demand, network structure and link performance functions incorporating time dependencies in both the supply and the demand

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attributes (Peeta and Yang, 2003). Extensive review of the DTA models and the formulation, characteristics, solution methodologies, limitations and practical applications are provided by Peeta and Ziliaskopoulos (2001), Boyce et al. (2001), TRB (2011) and FHWA (2012).

DTA models are categorized in literature into four main groups: mathematical programming, optimal control, variational inequality and simulation based. Another classification of DTA models, which takes into account the level of detail and traffic representation, categorizes the models into macroscopic, mesoscopic and microscopic. In this paper the case of a simulated-based mesoscopic traffic simulator is considered. Some of the frequently used DTA mesoscopic models include CONTRAM (Taylor, 1990), DYNASMART (Mahmassani, 2001), DYNAMIT (Ben-Akiva et al., 2001), METROPOLIS (Palma and Marchal, 1998), DYNAMEQ (Florian et al., 2008), VISTA (Ziliaskopoulos and Waller, 2000). Significant on-going research is performed over the past years in the field of Open-Source DTA software and traffic flow simulation engines, such as DTALite (Zhou and Lu, 2013), DynusT (Chiu and Nava, 2013), TRANSIMS (TRANSIMS, 2013), MITSIM (Azevedo et al., 2013), SUMO (Behrisch et al., 2013). Also Tamminga et al. (2012) proposed OpenTraffic (Forrester and Moore, 2013), a simulation platform which enables the collaboration of academics from different geographic areas and disciplines to work together.

The implementation of a DTA model on a large-scale network causes important challenges to the modeling procedure, such as the manipulation of network and demand data, the modeling of turning movements, the efficient computation of link travel times and the handling of complex path data (Ziliaskopoulos et al., 2004). The evaluation, development and optimization of Intelligent Transport Systems with regard to the successful deployment of traffic control strategies presume stable and robust network states. The development, application and optimization of control strategies and operation policies are based on the estimation of time dependent traffic states which depict the network efficiency through time evolution aiming to its enhancement. Comprehensive review of road traffic control strategies can be found in Papageorgiou et al. (2003). The optimization methods are based, traditionally, on fixed traffic flows, and on the other hand assignment methods for evaluating traffic conditions assume fixed traffic control. In both cases a level of inconsistency exists, since traffic control and traffic flows are highly interdependent especially in congested urban networks. Therefore the combination of DTA and traffic control models is necessary for eliminating of such inconsistencies and for enhancing both the evaluation of traffic conditions and the optimization of traffic control in urban networks.

The combined user equilibrium (UE) traffic assignment and signal optimization problem is defined as the optimization of traffic signals while users choose their routes according to UE principles (Maher and Zhang, 1999). The definition of equilibrium network traffic signal settings, which takes into consideration in the optimization of traffic signals the users' route choices, has been firstly addressed by Allsop (1974), as an iterative procedure for the UE static assignment problem in a pre-timed signal controlled network. Charlesworth (1977) implemented an iterative procedure in order to obtain mutually consistent traffic assignment and signal settings with the use of TRANSYT modeling software for optimizing the signal settings. Smith (1979, 1981) put forward the conditions for existence, uniqueness and stability of equilibrium in the case of interaction between signal settings and users' route choice. Yang and Yagar (1995) formulated this problem in saturated networks as a bi-level approach. Ceylan and Bell (2004) presented a bi-level approach, where in the upper level a genetic algorithm approach is used to globally optimize signal timings with TRANSYT, while in the lower level the equilibrium link flows are estimated based on the stochastic effects of users' route choice. Chiou (2005) presented a bi-level approach for jointly optimizing the area traffic control with TRANSYT and network flow on the basis of an algorithm for concurrent flow.

However the above mentioned research efforts were focused on static assignment. Ghali and Smith (1993) considered the combination of dynamic assignment and traffic control optimization problem using CONTRAM. Gartner and Stamatiadis (1997) presented the conceptual framework for the combined solution of DTA and signal control. Abdelfatah and Mahmassani (1998) proposed a solution algorithm for the combined dynamic system optimum and signal control. Chang and Sun (2004) proposed a dynamic method for controlling oversaturated traffic signal network using a bang-bang-like model for the oversaturated intersections and TRANSYT for the undersaturated intersections. Lian and Gao (2005) presented a generalized bi-level programming model for combining DTA and traffic signal control for determining equilibrium queuing delays on saturated links for dynamic network signal control satisfying the FIFO rule with a chaotic optimal algorithm. Koehler and Strehler (2012) proposed a combined optimization approach for simultaneous dynamic traffic assignment and signal control with a cyclically time-expanded model. Varia et al. (2013) presented a joint optimization of signal setting parameters and dynamic user equilibrium traffic assignment for the congested urban networks, where genetic algorithms were applied for obtaining optimal signal settings and path flow distribution for the Dynamic User Equilibrium (DUE) condition.

Most of the overviewed approaches adopted a bi-level approach instead of a joint optimization approach to tackle the problem of combined dynamic traffic assignment and optimization of traffic control. In a bi-level approach, signal optimization is the upper level problem and DUE is the lower level problem. The main drawbacks of this approach is the computational time and resources and the fact that the derived solution may represent a local optimum solution, and not global, since heuristic strategies are non-convex and therefore cannot lead to analytical optimization approaches.

The analysis period and the selected intervals used in the combined optimization process are important variables to the optimization strategy. If traffic fluctuations during the analysis period are minor (in either oversaturated or undersaturated networks), traffic control optimization will closely converge to a global optimum. However, if the demand profile presents significant variations between intervals of the analysis period, global optimum cannot be guaranteed. Especially for oversaturated networks, the selected time intervals are key aspects for the optimization procedure, which has as objective the improvement of the overall network performance throughout the analysis period. In the case of fixed traffic control for a

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