Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 6 (2015) 101 – 110

Transportation Research Procedia

www.elsevier.com/locate/procedia

4th International Symposium of Transport Simulation-ISTS'14, 1-4 June 2014, Corsica, France

Reducing gridlock probabilities via simulation-based signal control

Carolina Osorio[a]*, Xiao Chen[b], Michael Marsico[c], Mohamad Talas[c], Jingqin Gao[c], Shitao Zhang[c]

[a]*Massachusetts Institute of Technology*
[b]*University of Coimbra*
[c]*New York City Department of Transportation*

Abstract

This paper studies a fixed-time signal control problem for a highly congested urban network with multimodal traffic, numerous signalized intersections, short links and a grid-type topology. The design of signal plans that indeed improve traffic conditions for a network with such complex traffic dynamics is a real challenge. In this paper, we propose a simulation-based approach. We use a simulation-based optimization algorithm to identify a signal plan for an area in eastern Manhattan (New York City, USA), where spillbacks frequently occur and impact the flows on major arterials as well as on the access/ egress to the highly congested Queensboro Bridge. We consider a signal control problem where the objective function explicitly considers queue-length information. We compare the performance of the proposed signal plan to that of the prevailing signal plan in the field. The proposed plan indeed improves traffic conditions as measured by a variety of performance metrics.

Selection and/or peer-review under responsibility of the Organizing Committee of ISTS'14

Keywords: queue-length; spillbak, simulation-based optimization, signal control, highly congested urban networks

1. Introduction

For uncongested networks, there is no significant queue formulation, but for congested networks, demand typically approaches or even exceeds capacity, leading to the build-up of vehicular queues. Thus, the design of signal plans may differ for uncongested versus congested scenarios. This paper focuses on the design of traffic signal plans for congested networks with complex traffic dynamics. In particular, we consider urban networks with, high levels of congestion, multimodal traffic, numerous signalized intersections, short links and a grid-type topology.

Selection and/or peer-review under responsibility of the Organizing Committee of ISTS'14
doi:10.1016/j.trpro.2015.03.009

Short links allow for congestion to spatially propagate quickly, leading to complex between-link dependencies. For instance, a link that spillbacks will impact the performance of its upstream links. The grid-type topology leads to high-dimensional route alternatives, and may lead to complex behavior of travelers as they react to the formation and propagation of congestion. Congested network with both short links and grid-type topologies are highly prone to the occurrence of spillbacks. The spatial propagation of congestion in the form of vehicular spillbacks may have major impacts in the vicinity of major arterials or on/off ramps of freeways. This is the case of the network studied in this paper.

Past work that focus on signal control while considering the occurrence, dynamics and impacts of spillbacks and gridlocks, include [1, 2, 3, 4]. Detailed reviews of queue management in the context of signal control are given, for instance, in [5] and in [6].

In this work, we consider a stochastic simulation-based approach to the design of signal plans for highly congested, multimodal urban networks with grid-type topologies. Given the complexity of traffic dynamics and the complexity of demand-supply interactions in such networks (e.g., driver behavior, numerous transit travel options, pedestrian behavior), the use of detailed traffic simulators has received much attention for both the design and the evaluation of various traffic management strategies.

2. Methodology

2.1. Simulation-based optimization framework

In this work, we consider the use of a calibrated microscopic traffic simulator. These simulators embed the most detailed demand and supply models. They represent individual vehicles, individual travellers, and describe how each of these travellers make decisions (e.g., travel mode, departure time, route, lane-changing). They also embed detailed supply models (e.g., detailed representation of signal plans, of public transport priorities). We use the simulator to study a signal control problem that mitigates the occurrence, length and duration of vehicular-queues and spillbacks.

A general simulation-based signal control problem can be formulated as follows:

$$min_{x\in\Omega} f(x) = E[F(x,y;p)], \tag{1}$$

where the decision vector x represents the signal control variables (e.g., green times), and the objective function is the expected function of a stochastic network performance metric F (e.g., link speeds, trip travel time), which depends on x as well as on other endogenous simulation variables y (e.g., link flow capacities, route choice probabilities) and exogenous (i.e., fixed) simulation parameters p (e.g., dynamic origin-destination matrices, network topology, transit network). The feasible region Ω is typically a set of analytical differentiable constraints and bound constraints. The main challenge in addressing such a problem is that there is no closed-form expression available for $f(x)$, it can only be estimated via stochastic simulation. Additionally, an accurate estimation involves running numerous simulation replications and is hence computationally costly to obtain.

Traditional simulation-based optimization (SO) algorithms are general-purpose optimization algorithms that treat the microscopic simulator as a black-box, using no structural information about the underlying transportation problem. Hence, they require a large number of simulation runs in order to identify signal plans with improved performance. They are computationally inefficient techniques, and are of little interest for practitioners.

In this paper, we use a simulation-based optimization (SO) algorithm that is computationally efficient. We use the recently proposed algorithm [7], which is designed for continuous generally constrained urban transportation problems. It is an SO metamodel approach that achieves computational efficiency by combining information from the simulator with information from a macroscopic analytical and differentiable traffic model. The latter provides analytical structural information to the SO algorithm. The macroscopic model used is based on finite (space) capacity queueing network theory. It provides a probabilistic description of network performance. For details