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A path marginal cost approximation algorithm for system optimal quasi-dynamic traffic assignment☆

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ABSTRACT

This study introduces an efficient path-based System-Optimal Quasi-Dynamic Traffic Assignment (SOQDTA) framework that benefits from the computational efficiency of static traffic assignment models, yet captures the realism of traffic flow, with less complexity and a lower computational burden, compared to dynamic traffic assignment models.

To solve the proposed SOQDTA problem, we have developed a novel Path Marginal Cost (PMC) approximation algorithm, based on a Quasi-Dynamic Network Loading (QDNL) procedure (Bliemer et al., 2014), that incorporates a first order node model, and thus produces realistic path travel times consistent with queuing theory, and similar to those of dynamic network loading models, but at a lower computational cost. The model considers capacity constrained static flows, residual vertical/point queues and no spillback.

The proposed SOQDTA model is applied to the test network of Sioux Falls and is demonstrated to result in system optimal traffic flow patterns that improve total system travel times compared to the user equilibrium solution. In the case study experiment, the convergence of the algorithm is demonstrated using a relative gap function. A sensitivity analysis is performed to realize the impact of perturbation size on the solution quality, and a discussion is presented on the selection of perturbation size for general network applications.

1. Introduction

System optimal (SO) traffic assignment models belong to the class of transportation network modelling problems and have various applications in traffic management. These applications range from recurrent traffic management practices, such as congestion pricing, and traffic control/information systems, to non-recurrent traffic management practices, such as Incident Traffic Management (ITM) and evacuation scenarios. With recent advancements in information and communication technologies, vehicle automation (Autonomous Vehicles) and vehicle/infrastructure connectivity (Connected Vehicles), unprecedented possibilities emerge for communicating and enforcing advanced traffic routing directions for efficient utilization of existing traffic network capacities. Therefore, the task of finding optimal traffic directions becomes more essential, as the required technologies will be available to facilitate the implementation and enforcement of optimal directions, regardless of possible complexities. The research reported in this paper

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studies and presents a method for finding efficient traffic directions within reasonable computational times, to be applied to real-time decision making scenarios.

SO and user optimal (user equilibrium – UE) traffic assignment problems, have been widely studied under both static and dynamic traffic flow assumptions. Despite the growing interest in the development and application of dynamic traffic assignment (DTA) models, static traffic assignment (STA) models are still widely used, particularly in strategic transportation planning, due to their higher efficiency and scalability, and lower computational complexity. The computational efficiency of a traffic assignment model becomes even more crucial in real-time decision making applications such as emergency evacuations and incident management, compared to long-term strategic transportation planning applications.

In traffic assignment, whether static or dynamic, the assumptions regarding the propagation of flow in the network (network loading) highly affect the model outputs. Therefore, besides computational efficiency, the ability of an assignment model in realistically capturing traffic flow propagation in the network plays a critical role in determining the quality of solution outputs.

In classic STA models, no link capacity constraints are presumed and the impact of high link flows are only captured through increased link travel times. Therefore, there have been many efforts in the literature to improve the precision and realism of STA models to generate feasible and more accurate traffic flow patterns and travel times, whilst taking advantage of their high computational tractability. Research along this path has led to a class of assignment models where link capacity constraints and/or residual queues are incorporated into static traffic assignment. In the literature, capacity constrained static models with residual queues are referred to as Quasi-Dynamic Traffic Assignment (QDTA) models.

A relatively recent study by Bliemer et al. (2014) has introduced an efficient path-based quasi-dynamic traffic assignment approach to alleviate the existing issues with the current capacity constrained static models. Their model considers static but capacity-constrained flows with residual vertical/point queues and no queue spillback. They have incorporated a first order node model in their Quasi-Dynamic Network Loading (QDNL) procedure, to compute actual turn flows at nodes as well as residual point queues upstream of bottlenecks, which improve the accuracy of path travel time estimations. They used their proposed QDNL method to solve a path-based stochastic UE problem for general network settings. Such QDNL procedures, which generate reliable traffic flow patterns at a relatively low computational cost, can also be utilized to define and efficiently solve a path-based SO Quasi-Dynamic Traffic Assignment (SOQDTA) problem. A SOQDTA model can generate practical solutions at a lower computational cost compared to SO Dynamic Traffic Assignment (SODTA) models.

As will be explained in the Literature Review section, one further advantage of a path-based SOQDTA problem is that it can be solved using the conventional and widely-studied algorithms developed for UE traffic assignment problems. However, using these methods to solve a path-based SOQDTA problem requires the computation of Path Marginal Costs (PMC), defined as the derivative of the total system travel time with respect to the flow on each path. In STA, PMC is simply computed by taking the derivative of the total travel time function with respect to flow, however in DTA and QDTA, travel time is calculated through implicit functions and exact PMC computation is very challenging. A variety of studies have introduced algorithms to approximate PMC for *SODTA* (Shen et al., 2007; Peeta and Mahmassani, 1995b; Ghali and Smith, 1995; Qian et al., 2012), however to the best of our knowledge, there exist no similar examples of PMC approximation for QDTA models.

The contribution of the present study is twofold. First, we have developed a generic SOQDTA framework which embeds a state-of-the-art QDNL model and can benefit a variety of traffic management applications. It needs to be highlighted that the QDNL model considers capacity constrained static flows and residual vertical queues without queue spillback. It also does not directly model signalized intersections. Second, we have developed a PMC approximation algorithm that can efficiently solve this path-based SOQDTA problem for general transportation networks, with realistic traffic flow assumptions and a low computational cost. The exactness of the proposed method is not guaranteed because the PMC values are approximate; however, the case study experiment demonstrates considerable improvement of the objective value as compared to the UE solution (the do-nothing scenario). For the case study experiment, we have applied the model to the medium-sized test network of Sioux Falls and demonstrated improvements in the total system travel time.

The following section elaborates on the existing literature in the context of this study. Next, the proposed methodology and algorithms are explained and lastly, the model is applied to the Sioux Falls network and the results are discussed and concluded.

2. Literature review

The SOQDTA problem is founded upon multiple components, including a QDNL model, a first order node model, and a PMC approximation algorithm required for solving the system optimal traffic assignment problem. Therefore, the literature review section covers the aforementioned components.

2.1. Quasi-dynamic network loading

In an effort to improve the accuracy of static network loading models, Bliemer et al. (2014) introduced an efficient QDNL model, which incorporates a comprehensive first order node model to properly constrain turn flows, predict the average number of vehicles in the vertical queues and correctly locate queues upstream of bottlenecks. This model considers static traffic demand with residual vertical queues and no spillback, however produces traffic flow patterns and travel times similar to dynamic network loading models, considering realistic supply-demand interactions. This QDNL model represents traffic flow characteristics in the network via link reduction factors, defined as the ratio of link out-flow to link demand (or link in-flow), and uses these reduction factors to compute average path travel times consistent with queuing theory. Bliemer et al.'s model proposes a reasonable balance between static and