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# Simulation-based optimization of mixed road pricing policies in a large real-world network

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## Abstract

The joint optimization of various types of road pricing strategies for a large-scale real-world network is challenging. Dynamic network supply models can overcome this shortcoming, and provide more detailed information regarding the system performance. However, the computational burden of simulation is still a big challenge for the optimization. Utilizing a simulation-based dynamic traffic assignment model, this paper proposes a simulation-based optimization method to solve the mixed road pricing problem, which is characterized by expensive-to-evaluate and non-closed-form multi-objectives. The mixed road pricing problem is formulated to satisfy dynamic user equilibrium conditions. It enables to capture the time-varying network performance via dynamic traffic assignment. The simulation-based optimization method is successfully applied to the joint optimization of a variety of toll facilities in a real-world network of the Montgomery County in Maryland, i.e. an HOT lane, express toll lanes, and a toll road.

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## 1. Introduction

### 1.1. Network road pricing

Traffic congestion, which causes huge social costs, is witnessed in large cities and on major highways all over the world. In order to mitigate traffic congestion as well as generate revenue, road pricing has been extensively explored

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theoretically and implemented in practice. The theoretical foundation of road pricing is related to marginal-cost pricing in economic principles (Verhoef, 1996, 2002; Yang and Lam, 1996; Yang and Zhang, 2002; Yin, 2002). In addition, toll roads enable drivers to travel at a comfortable speed when regular roads/general-purpose lanes are congested during peak hours. There are numerous categories of implementing road pricing, including cordon-based tolls, distance- or time- based tolls, and charges designed for certain classes of vehicles. This study mainly focuses on the distance-based network road pricing for multi-class travelers.

One critical issue for road pricing is how to determine/optimize toll rates. In the literature, the network road pricing is usually classified as the first-best and second-best problems. The toll in the first-best problems was equal to the gap between the marginal social cost and private cost (Verhoef, 1996). Static stochastic equilibrium models were applied to solve the first-best problems (Yang and Huang, 1999). In the second-best problems, tolls only existed on some pre-specified subset of links. Many studies were conducted to decide toll locations, toll levels, or these two variables simultaneously to obtain an optimal revenue or congestion level (Verhoef, 2002; Hearn and Ramana, 1998; Yang and Zhang, 2002; Shepherd and Sumalee, 2004). However, not many models were widely implemented for large-scale dynamic networks.

Public agencies consider the complex influence of pricing on travel behavior and the system level performance before determining the toll rates. However, due to the complicated interactions among travelers and between travelers and the network in the transportation system, it's very difficult to formulate pure mathematical models to evaluate performance. Simulation has been used widely to evaluate the transportation system performance under different policies. While on the other hand, simulation suffers from its heavy computational costs when utilized as the evaluation tool for optimization problems. We will propose an efficient method that only requires a limited number of objective function evaluations for solving the network road pricing in Section 2.

## 1.2. Priced managed lanes

Managed lanes are designated lanes or roadways within highway rights-of-way where traffic flow is managed by restricting vehicle eligibility, limiting facility access, and in some cases collecting variably priced tolls (Perez et al., 2012). The common benefits of priced managed lanes include travel time savings, more revenue generation, increased trip travel time reliability, enhanced corridor mobility, efficient use of capacity, and travel options for travelers, etc. A variety of priced managed lanes including high-occupancy/toll (HOT) lanes and express toll lanes have been implemented in the U.S. (FHWA, 2006).

HOT lanes are encouraged because of characteristics of performance improvement and revenue generation. HOT lanes maximize the person-throughput of freeway lanes by using pricing, occupancy and access restrictions to balance the capacity consumed by high-occupancy vehicles (HOV) and single-occupancy vehicles (SOV). Typically, HOV are allowed into HOT lanes free of charge, while SOV are charged tolls if choosing HOT lanes instead of free general-purpose lanes.

Express toll lanes are dedicated managed lanes within highway rights-of-way that travelers may use by paying a toll. Unlike HOT lanes, express toll lanes charge all vehicles including HOV. In some cases, carpooling with a minimum number of passengers can be offered discounted charge or free passage.

Successful HOT lanes are implemented, such as I-95 in Miami, I-10 in Los Angeles, Northwest Freeway (U.S. 290) QuickRide in Texas, MnPASS I-394 in Minnesota, etc. For example, I-495 Express in Northern Virginia adds two new priced managed lanes in each direction on an 11-mile segment of the Capital Beltway. This paper will optimize the toll rate of North I-495 by assuming the existing express toll lanes to be expanded to Maryland.

Tolls of priced managed lanes may vary according to a fixed schedule or in real time based on actual traffic conditions in the corridor. Road pricing can be in various mechanism, such as flat toll (or fixed-rate pricing) that is easy to implement, and variable pricing (time-of-day pricing or dynamic variable pricing) that is well suited to priced managed lanes. While regarding the toll collection scheme, there are four primary options: distance-based pricing (per-mile basis), segment-based pricing, facility-based pricing, and system pricing.

For illustrative purposes, this paper aims to optimize the joint pricing strategy on various types of toll facilities during the morning peak, then the fixed toll schedule is considered for its simplicity of implementation and predictability of toll charge to travelers. On the other hand, the distance-based pricing is taken into account because it is able to apply detailed toll rates by mileage and maximize efficiency of toll rates per mile of toll facilities.

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