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A real-time road pricing system: The case of a two-link parallel network

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Abstract

A real-time road pricing system in the case of a two-link parallel network is proposed in this paper. The system that is based on a combination of Dynamic Programming and Neural Networks makes "on-line" decisions about road toll values. In the first phase of the proposed model, the best road toll sequences during certain time period are calculated off-line for many different patterns of vehicle arrivals. These toll sequences are computed using Dynamic Programming approach. In the second phase, learning from vehicle arrival patterns and the corresponding optimal toll sequences, neural network is trained. The results obtained during on-line tests are close to the best solution obtained off-line assuming that the arrival pattern is known.

Scope and purpose

The basic idea behind the concept of congestion pricing is to force drivers to travel and use transportation facilities more during off-peak hours and less during peak hours, as well as to increase the usage of underutilized routes. In this paper, congestion pricing that offers variable tolls to road users based on the time of day and level of traffic is analyzed. There is a need to develop a more concrete methodology to establish time-variable tolls that will optimize the objectives of stakeholders. This research proposes the methodology that can calculate in real-time, appropriate amount of toll to be charged based on the time of day, traffic volumes, value of time distributions and other user and system variables.

Keywords: Congestion pricing; Dynamic Programming; Fuzzy logic; Neural Networks

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1. Introduction

The number of trips by private cars has significantly increased in recent decades in many cities, and on many highways. At the same time, road network capacities have not kept up with this increase in travel demand. Urban road networks in many countries are severely congested, resulting in increased travel times, increased number of stops, unexpected delays, greater travel costs, inconvenience to drivers and passengers, increased air pollution and noise level, and increased number of traffic accidents. Expanding traffic network capacities by building more roads is extremely costly as well as environmentally damaging. Planners, engineers, economists, and city authorities have widely accepted the concept of "congestion pricing" in an attempt to alleviate the congestion during peak periods. William Vickrey, winner of the Nobel Prize for Economics, is considered among researchers as the "father" of congestion pricing concepts [1–4].

The concept of congestion pricing (value pricing) is to charge road users with different fees during different traffic conditions. Various fees or tolls that vary with a location in the network, time of day and/or level of traffic congestion have been proposed. In other words, drivers should pay for using specific road, corridor, bridge, or for entering particular area during some time periods. The basic idea behind the concept of congestion pricing is to force drivers to travel and use transportation facilities more during off-peak hours and less during peak hours, as well as to increase the usage of underutilized routes. Congestion pricing projects that are well planned and successfully implemented could result in significant toll revenues, decreased total number of vehicle trips, decreased total number of vehicle trips during peak periods, increased number of vehicle trips during off-peak periods, increase in ridesharing, greater number of passengers in public transit, and in some cases increased cycling and walking.

Various congestion pricing models have been developed during the last four decades. Some of them have been already implemented. The widely known implementations are in Singapore [5], Hong Kong, and London. Following the pioneering work of Vickrey [1–4], many researchers studied various aspects of the congestion pricing problems [6–27].

Walters [6] was first who made the connection between congestion pricing concepts and traffic flow theory. His work was followed by papers of Yang and Huang [14,15], and Li [17,19]. Special attention has been given to the "second-best" congestion pricing problem "where not all links of a congested transportation network can be tolled" [21,22]. The second best congestion pricing problem in the network was studied, among others, by Verhoef et al. [10–12], May et al. [28], Yang and Zhang [24,25]. Yang and Huang [15] studied optimal congestion pricing in a multilane highway with or without High Occupancy Vehicle (HOV) lanes. Yang [29] proposed "a joint implementation of route guidance and road pricing in a network with recurrent congestion" and developed appropriate model to study the interaction between route guidance and road pricing. The starting point in the research of Yang et al. [26] is the statement that analytical demand functions to be used in congestion pricing analysis are difficult to be established. The authors developed "a trial-and-error implementation scheme of marginal-cost pricing on a general road network when the demand functions are unknown". The methodology proposed by the authors is an iterative toll adjustment procedure based on the method of successive averages. Yang and Zhang [24] investigated network toll design problem taking into account the social and spatial equity constraints. The solution technique is based on simulated annealing method. Yang and Zhang [25] considered the second-best link-based pricing problem. Problem of determining optimal toll levels and optimal toll locations is solved by combination of genetic algorithm and simulated annealing technique. Zhang and Yang [27] studied also the cordon-based second-best congestion pricing on networks. In order to optimally select