Transportation Research Part C 81 (2017) 268–285

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Auction-based tolling systems in a connected and automated vehicles environment: Public opinion and implications for toll revenue and capacity utilization

Gulsevi Basar [a,*], Mecit Cetin [b]

[a] Modeling, Simulation, and Visualization Engineering Department, Old Dominion University, 132C Kaufman Hall, Norfolk, VA 23529, United States
[b] Civil & Environmental Engineering Department, Old Dominion University, 135 Kaufman Hall, Norfolk, VA 23529, United States

ARTICLE INFO

Article history:
Received 2 February 2017
Received in revised form 11 June 2017
Accepted 12 June 2017
Available online 20 June 2017

Keywords:
Auction-based tolling
Connected vehicles
Autonomous vehicles
Online survey
Public attitudes
Choice models

ABSTRACT

Autonomous and connected vehicles are expected to enable new tolling mechanisms, such as auction-based tolls, for allocating the limited roadway capacity. This research examines the public perception of futuristic auction-based tolling systems, with a focus on the public acceptance of such systems over current tolling practices on highways (e.g., dynamic and fixed tolling methodologies). Through a stated-preference survey, responses from 159 road-users residing in Virginia are elicited to understand route choice behavior under a descending price auction implemented on a hypothetical two-route network. Analysis of the survey data shows that there is no outright rejection of the presented auction-based tolling among those who are familiar with the current tolling methods. While males strongly support the new method, no clear pattern emerges among other demographic variables such as income and education level, and age. While high income respondents and regular commuters are more likely to pay higher tolls, no statistical significance between different genders, age groups, household sizes, and education levels is found. Based on the modeling results and the hypothetical road network, it is found that descending price tolling method yields higher average toll rates, and generates at least 70% more revenue when travel time saving is 30 min, and improves capacity utilization of the toll road significantly compared to fixed tolls.

1. Introduction

Traffic congestion has been a serious problem around the globe, particularly in large metropolitan areas. It imposes a huge burden on society, with negative impacts on daily life, health, the economy, and the environment. Since congestion stems from the imbalance between supply and travel demand, transportation professionals relied on the expansion of road networks to increase supply for congestion mitigation in the past. However, this approach has been proven to be impractical due to the shortage of land availability and scarce economic resources. Since roadway supply increases at much slower rate than travel demand does, policy-makers have focused on the management of demand side, particularly on congestion pricing, or tolling, which was first introduced by Pigou (1920) and later supported by Vickrey (1969).

As proposed in Vickrey (1969), road pricing is necessary to efficiently utilize the existing facilities in the short run while providing means to invest in future transportation systems. Thus, the toll rates should be set to match the severity of con-

* Corresponding author.
E-mail addresses: gbasa002@odu.edu (G. Basar), mcetin@odu.edu (M. Cetin).

http://dx.doi.org/10.1016/j.trc.2017.06.006
0968-090X/

gestion. In the early stages of tolling, researchers focused on static networks with fixed toll rates. This trend, recently, switched to dynamic tolling on high-occupancy toll (HOT) lanes, and many researchers proposed different algorithms to centrally optimize traffic network from the operator's perspective in which toll rate can change by travel distance, travel demand or a feedback control mechanism (Zhang et al., 2008; Jou et al., 2012; Yang et al., 2012; Liu et al., 2017). Even though these algorithms are complicated to implement, computationally intensive, and often have operational delays in response to the real-time traffic conditions, there are several successful implementations. Examples include San Diego I-15 FasTrak toll lanes, and Minnesota I-394 toll lanes (Brownstone et al., 2003; Zmud et al., 2007).

New vehicle technologies such as connected and automated vehicles (CAVs) will be entering the roadways sooner than expected as vehicle technologies rapidly evolve. These vehicles with full automation are expected to perform all critical driving activities and make safety-critical decisions while monitoring the traffic conditions (Gasser and Westhoff, 2012; National Highway Traffic Safety Administration, 2013). CAVs will eventually free up the riders from driving tasks allowing them to engage in other activities which may as well include participating in auctions for the toll roads. Also, new types of road infrastructures such as electronic toll collection (ETC) systems increase the traffic efficiency by eliminating stop-and-go at toll booths. The deployment of these telematics technologies and enabling vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communications opened new research avenues to devise dynamic toll rates based not only on network attributes as travel distance and demand, but also on the drivers' interests and willingness-to-pay (WtP). By giving drivers a degree of autonomy over tolls to be paid, a market competition will be created. It is practically proven that market competition adapts rapidly to the unexpected changes in economy more efficiently than centrally controlled markets. Likewise, providing a mechanism where travelers could compete for the limited roadway capacity can result in a more equitable and efficient operation. One way to create a competitive market for toll roads is auctioning, which is proposed by Iwanowski et al. (2003) as a solution to individual route selection problem under congestion. Different auctioning techniques as traffic management schemes are later discussed and supported by several other researchers (Markose et al., 2007; Teodorović et al., 2008; Vasirani and Ossowski, 2011; Carlino et al., 2013; Zhou and Saigal, 2014; Collins et al., 2015; Isukapati and List, 2015; Raphael et al., 2015; Olarte and Haghani, 2017).

Even if auction-based tolling could technically be implemented on highways today, some fundamental questions pertaining to public response and driver behavior need to be addressed. These include understanding the drivers' WtP for toll roads in an auction setting, the impacts on different socio-demographic groups, and the effects on revenue and system utilization. Several past studies suggest that the public is generally opposed to tolling and that public acceptance is necessary for the implementation of toll roads (Sumalee, 2001; Schade and Schlag, 2003). To overcome public opposition to tolling, some researchers suggested alternative options, such as transit incentives and subsidies on alternative un-tolled roads (Adler and Cetin, 2001). Most studies focus on similar variables, which include public awareness of the purpose of tolling, political ideology, past experiences with tolling, and transportation taxation, while some focused on transportation equity concerns (Odeck and Bråthen, 1997; Podgorski and Kockelman, 2006; Odeck and Kjerkreit, 2010). Second body of research studies focus on public perception of connected and autonomous vehicles. Several researchers conducted different surveys on perception about autonomous vehicles (AVs) and connected vehicles (CVs), and found out that majority of the population have positive opinion on these technologies, and they express desire to have them (Schoettle and Sivak, 2014a,b). Even though researchers have focused on public attitudes towards tolling and CAV technologies separately, they have not paid attention to alternative tolling schemes under new technologies and their potential behavioral and attitudinal impacts on the public. Therefore, it is necessary to address this open question for the successful implementation of futuristic tolling techniques proposed by several studies as mentioned earlier.

In this paper, an online stated preference survey is conducted to examine the public perception and attitudes towards futuristic auction tolling mechanism under fully automated and connected vehicle environments, to study their possible effects on travel and toll selection behavior, and to understand its advantages and drawbacks compared to current tolling methods (i.e., fixed tolling). Full automation will allow passengers on board to actively engage in different activities without sacrificing safety as mentioned earlier, and this includes participating in a bidding process in an auction setting. Moreover, connectivity is necessary for two main reasons: i) toll operator must offer individual toll rates and communicate tolling decision and assigned route to drivers via reliable wireless communication, and ii) Drivers must communicate back to the toll operator whether they accept to pay a toll offer. In this study, the focus is particularly on descending price auctions for multiple reasons. First, descending price auctions are suitable for identical and perishable goods that must be sold quickly such as fish, and tulips (Li and Kuo, 2013). The capacity slots on the highways can be treated as perishable and identical, except they can be considered multiple item auctions in which items are heterogeneous in terms of their expiration time (time when they are perished). Particularly under unexpected congestion on highways, which may occur for various reasons such as road work and incidents, this type of auction may be used to alleviate congestion in a quick manner, thanks to its speed. An earlier study showed that descending price auctions for multi-item auctions continue until all items are sold and a price vector close to competitive prices can be achieved (Mishra and Garg, 2006; Mishra and Parkes, 2009). The main contributions of this study are fourfold: (i) deploying an online stated preference survey to understand public perception towards auction-based tolling mechanism enabled by V2I and V2V communication under CAV environment, (ii) showing that instead of an outright rejection, there is a support for new designs for tolling, (iii) analyzing toll selection and travel behavior of respondents under descending price auctions via discrete choice models, and (iv) exploring the effects of descending price auction mechanism on toll revenue and capacity utilization compared to fixed tolling.