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Optimal location of electronic toll gantries: The case of a Portuguese freeway

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Abstract

This paper presents a decision supporting tool for the location of electronic toll gantries in freeways, regarding the maximization of the toll revenue. The adopted case study consists in one of the most important Portuguese freeways, with 180 km of extension and a recently introduced electronic toll collection system. In the first stage of the modeling procedure, we applied a categorical binary model to set drivers' route choice between the tolled freeway segments and the fastest non-tolled alternative paths, based on traffic data collected before and after the introduction of the toll fees. Then, we developed an optimization model to assign a limited or unlimited number of toll gantries to the freeway segments considering the generalized costs of the trips performed using the freeway and the alternative routes. The results showed that charging for all of the freeway segments may not be the best solution to increase road pricing revenue.

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Keywords: electronic toll collection; freeways; optimization model; decision support.

1. Introduction

The electronic toll collection system (ETC) is a widespread technology used to implement road pricing policies. ETC has become popular among public authorities and road concessionaires for congestion charging in the urban areas and freeway or highway tolling. ETC gantries are easy to install both in urban and non-urban roads and allow for the registration of the vehicles crossing the charging zones either by license plate recognition and/or by in-vehicle transponders. The system may adopt a prepaid or postpaid scheme.

Urban congestion charges have been introduced in some large cities aiming to mitigate the impacts of road traffic in the safety and environment of central areas, and at the same time to promote and invest in cleaner and more efficient public transport systems. This was the case of Singapore, London, Stockholm, Oslo, and Milan,

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among other major cities (Odeck & Bråthen, 1997; Santos, 2005; Eliasson et al., 2009). Smaller cities like Durham and Valletta also adopted ETC as a measure to protect their historical centers from traffic jams and illegal parking, promoting a friendlier environment for pedestrians and tourists (Attard & Ison, 2010; Ieromonachou et al., 2004).

Freeways are by definition multilane, divided roads with full control of access and without traffic interruption (TRB, 2010). Being rapid transit facilities due to their high geometric standards, freeways are also expensive to build and maintain. Therefore, freeways often have toll charges in order to cover the building and operational costs and eventually to guarantee the profit margin of the concessionaire and to finance other projects. Because drivers' willingness to pay for road use is closely related with travel time savings, non-freeway toll roads are much more uncommon, being in most cases associated with highly expensive infrastructures crossing natural barriers (e.g. mountain base tunnels). Nevertheless, the public acceptance of road pricing policies is also dependent on the socioeconomic context and cultural values (Jakobsson et al., 2000). Examples of studies on the ETC acceptance can be found in Schuitema et al. (2010) and Chen et al. (2007), respectively for the cases of the Stockholm city center and the Taiwanese freeway network.

ETC in freeways were firstly introduced in some of the lanes of toll plazas, along with the manual lanes with attendants or coin machines. This was the case of Portugal, when in 1995 it was the first country to adopt a universal ETC to all tolls in its territory: the "Via Verde" system. The practical implementation and the reduction of traffic delay observed in toll plazas soon attracted more users to the system. Extensive research on the benefits of ETC on the operational performance of toll plazas has been developed by many authors such as Al-Deek et al. (1996), Zarillo et al. (1997), and Levinson and Chang (2003).

In 2010, the Portuguese government decided to introduce fees in all of the interurban freeways as a consequence of the country's financial crisis. The installation of electronic toll gantries at selected locations on the mainline road was the option undertaken by the government in order to avoid the higher construction costs of toll plazas. Those gantries ensure a single toll collection system which is interoperable with the "Via Verde" system.

The decision on the gantries location may be related with diverse criteria, such as the maximization of the profit, the impacts on the local mobility and economy, and the characteristics of the alternative routes. In this paper, we present a decision supporting tool for the location of electronic toll gantries regarding the maximization of road pricing revenue. Our case study is one of the Portuguese freeways where ETC has recently started to operate. Aiming to set drivers' route choice between the tolled segments and the fastest alternative routes, we applied a categorical binary approach (logit model) to traffic data collected before and after the introduction of the toll fees. Then, considering the generalized costs of the trips in the freeway and in the alternative roads, we developed an optimization model to assign toll gantries to the freeway segments. The developed model takes into account the effects on route choice of two consecutive freeway segments being tolled, and also the differentiation of the kilometric toll fees within a predefined range, to return the optimal location and price per kilometer of each gantry. Moreover, the evaluation of the optimal solution may also be constrained by a maximum number of toll gantries, which is often pre-established by political reasons.

In previous optimization studies concerning the operation of freeway corridors, Repolho et al. (2010 & 2011) developed methodologies to define the location of the interchanges regarding either users' or concessionaires' perspectives. Danczyk and Liu (2011) developed an optimization model to allocate a limited number of speed sensors to the segments of a freeway corridor, bearing in mind the minimization of performance measurement errors. However, because the installation of toll gantries at strategic road sections is not a widespread practice to implement toll collection in freeways, little research has been conducted on this subject, for which this paper aims to provide an important contribution.