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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.

2. General features of the case study

We used the case study of a Portuguese freeway to develop the toll gantries location model presented in this paper. For data confidentiality issues, we are not allowed to identify the freeway in question.

Nevertheless, the selected freeway is part of the Portuguese fundamental road network, being one of the most used freeways in the country both in interregional and international journeys. The freeway is one of a set of seven freeway concessions which were initially planned to be toll-free for users. Private concessionaires and the Portuguese government established Public-Private Partnerships according to which the former would be responsible for the construction and maintenance of the infrastructure and the latter would pay for the traffic observed. While this arrangement was in force until 2010, at that time the government decided to renegotiate the contracts as a consequence of the country's debt crisis, and the user-pays principle was gradually introduced in 2010 and in 2011 in all of the seven concessions. The freeway under consideration gained 13 ETC gantries which in total represent a toll expense varying from around 15 to 40 EUR, depending on the vehicle class, to travel the entire route of about 180 km.

Because of the high density of interchanges (around one per each seven kilometers), the ETC was considered as a less expensive alternative to the closed toll collection system which is implemented in the majority of the Portuguese freeways and requires the construction of toll plazas covering all of the entrances and exits.

In our model, we considered 21 segments and 22 nodes. The travel times between nodes using both the freeway and the fastest alternative were obtained in the *Google Maps* website (*maps.google.com*). The traffic data was provided by the concessionaire and consisted in the average daily traffic (ADT) observed in each freeway segment, observed in two distinct periods: (i) from 1 January 2011 to 29 February 2011, before the introduction of the ETC, and (ii) from 1 January 2012 to 28 February 2012, after the introduction of the ETC. Despite the ADT being categorized by light and heavy vehicles, it was not segregated by traveling direction; hence we considered a 50% split for modeling purposes. The general data is presented in Table 1.

Table 1. General data on the studied freeway

Segment	Freeway		Fastest alternative		ADT light vehicles		ADT heavy vehicles	
	Dist. (km)	Time (min.)	Dist. (km)	Time (min.)	Before ETC	After ETC	Before ETC	After ETC
A	5.6	3	9.1	11	14 673	11 959	3 254	2 601
B	4.2	2	6.6	9	13 886	11 568	2 932	2 507
C	11.0	6	14.2	22	11 328	7 992	2 799	1 801
D	7.2	4	8.4	11	12 305	10 491	2 866	2 553
E	6.3	3	10.2	18	11 884	9 172	2 855	2 398
F	5.8	3	7.6	11	11 194	8 847	2 738	2 600
G	14.1	7	13.5	10	11 303	7 558	2 655	1 846
H	11.7	6	18.5	12	8 930	5 901	1 924	1 293
I	10.1	6	9.3	13	6 576	3 909	2 241	1 382
J	5.3	3	7.5	9	14 798	9 003	2 563	1 846
K	3.9	2	7.1	9	14 316	11 108	2 487	2 016
L	12.8	7	15.5	19	8 433	5 390	2 831	1 995
M	8.5	4	11.6	14	7 613	5 217	2 794	2 048
N	12.9	7	14.2	20	7 493	5 095	2 797	2 170
O	5.8	3	7.3	10	8 657	5 241	2 857	2 004
P	2.5	1	4.5	6	9 252	6 647	2 844	2 662
Q	15.6	8	15.1	16	10 578	6 994	2 900	2 329
R	3.9	2	7.0	12	7 478	5 089	2 614	2 176
S	14.5	8	15.6	15	4 964	2 842	3 048	2 307
T	8.1	4	10.4	12	4 669	3 284	3 075	2 367
U	12.6	7	18.6	25	4 034	2 462	3 045	2 338
Total	182.4	96	231.8	284	—	—	—	—

3. Path choice: logit model

The first step of the modeling process is to set users' decision route when the next segment of the main road is tolled. Thus, this step aimed to identify the probability of a user to keep on the main road (alternative A) despite the toll charges in the next segment. As criteria, it was assumed that (i) the users have only an alternative route choice between nodes (alternative B), (ii) for two consecutive segments, the alternative route B is composed by the two alternative routes B of each segment, (iii) the travel time between nodes is set depending on the road type, which means that alternative roads with distinct characteristics have distinct operating speeds and consequently distinct travel times, and (iv) for each tolled segment, the toll cost is set as being an unitary cost per kilometer times the distance between nodes.

In this way, for each segment, traffic observations are divided into two categories: alternatives A and B. On the basis of this division, a categorical binary variable can be created. This variable (Y) is made equal to one for users that chose alternative A and zero otherwise. The dichotomous nature of the dependent variable facilitates the application of a binary logistic regression, for which the probability of using alternative A instead of alternative B is estimated by a maximum likelihood method. In this logistic regression model, the latent variable is formulated by Eq. 1.

$$f(x_i)= \beta_0+\beta_i .\ x_i \qquad (1)$$

where x_i are the covariates and β_0, β_i are regression coefficients.

With this latent variable, the conditional probability of a positive outcome (Alternative A, *Y=1*) is determined by Eq. 2.

$$Prob(Y=1|x_i)=\frac{\exp(f(x_i))}{1+\exp(f(x_i))} \qquad (2)$$

The resulting model was used to calculate the probability of a user choosing the alternative A given the characteristics of the following segments (covariates x_i).

The covariates chosen which support the decision making were: road segment toll price (TOLLP), travel time difference between alternative A and B (TIMED), main road extension between nodes (DIST), and a dummy variable (PAD) which took the value 1 if the next stretch is also a tolled segment and 0 otherwise. The last variable was introduced to take into account the effect on users' behavior of two consecutive tolled road segments.

The observations of the two time periods (before and after the ETC introduction) measured along the main road were used to estimate the probabilistic model. As a base criterion it was assumed that between the two time periods in analysis there was no variation on traffic generation. This assumption implies that the traffic differences between both periods are exclusively due to users that chose to follow the alternative B in face of a tolled road segment. To avoid the excessive replication of traffic observation, i.e. excessive number of observations with the same x_i and the same response Y, it was considered as an individual observation the response of a group of 1000 vehicles. In this sense, final data base used to model estimation consists of 410 and 120 observations for light and heavy vehicles, respectively.

Table 2 presents the major statistics and the equations related to the two logistic regression models (light and heavy vehicles).

Table 2. Logit model parameters

	Parameter	Estimated value		Standard error	P[|Z|>z]
Light Vehicles	TOLLP	-2.9402		0.4257	0.0000
	TIMED	0.1614		0.0326	0.0000
	DIST	0.2894		0.0551	0.0000
	PAD	-0.9453		0.3184	0.0000
	Log-likelihood		-141.3075		
	Number of observations		410		
Heavy Vehicles	TOLLP	-1.3659		0.3489	0.0001
	TIMED	0.1786		0.0615	0.0037
	DIST	0.2718		0.0975	0.0053
	PAD	-0.5998		0.6054	0.3218*
	Log-likelihood		-38.0585		
	Number of observations		120		

* Despite the variable PAD in the heavy vehicles model not being statistically significant, it was not excluded in order to preserve an identical formulation of both models.

4. Location of toll gantries: optimization model

The optimization model we constructed attempts to capture the loss of traffic in each freeway segment due to the existence of a toll fee. As per the logit model, the freeway user will assess the alternative routes and the delay that he/she will be willing to support in order to save the toll price of the next segment. In addition, consecutive tolls will increase the chance of a driver to detour from the freeway as this will improve the driver's savings/delay ratio. A toll is always set in both directions (paired sections) although kilometric toll fees may vary within. Fig. 1 represents how each freeway segment is denoted and the paired sections relation that will be referred as such form now on.

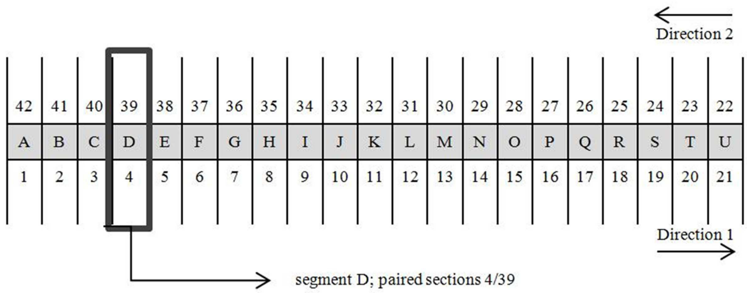

Fig. 1. Schematic representation of the freeway segments and sections

To capture the law present in the logit model we established 11 stages of toll fees per kilometer in order to comply with a real situation. This would be the same as if we had an integer variable limited between two values, but making it possible to use a binary variable and group together light and heavy traffic. Moreover, the use of a binary variable allows us to better manage the true or false situations required in our model.

The decision variable, $toll_{ij}$, represents the choice of toll charging, being equal to 1 if kilometric toll fee j is applied in freeway section i, and to 0 otherwise.

The model tries to optimize the toll gantries localization by maximizing the toll revenue (Eq. 3), knowing that a toll will lower demand in a non-linear proportion to the quality of the alternative routes (Eq. 4 and 5) and tolls concentration (Eq. 6 and 7). The objective function is as following:

$$\text{Maximize:} \quad \text{Gain} + \text{GainH} - \text{Loss} - \text{LossH} \tag{3}$$

with

$$\text{Gain} = \sum_i \sum_j toll_{ij}\ c_j\ pt_{ij}\ t_i\ l_i \tag{4}$$

$$\text{GainH} = \sum_i \sum_j toll_{ij}\ ch_j\ pth_{ij}\ th_i\ l_i \tag{5}$$

$$\text{Loss} = \sum_i \sum_j \left(toll_{ij}\ c_j\ pt_{ij}\ t_i\ l_i\ pr_{ij} \sum_j toll_{i+1,j}\right) \tag{6}$$

$$\text{LossH} = \sum_i \sum_j \left(toll_{ij}\ ch_j\ pth_{ij}\ th_i\ l_i\ prh_{ij} \sum_j toll_{i+1,j}\right) \tag{7}$$

where l_i is the extension of freeway section i, c_j and ch_j represent the kilometric toll fee j for respectively light and heavy vehicles, pt_{ij} and pth_{ij} are the proportion of light and heavy vehicles using section i if kilometric toll fee j is applied, t_i and th_i are the number of light and heavy vehicles in section i, and pr_{ij} and prh_{ij} are the proportion of light and heavy vehicles lost if kilometric toll fee j is applied in section i and any toll fee is set in section $i+1$.

The kilometric toll fee variation allowed in the model application to the case study freeway is presented in Table 3.

Table 3. Kilometric toll fees

Toll fee stage (j)	Kilometric toll fee for light vehicles (c_j) in EUR	Kilometric toll fee for heavy vehicles (ch_j) in EUR
1	0.07	0.18
2	0.08	0.20
3	0.09	0.22
4	0.10	0.24
5	0.11	0.26
6	0.12	0.28
7	0.13	0.30
8	0.14	0.32
9	0.15	0.34
10	0.16	0.36
11	0.17	0.38

The probability of light and heavy traffic choosing the freeway when a toll is present, pt_{ij} and pth_{ij}, results from the binomial choice model that was converted in 2 pairs of matrixes, one pair for the probability mentioned and another for the proportion of runaway traffic which would potentially stay in the freeway when a toll is present but decides to abandon the freeway due to the existence of a second tolled section, pr_{ij} and prh_{ij}. Each matrix cell varies from 0 to 1 (probabilities), each row represents a road section in a total of 21 segments times 2 directions, and each line corresponds to a toll fee stage. Note that for direction 1, sections are numbered from 1 to 21, while direction 2 is numbered from 22 to 42. This means that e.g. sections 4 and 39 are paired sections (see Figure 1 for all the other paired sections) as they belong in fact to the same segment D but in opposite directions, allowing for the allocation of individual kilometric fees to each of them.

The argument $\sum_j toll_{i+1,j}$ captures the existence of tolls in the following section, assuming the value 1 if any charge is applied or 0 otherwise. In the latter case, the Loss (Eq. 6) and LossH (Eq. 7) parcels become null and there will be no penalty on the objective function (Eq. 3).

In order to cope with a realistic situation, we added some constraints to our optimization model for the location of toll gantries, described as follows.

$$\sum_j \mathrm{toll}_{ij} \leq 1,\ \forall i \quad (8)$$

$$\sum_j \mathrm{toll}_{ij} = \sum_j \mathrm{toll}_{43\text{-}i,j},\ \forall i \quad (9)$$

$$\sum_i \sum_j \mathrm{toll}_{ij} = \text{Number of Tolls} \times 2 \quad (10)$$

where the parameter $\sum_j toll_{43\text{-}i,j}$ returns the existence or not of tolls in the segment containing section i.

The restriction in Eq. 8 allows for a maximum of one toll gantry installed in each section. It would make no sense to allow multiple tolls in the same section as it would be the same as having a higher kilometric toll fee.

With the use of both directions it is possible to allow different prices per kilometer in the same pair of sections. However, if a toll gantry is present in one of the paired sections it must be present in the other one as well. Therefore, the constraint set by Eq. 9 guarantees that if a toll exists between two interchanges, it exists in both directions, and only price may vary.

For the particular case study, in order to analyze the variation on revenue and traffic with the number of toll gantries, as well as to compare with the current situation, we implemented an optional constraint that allows setting the total number of gantries (Eq. 10).

We used the software IBM ILOG CPLEX Optimization Studio to run our model. In order to maximize the objective function (Eq. 3), CPLEX solving settings were set as automatic and Boolean variables were used to set the decision variables as binaries. This lead to a presolve process using mixed-integer quadratic programming. After, the solving goes through a mixed-integer programming that emphasis the balance between optimality and feasibility with a dynamic search method and a deterministic parallel mode with up to 4 threads. Early trial runs of the model were carried out by relaxing the constraint associated with the number of toll gantries (Eq. 10). For running times between 0 seconds and 1 day we found that the best feasible solutions were reached in less than 400 seconds, thus we set 400 seconds as our running time limit for the following experiments.

5. Result analysis

5.1. Analysis of the existing solution

In order to analyze the current location of toll gantries in our case study, we ran the model by setting the maximum number of gantries to match the existing solution (i.e., 13 gantries), which has allowed us to verify if our model is capable of improving the current situation. We found that the tolled segments are almost the same in both solutions; our model places one gantry in segment M instead of the existing gantry in segment I (see Fig. 1). Despite the similarities in the gantries location, the toll fees in corresponding segments vary between both solutions.

The current solution when governed by our logit path choice model represents a daily average revenue of 147 716 EUR, while in our solution that income raises up to 165 379 EUR. Despite this fact, the latter solution represents savings of around 0.80 EUR and 3.55 EUR in one-way trips across the entire freeway, respectively for light and heavy vehicles. Comparing with the previous situation of a non-tolled freeway, the decrease in the average number of vehicles.km per day observed for the adopted solution is around 29%, while our solution predicts a reduction of only 20%. In sum, the price variation included in our model and the relocation of one of the toll gantries resulted in the reduction of the runaway traffic, allowing for an increase of 12% in the concessionaire's daily revenue, while reducing in 9% the tolls charged for end-to-end journeys.

5.2. Analysis of the number of toll gantries

A second analysis is focused in defining the best feasible solution with no restrictions to the number of toll gantries. At first sight it would be expected that an increase in the number of tolls would lead to a near linear increase of the revenue. With our model, this is true as long as tolls are set in alternated segments. However, when one tolled segment is followed by another, the losses in the objective function start to penalize the toll revenue due to an increase in the runaway traffic.

The results showed a maximum achievable revenue of 186 505 EUR, with 20 out of the 21 freeway segments being tolled. The segment P is not tolled to avoid penalties on the neighboring segments. Also this indicates good alternative routes in the adjacent nodes, which we were able to confirm.

Subsequently we ran our model fixing the number of gantries from 1 to 21, which allowed understanding the change in vehicles.km and in toll revenue when varying the number of tolls implemented. This approach makes it possible to study the best compromise between the toll revenue and the users' interests.

Firstly we analyze the relation between the toll revenue and the average number of vehicles.km per day, presented in Fig. 2.

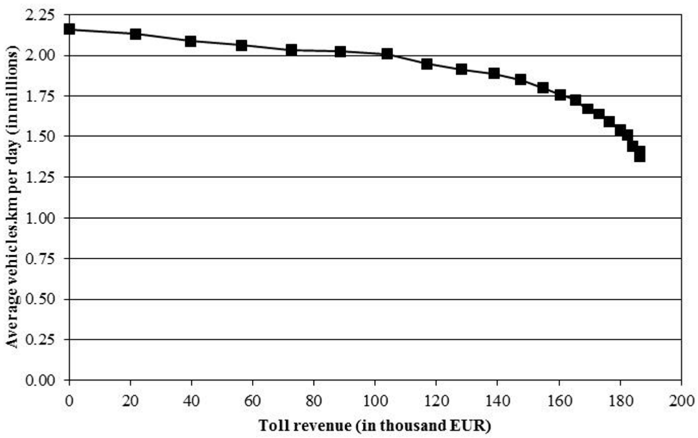

Fig. 2. Relation between the toll revenue and the average number of vehicles.km per day

We may observe that up to a total income of around 100 000 EUR, the average vehicles.km has an almost linear and slow decrease; this reflects a low runaway traffic. The same occurs within the range from 100 000 EUR to 150 000 EUR, although with a slightly higher decrease rate. The correspondent numbers of toll gantries for the mentioned situations are between 1 and 10. In these solutions, we identified an alternation between tolled and non-tolled segments, thus avoiding the penalty in the objective function. When using 10 or more gantries, it is no longer possible to avoid consecutive tolled segments, which activates the penalty and lowers the income increase rate and also the number of vehicles.km.

The graph in Fig. 3 shows the relation between the number of gantries and the toll revenue.

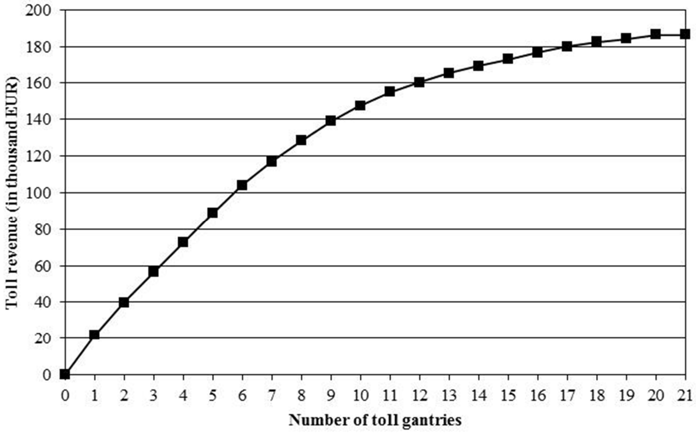

Fig. 3. Relation between the number of toll gantries and the toll revenue

In Fig. 3, it is possible to observe that after a certain number of tolls (around 10), the revenue increase starts slowing down, which is consistent with the analysis of Fig. 2. Moreover, from 20 to 21 gantries, the toll revenue slightly decreases, making the latter a non-recommended solution.

In order to analyze the trade-off between the concessionaire's and users' interests, we present in Fig. 4 the relation between the number of toll gantries and the demand elasticity. This indicator was estimated on the basis that it reflects the variation of the total number of vehicles.km with the increase in the sum of toll fees produced by each additional gantry.

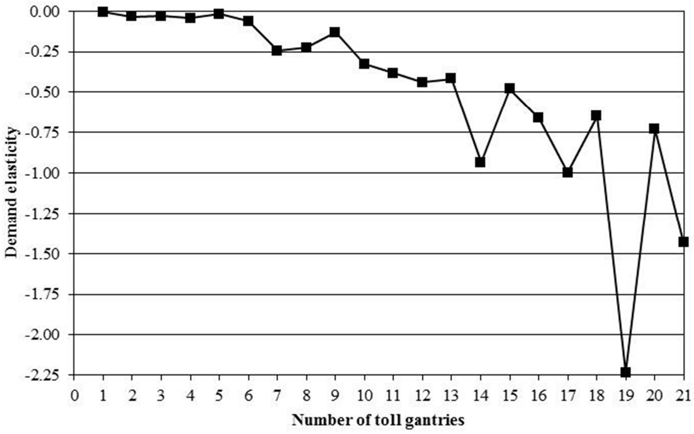

Fig. 4. Relation between the number of toll gantries and demand elasticity

Fig. 4 shows that up to the instalation of the 6^{th} gantry, the demand reveals an almost inelastic behavior, resulting from small losses in the traffic using the freeway. From the 7^{th} to the 13^{th} gantry, small variations on demand elasticity may occur, and from this point onwards the elasticity values present greater variations, reflecting significant impacts on the freeway demand caused by the solutions with more tolled segments. Therefore, the solutions adopting between 7 and 13 offer a better compromise between the maximization of the revenue intended by the concessionaire and the minimization of the toll costs and traveling delays sought by drivers, which is also consistent with the analysis of Fig. 2 and 3.

6. Conclusions

In this paper we developed an optimization tool to define the location of ETC gantries in freeways, applying it to the case of a Portuguese freeway. The recent introduction of ETC was determinant to the choice of the case study, allowing for (i) the use of traffic counts observed before and after the toll charging to develop a logit path choice model, and (ii) the comparison of the adopted solution with the results of the optimization model. With respect to this, we concluded that using the same number of toll gantries (13) currently implemented in the field, our model was capable to increase the toll revenue in around 12% while at the same time the costs of end-to-end journeys were reduced. Such result was achieved by the differentiation of kilometric toll fees within the freeway segments and by the reallocation of one gantry, resulting in fewer vehicles opting by the alternative routes.

Regarding the maximization of the concessionaire's revenue, the model returned a solution with 20 tolled segments out of the 21 which compose the freeway, being the non-tolled segment the one with the most practical alternative route. Therefore, we have demonstrated that price discrimination may be a feasible procedure to increase toll income and decrease the runaway traffic in alternative to the addition of more gantries.

Despite the main objective of our model being the maximization of toll revenue, we analyzed the trade-off between this perspective and the users' interests. In this sense, we found that above a certain number of tolled segments, the increase rate of the revenue significantly slows down, as well as the total demand as drivers are more eager to use the alternative routes. Therefore, as a future line of research, we propose the development of a model using a multi-objective approach to conciliate the revenue increase with the social welfare.

References

Al-Deek, H. M., Radwan, A. E., Mohammed, A. A., & Klodzinski, J. G. (1996). *Journal of Intelligent Transportation Systems*, *3*, 205-223.

Attard, M., & Ison, S. G. (2010). The implementation of road user charging and the lessons learnt: the case of Valletta, Malta. *Journal of Transport Geography*, *18*, 14-22.

Chen, C. D., Fan, Y. W., & Farn, C. K. (2007). Predicting electronic toll collection service adoption: An integration of the technology acceptance model and the theory of planned behavior. *Transportation Research Part C*, *15*, 300-311.

Danczyk, A., & Liu, H. X. (2011). A mixed-integer linear program for optimizing sensor locations along freeway corridors. *Transportation Research Part B*, *45*, 208-217.

Eliasson, J., Hultkrantz, L., Nerhagen, L., & Rosqvist, L. S. (2009). The Stockholm congestion – charging trial 2006: Overview of effects. *Transportation Research Part A*, *43*, 240-250.

Ieromonachou, P., Potter, S., & Enoch, M. (2004). Adapting Strategic Niche Management for evaluating radical transport policies – the case of the Durham Road Access Charging Scheme. *International Journal of Transport Management*, *2*, 75-87.

Jakobsson, C., Fujii, S., & Gärling, T. (2000). Determinants of private car users' acceptance of road pricing. *Transport Policy*, *7*, 153-158.

Levinson, D., & Chang, E. (2003). A model for optimizing electronic toll collection systems. *Transportation Research Part A*, *37*, 293-314.

Odeck, J, & Bråthen, S. (1997). On public attitudes toward implementation of toll roads – the case of Oslo toll ring. *Transport Policy*, *4*, 73-83.

Repolho, H. M., Church, R. L., & Antunes, A. P. (2010). Optimum Location of Motorway Interchanges: Users' Perspective. *Journal of Transportation Engineering*, *136*, 956-963.

Repolho, H. M., Antunes, A. P., & Church, R. L. (2011). Optimization Models for the Location of Motorway Interchanges: Concessionaires' Perspective. *Journal of Transportation Engineering*, *137*, 962-970.

Santos, G. (2005). Urban Congestion Charging: A Comparison between London and Singapore. *Transport Reviews*, *25*, 511-534.

Schuitema, G., Steg, L., & Forward, S. (2010). Explaining differences in acceptability before and acceptance after the implementation of a congestion charge in Stockholm. *Transportation Research Part A*, *44*, 99-109.

TRB (2010). *Highway Capacity Manual 2010*. Washington, D.C.: Transportation Research Board of the National Academies.

Zarillo, M. L., Radwan, A. E., & Al Deek, H. M. (1997). Modelling Traffic Operations at Electronic Toll Collection and Traffic Management Systems. *Computers and Industrial Engineering*, *33*, 857-860.