Making Big Data Real in Upcoming Future: the Dynamic Toll Prices in the Portuguese Highways

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Abstract. In the present context, it is frequent for urban and national road networks to be highly congested, resulting in increased travel times and delays. At the same time, due to toll charging, some high-quality highway networks, particularly in Portugal, are underused. Dynamic charging on highway networks can contribute towards the optimization of the network performance and understanding the behavior of logistic operators as one of the main users of the network is of great importance for the development of any dynamic charging toll model. Within this context, one of the pilot cases of the H2020 project OPTIMUM includes the development of such a forecasting and dynamic (toll) charging model with the key objective of transferring heavy traffic from the urban and national roads to highways. The first run of pilot ocurred between March 09th, 2017 and April 07th, 2017, performance indicators (KPI) were highly positive in terms of freight traffic shift from the national roads to the highways and, consequently, an increase in toll revenues and freight operations efficiency was registered.

Keywords: dynamic charging, OPTIMUM project, heavy traffic, toll prices, traffic model, route choice model, freight operations efficiency.

1 Introduction

Urban and national road networks in many countries have become more and more congested, resulting in increased travel times, operational difficulties, greater travel and maintenance costs and a higher inconvenience level for both drivers and passengers, increased number of traffic accidents (particularly the ones involving pedestrians), and negatively impacting to the environment.

At the same time, Portugal has a good underused tolled highway network, most of the times closer to urban or national toll-free road. Frequently, Portuguese drivers prefer using toll-free roads, disregarding their own safety and relying their decision-making process only on the more easily and objectively identifiable criteria, such available time, fuel costs and toll prices [1] leading to an increased use of the network increasing maintenance costs and pollutants emissions.

Expanding the road network, or its capacity, is both extremely costly and harmful to the environment, thus the way to accommodate growing travel demand is using existing networks more efficiently. The implementation of a dynamic pricing scheme can help to reduce congestion by shifting some traffic demand from national roads to underused highways. Thereby, the European H2020 project "OPTIMUM – Multi-source Big Data Fusion Driven Proactivity for Intelligent Mobility"[1] considered a pilot case that involves the development of a forecasting and dynamic (toll) charging model.

This paper presents an analysis of the current situation in the Portuguese road sector and the toll collection strategies in the country. In addition, it presents the pilot case developed under the OPTIMUM project, as well as the results of the defined key performance indicators (KPI).

2 Literature review

2.1 Implemented charging models and dynamic pricing

In Europe, several cities have adopted 'congestion charge' schemes, mainly to address congestion and/or environmental problems. Usually, these cities adopt constant prices during the day, although exceptions exist, such as Stockholm (where the amount of tax paid to enter and exit the central area varies with the period of the day) [2].

In the United States of America, one of the most common solutions regarding dynamic pricing is the conversion of high-occupancy vehicle (HOV) lanes into high-occupancy toll lanes (HOT), which consist of allowing lower occupancy vehicles paying a toll to gain access to the HOV lanes [3]. These systems came up in 1995 with the objective of avoiding underutilization of HOV lanes and generating additional revenues [4].

To achieve the objectives efficiently, toll prices should be adjusted in real time, as a response to changes in traffic [3]. This is what happens, for instance, in the dynamic toll system implemented on the "fast lane" of the highway between Jerusalem and Tel Aviv (Israel). This system is based on an algorithm developed by Siemens which ensures that the dedicated lane's capacity is sufficiently used while preventing traffic jams: when traffic is light, the toll fee drops, and when traffic gets heavier, the fee increases.

2.2 Current situation in Portugal

The first section of Portuguese motorways was built in 1944, and in 1985 the national highway network had an extension of 158 km. Nowadays, there are about 3.000 km of highways in Portugal, and about 84% of them are toll-controlled. The introduction of tolls, from 2008 onwards, in a set of highways with "shadow toll" schemes, had a significantly negative impact on travel demand (and consequently on the region's mobility and accessibility), despite the application of some temporary positive discrimination measures.

[1] http://www.optimumproject.eu/

Infraestruturas de Portugal, S.A. (IP), with 100% public capital, is a national authority that has now a 75-year concession agreement with the Portuguese State for maintaining the national road network (more than 15.000 km), except for the highway network integrated in other State concessions (**Fig. 1**), including those former "shadow toll highways".

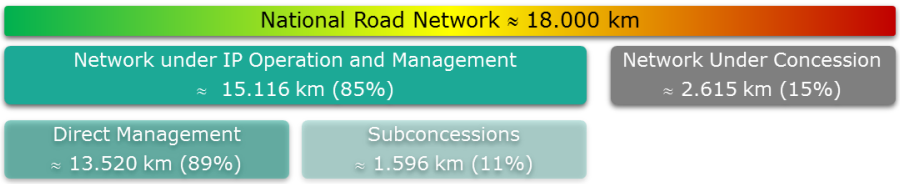

Fig. 1. Portuguese national road network.

All previous "shadow toll" concessions have Multi Lane Free Flow (MLFF) systems, that allow automatic toll collection without requiring vehicles to stop at a toll booth, and have also made crucial the possibility of launching tolling schemes focused on obtaining and retaining frequent highway users.

About 60% of the highway extension had average annual daily traffic (AADT) values lower than 10.000 vehicles [5]. For this reason, about 94% of the highway network registered a higher level of service, representing a clear situation of underused infrastructures.

Since the toll introduction on those highways, IP has been trying to devise strategies to recover traffic, by implementing specific charging schemes such as positive discrimination for local users (private and companies), higher discounts for Heavy Goods Vehicles (HGV) at night period and weekends or discounts applied on highways located in municipalities with lower development rates. Regardless of the effort, the HGV scheme had low acceptance and failed to serve freight sector needs. Also, some of the measures turned out to have a negative impact on toll revenues. Therefore, there is an apparent need for a more commercial approach, providing more flexibility on pricing.

In many situations, highways are underused, and the alternative national road is highly congested, and IP is dealing with two major issues:

- The national roads were not planned to have such a high traffic demand (particularly of heavy vehicles), therefore they are deteriorating faster than expected with higher maintenance costs involved;
- The massive investment that was made on highway networks is not giving back the expected results, with traffic flows lower than initially planned providing, in turn, lower revenues.

3 The dynamic charging pilot case

3.1 Methodology

The European H2020 project "OPTIMUM – Multi-source Big Data Fusion Driven Proactivity for Intelligent Mobility" involves a pilot case running in Portugal with the collaboration of Luís Simões (LS), one of the biggest Portuguese logistic operators, where a model of forecasting a dynamic toll charging scheme is used in order to reduce the congestion by shifting traffic from national roads to the highway network.

The road network involved in this pilot case is composed by 5 highways (A4, A25, A28, A29, A41) from 4 previously "shadow toll" concessions (Grande Porto, Norte Litoral, Costa de Prata and Beiras Litoral e Alta), whose toll collection revenues are controlled by IP. Together with these highways, the pilot network integrated the national roads used by Luís Simões as a free alternative to tolled highways.

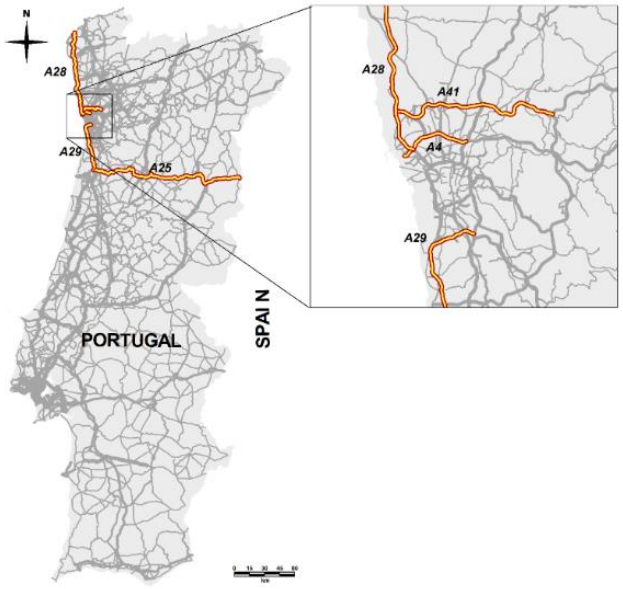

Fig. 2. Portuguese pilot case network.

Toll prices were calculated considering a *variable pricing solution* that aimed to increase highways demand of heavy vehicles and reduce traffic volumes in national roads, combining historical and current data (traffic flows, characteristics of the road networks, quality of service), presenting it in a dedicated web-interface. The pilot case used an econometric dynamic route choice model developed by University of Aegean in Greece.

To support the pilot development, a traffic model developed by TIS (a consultancy company specialized in mobility and transport based in Lisbon, Portugal) was used.

With different variations in the toll prices in each section, some reasonable boundaries were calculated (in terms of maximum and minimum values of discount, with the minimum possible price being defined by the road operator) based on the traffic shift registered, as well as the number of traveled kilometers and expected revenues.

The econometric model was fed by these outputs and by an online survey conducted in Portugal targeting to understand the behavior of logistics operators and truck drivers, with both revealed and stated preference data. In the stated preference scenarios tested, the freight operators were presented with two route alternatives for a future trip (one with a tolled highway and one toll-free), as well as a variety of incentives that the toll users might benefit from (discounts in fuel prices, higher speed limits, dedicated truck lanes and toll discounts, for instance). The survey results were used for getting a more realistic value of time (VOT) and for the definition of a better pricing strategy that would respect the road operator objectives.

Both tested models contributed to the assessment of the trucks' route choice (facing the discounts that should be applied to tolled roads). A "toll discount" was calculated for each hour of each day based on the calculated VOT, the traffic conditions in the highway (to avoid new congestion issues in these roads) and the difference of times between the alternatives.

To evaluate the pilot results, three main key performance indicators (KPI) were set:

- Reduction of traffic congestion in national and urban roads, by shifting traffic from national road network to the underused highways – a 15% shift from freight vehicles to the highways is expected;
- Increase in IP's toll revenues reflecting a higher use of highways – 10% increase;
- Improvement in the efficiency of Luís Simões' operations of at least 10% prior to the project estimates.

3.2 Results

This pilot "run" was kicked off on March 09th, 2017, and it was running until April 07th, 2017. From acquired results prioritized suggestions involved some important improvements of the econometric model and of the web-interface (front-end) developed for the consultation of the calculated toll prices.

To undertake this first iteration of the pilot, dedicated training was provided to drivers and route planners by Luís Simões, as well as explanations on the purpose of the pilot and how the web-interface front-end of the software would be used.

During this pilot, Luís Simões had to rebuild their business planning procedure. In fact, a new process was implemented so as to evaluate the competitiveness of the "new" toll price. From Luís Simões' side, the calculation was simple: a toll would be payed if, at the same time, they had an economical advantage regarding fuel consumption, transit time reductions and total number of kilometers.

For each trip conducted, Luís Simões collected information relating to two different route scenarios *applied per trip* for *each singular trip* of the 10 trucks operating in the pilot:

- Scenario 1: Trip using Luís Simões original routes – corresponding to the routes chosen by Luís Simões without applying the dynamic charging model, i.e. using the current toll prices. It defines the "base case" of the pilot;
- Scenario 2: Trip using OPTIMUM routes – these are the routes chosen by Luís Simões using the discounts prices calculated by the dynamic model, which correspond to the routes selected by the logistic operator.

In each trip, Luís Simões made their route planning using their normal route and the alternative route ("OPTIMUM route"), for each singular trip of the 10 trucks operating in the pilot. A total number of 285 trips during this period were made.

As previously described, a set of KPI were defined to evaluate quantitatively the pilot, regarding the shift of freight traffic from the national roads to the highways as an effect to achieve the increase in toll revenues and freight operations efficiency.

The results from the first iteration of the pilot are highlighted in the following sections and summarized in **Table 1** depicted below.

1) Traffic shift from urban/national roads to highways

From the information collected by Luís Simões during their pilot operation, the usage of the highways increased by about 4,4%. At the same time, the reduction of the national road usage was quite significant: a reduction of approximately 14%, which is just 1% away by the target defined by the project (15%).

A closer view to the kilometers run by trucks in each one of the pilot highways shows that only the A41 highway had a reduction in its overall usage. Although the shift from other concessions is not a goal of the pilot, it should be underlined that in many cases a shift was observed from other private concessions (like A1, A3 or A11) to the pilot highways, which leads to better results for IP, in terms of traffic shift and revenues.

2) Increase on IP's toll revenues

Even though a discount was applied to make the highway more attractive, it was expected that the increase in traffic and therefore in toll transactions would compensate the lost in revenue originated by the discounts – this is an important aspect for the road operator and crucial for the commercial feasibility of the dynamic model; road operators won't be interested in the dynamic model if that is translated as a loss of revenues.

For this KPI, the same methodology between the scenario usage of original routes and the "OPTIMUM routes" was used. At the end of pilot's first run, the performance of this indicator was very good, exceeding more than double the defined value (10%).

It is also important to note that the increase in toll revenues within the pilot network is not the same as the increase in toll costs by Luís Simões, since the route shift of their trucks might happen from the other highways not included in the pilot (namely A1, A3 or A11) to the pilot's highways.

Although the results of the pilot were based on 10 Luís Simões' trucks operating in this pilot (and their respective 285 trips), they could be generalized as counting also in the case of the heavy vehicles fleets of the Portuguese road network to infer a possible measurable impact that this dynamic charging model would have on IP's toll revenues.

In 2016, the 4 concessions that involve this pilot (Norte Litoral, Grande Porto, Beiras Litoral e Alta e Costa de Prata) generated a revenue of near 30 million euros with heavy vehicles (class 4 vehicles). If the results from this KPI are generalized to the universe of the class 4 vehicles in these concessions, it is estimated an increase of about 6 million euros in the toll revenues would be reached.

3) Cost improvement in the efficiency of LS operations'

The daily process performed by Luís Simões using "OPTIMUM routes" increased the efficiency of the operation in almost 3% (i.e., reduced their costs), even considering the payment of the new toll prices in sections they used to avoid. These values are a little far away from the initial goal of increasing in 10% the efficiency.

The reduction of fuel consumption was the main reason for the accomplished reduction of costs: a reduction of almost 1 liter of consumption per 100 km (1l/100 km) during the pilot was calculated.

A second factor that contributed to the increase in the competitiveness of the logistic operator was the reduction on transit time. The average time per trip was reduced in about 5,3%, which means that the route was accomplished approximately 11 minutes sooner than before. This is a crucial indicator for a logistic operator, since it reduces the risk of failing to accomplish their service level agreements with their clients.

Furthermore, since the beginning that the logistic operator kept some doubts about the effect in the total number of kilometers. However, according to the data available, the increase in the distance traveled was about 77 km, which is an immaterial value.

This pilot was also a great opportunity to calculate in a more accurate way the competitiveness of toll prices.

Table 1. Results from the pilot case.

		Scenario 1	Scenario 2	Variation (%)
Traffic shifting (v.km)	Total (km)	43.270	43.347	+0,2%
	Pilot national roads (km)	9.807	8.399	-14%
	Pilot highways (km)	33.463	34.948	+4%
Revenues (€)		3.720 €	4.484 €	+20,5%
Operations efficiency (€)	Length (km)	43.270	43.347	+0,2%
	Time spent (h)	963,9	913,0	-5,3%
	Costs (€)	44.316	43.028	-2,9%

4 Conclusions

The freight operators are responsible for economic benefits but at the same time for measurable road network's greatest environmental impacts as well as road maintenance costs. H2020 OPTIMUM engaged with Luís Simões (one of the biggest Portuguese logistic operators) to test possible solutions offering some assurance that the project

developed model will be appropriate for large-scale use and will reflect the needs expressed by the operators.

Indeed, at the end of this first run of the pilot (that lasted for approximately one month), it became clear that the dynamic charging model generated interesting toll prices to logistic operators and, given some conditions, the logistic operators changes their routes from the free national road to the tolled highways. However, it was also clear that evaluating the final prices is an arduous process and could discourage logistic operators to evaluate prices daily.

A second run of the pilot took place by the end of 2017, considering improvements in the pricing model applied in the first run, so as to consider a more accurate comparison between the traffic conditions in the highway and in the free alternatives. Some changes in the web-interface were also included that improved the logistics operator planning process. The conclusive results from the second pilot run are under evaluation, but the project already registered important impact in Luís Simões' daily operations: some of the historical decisions regarding the choice between highways and national roads were already revised by the logistic operator after the first pilot run evaluation results.

Given these results, IP is seeing in this pilot an opportunity to implement a model that could reduce traffic on national roads and maintenance costs, improve client's satisfaction and environmental indicators, as well as increase highways performance with higher revenues. The system is in its first steps, but it is this project's conviction that in a near future it will be the chosen option not only for logistic operators but for the common citizen that may at a certain moment decide the route that suits better their needs.

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