HIGHWAYS TOLL PLAZA DESIGN

ABSTRACT
Currently, on a worldwide scale, we are assisting to the transformation of the toll plaza concept, as a barrier, as their physical presence is decreasing to be a slight structure deployed in strategic locations a motorway. This study presents three separate design tolls: in Austria, in the United States of America and in Portugal, describing designs methodologies used to the present day, providing an idea of how it will become in the future. This document discusses the different payment methods available, exposing its operation and gives a comparison between them. In the case study, it was considered that the toll plaza, named “Praça de Portagem de Plena Via de Benavente”, faced with an amendment of the assumptions made in its design, and at this point, seems to be lacked an analysis of the reformulation for the design criteria used, addressing and proposing new design parameters. The issues regarding the environment, safety and managing optimization for the operation of motorways, interlinked with the technological area of telecommunications have been dominant factors for this processing.

INTRODUCTION
Toll plazas are created as a demand of roads, bridges or tunnels, whose characteristics for a movement, faster and in safety, lead to a high cost of construction and the consequential costs of maintenance and operation. The document now stands, entitled "HIGHWAYS TOLL PLAZA DESIGN", is organized and structured into five chapters. After this introduction, chapter two presents the framework and the State art describing three cases, the Austrian, the American and Portuguese for design of toll plazas, highlighting current practices in each country.

In the third chapter comes the description of the case study, the toll "Praça de Portagem de Plena Via de Benavente" analyzing initially the impact that the entry into service of the Lezíria bridge has had on other crossings Tagus River, which are located in Lisbon Metropolitan area. since that the inauguration of the Lezíria bridge could not occur without opening the stretch where toll plaza is implemented. Then the description of the methodology that originated the concept that toll plaza, referencing the solutions set out in its various phases. It is also presented with the timing of the construction of this project, indicating the construction processes.

In the fourth chapter presents proposals for the adoption of new design parameters of the criteria adopted in toll plazas of other countries, and its application to the case study. With these new proposals, it is possible to redesign the Toll Plaza being study with new assumptions that suited to current reality.

In Chapter five are set out the main conclusions of the study, in particular the prospect of future toll plazas in Portugal and listed possible future studies.

STATE OF THE ART
There are reports of the existence of toll road from 2700 years ago (Gilliet, 1990). During the reign of Ashurbanipal in the seventh century before Christ, road travelers Susa-Babylonian (Iran-Mesopotamia) had to pay a fee for their journey. Aristotle left written testimonies referred to the payment of tolls elsewhere in Asia and several Germanic tribes obliged a payment to be able to make the crossing of the mountains. In the era of the Roman Empire was also required to pay to pass on the roads they belonged. It appears that the toll roads come from many years ago and will stay for the future, whether the payments are for maintain the infrastructure, for environmental benefit purposes or as a source of revenue of investors, the payment of tolls will continue to exist and the number of Toll Plazas will increase.
The Austrian case

Toll systems presented for the Austrian case are based on a common goal that focuses on minimizing the effects that the installation of a Toll Plaza impose upon its construction, i.e. the creation of entropy in road system (ASFINAG, 2009).

Collection methods, whether they are based on time or on distance travelled, meet the objective since both are not paid at the time of crossing the Toll Plaza road and do not create changes in the traffic current.

The system based on time allows, without great technological requirements, users to carry a seal put in the vehicle and circulate on the tolled roads where the corresponding fare paid. This method can be adjusted as the wearer since buying the seal to the validity that suits the best.

![Figure 1 – Austrian Highway network](image)

The distance-based system is based on the construction and implementation of a telecommunications system, which is widely interconnected with the technological advance. In terms of implementation and maintenance costs, it is a more expensive, however, the control gains arising and heavy traffic information may be fundamental for better traffic management. Comparing with the methods used in Portugal, the system which is based on distance travelled corresponds to the Via Verde "free-flow", where users do not need to stop or reduce the speed to pay the corresponding fare. The toll collection system is exemplary in its design, in particular the method presented to the toll rates for the heavy vehicles. And since this type of movement is not limited to internal traffic, the system created works in other countries outside of the Austrian border. The Swiss devices are allowed to circulate in the Austrian system, and it is possible for them to pay the corresponded toll fare. One of the objectives of other toll operators is to create an interoperable system in neighboring countries, as soon as possible, why are equipped with an interface DSRC (Dedicated Short Range Communication), used by various European countries.

The American case

The United States of America has an extensive road network with 6,515,476 kilometers of motorways. Only 8,215 km of these motorways (approximately 0.13% of total) are tolled. The majority of the toll is located in the infrastructure that require large maintenance or where the cost of construction were very high, particularly in bridges and tunnels (FHWA, 2009).

Due to its Constitution, the United States of America presents a different methodology for financing their roads, where the states that are part of the American Federation are responsible for the planning, construction, maintenance and operation of roads that lie within their boundaries. However, funding is provided by the American Government, transport departments responsibility of each State to define which roads to build or improve, always within the limits of funding. The American Government is only responsible for the construction of roads belonging to areas designated as federal, i.e. military reserves and natural/forestry.

Given that a large percentage of American road network of 40 to 60 years, the date this requires
proper maintenance, which generates large investment costs. This is why the American Government is studying more funding methods, especially the ones used in European countries, such as public-private partnerships (PPPs) and concessions. The demand for better management of maintenance and operation of developing the entities seek to produce equipment that they would take a better yield of infrastructure. Thus began the process of installing the designed machines in toll barrier, so called Automatic Coin Machines (ACM). This equipment no longer required the presence of a toll operator, where the user shall pay the fee by a machine, either by money or card.

The next step, also interwoven with technology, was the creation of a payment system which would not be necessary to stop the car users to pay the fare. This system was called Electronic Toll Collection (ETC), in the United States, and in Portugal has the designation of “Via Verde”. This name is assigned by the entity that created the “Brisa”. This system allows for improvements to the traffic management level, where the waiting time for pay is null, security conditions and conditions of CO2 concentration are improved, since gas emission levels decreases substantially. The American Government is now conducting a trial programmed designated Express Lanes Program Demonstration (ELPD), which consists of equip fifteen tolls with a system similar to that applied in Austria in order to monitor improvements, at the level of traffic management and security, gas emissions, introducing this payment method in all the Toll Plazas that are participating.

The document (NCHRP, 1997) concluded that the levyng of tolls over the years, served as an alternative source of revenue to help build, maintain, and/or rehabilitate the road infrastructure, roads, bridges or tunnels. The alternative funding study, originated that organizations involved to show interest in the toll plaza barriers and practices project. However, as demonstrated, they vary from entity to entity. Each one of them, and in accordance with consultants have developed their own criteria through its experience, their needs maintenance, operation, the requirements of its users and the constraints of their premises.

The document (NCHRP, 1997), noted that the criteria vary widely, with emphasis on the definition of convergence/divergence lengths, lengths of Islands, of equipment to install, etc. The environmental issues of the surrounding areas of the toll plazas, are also one of the areas that need to improve, in particular the concentration levels of CO2 and noise levels (decibels) achieved. Exposure time face of users and workers to these aggressors agents are factors that increasingly responsible authorities. The need for standardization of criteria all parameters relating to the operation of the remedies is needed (definition of criteria for the use of dedicated, traffic control measures and security definition of its position before the barrier, signaling and channeling of vehicles). All these aspects deserve an in-depth study of the operation of a more efficient Toll Plaza, at nationally level.

It is obvious that the operation of systems ETC depends on technological developments, in particular the efficiency and speed of information processing. However, there are still aspects whose definition criteria requires careful analysis, that is, different systems operate in different roads. In the future, it will be useful to have one system which that is compatible with all the other systems used in infrastructure nearby. As already mentioned, the entities responsible for the construction of motorways are the States. This fact generate different ETC methods and it is not possible to
cross the country with only one ETC system. Other issues which relate to the operation of toll roads are such equipment are legal issues, such as for example the availability of data and the use of images as supervisory policies support these infrastructure, financial and economic issues in view of the need for each user need pay transactions via bank transfer, etc.

In addition to the issues mentioned in the preceding paragraph, there are problems in the functioning of the systems, specifically the definition of radio frequency to be used without interfering with the systems used in nearby areas, as well as its own efficiency.

**The Portuguese case**

In the case of Portugal, the method chosen to finance the construction of highways was assign concessions to private entities. They are responsible for the construction, maintenance and operation of the infrastructure, whose revenues charged are for these institutions, during the concession period assigned by the Portuguese State. (Brisa, 2009)

Currently in Portugal there are three methods of payment available on toll: the manual (cash or card), e-toll and the Via Verde. The manual payment is based on the principle that each user stops to pay the fare, whatever their mode of payment, in cash, credit or debit card, or even through “via card” exclusive use “Lusoponte” users.

E-toll represents the need to improve the management of road networks. Operators have installed this method during the last year. This equipment allows to collect toll fare automatically. However, it is considered that their inclusion in Portugal suffers by delay. Since this method and its technology, are implemented for a few years ago in other countries such as the United States of America with ACM, and also in France. This method gains are just from the point of view of responsible entity and allows to improve personnel management.

The “Via Verde” represents innovation in Portugal, since its implementation in 1999 until today. The fact that this system will also be evolving leads to believe that the future Toll Plazas will be very different from what they are. The installation system “Via Verde - free flow” gives a great improvement to the efficiency of the toll collection, as well as improvements to the level of environmental, safety and comfort who uses this method.

![Figure 2 – Number of the “Via Verde” identifiers used (Lusíada, 2006)](image)

In Portugal there is witnessing a change in what concerns to the Toll Plazas design. The example of this stage, is the opening, in 2007, two new toll plazas equipped with the “Via Verde Free-flow” system, where it is possible to circulate at legal speed allowed on motorways, and the reading equipment is capable of capturing the signal by the issuer installed on the user’s car. The Toll plazas mentioned are “Praça de Portagem de Plena Via de Benavente”, in highway A10, the case study of this document, and a toll plaza in “Mira”, highway A17. This is the first step in designing Toll Plazas that introduces the advantages already mentioned. However, in view of the obligation contained in the concession
contracts, it is an obligation to include tolls with manual payment method in tolls. These Toll Plazas still have the original shape of the design of a Toll Plaza.

The so called “Sistema de Identificação Electrónica de Veículos (SIEV), is a new ETC system that will be installed on the Portuguese Toll Plazas. Although now is starting, it represents the new generation of payment methods. This system it will work like heavy vehicles collection in Austria, and will not cause any entropy in the road network.

Despite its functioning, SIEV has the same principle of “Via Verde”. Technologically will be more evolved, since may allow a geo-referenced through Global Positioning System (GPS). The future of this system may also pass by the mandatory inclusion in each vehicle transmitter equipment; interconnected solution with the technological developments of the automobile industry.

It is understood that the SIEV in its initial phase will work beside to the Via Verde, however, by the adoption of the directive number 95 of 15 of May of 2009, interoperability between the two systems will be required.

At this stage, it is still not possible to known how it will work in the medium term. The design solution for SIEV can pass through the inclusion of a chip on vehicles, during its manufacture.

In short, the Portuguese toll plazas, will not be more than one set of walk-tough structures, where equipment is installed to receive a signal emitted by equipment installed in the vehicle that is associated with an entity. The gathered data will be invoiced to the entity responsible for that vehicle and will pay the values for travelling on tolled roads.

Case Study: characterization of the “Praça de Portagem de Plena Via de Benavente”

The aim of this chapter is to characterize all stages of the “Praça de Portagem de Plena Via de Benavente”, since its conception in project until completion of its construction.

In the case study it was found to be interesting to investigate the impact that the inauguration of the Leziria bridge had in the reorganization of traffic through the Tagus river crossings, near the metropolitan area of Lisbon. It was concluded that this opening created more an alternative to passing through this area without having to enter within the city itself. However, that the values of tariffs for travelling in these infrastructures influence the choice of route by which user. With seasonal variation found support in figures, it is concluded that the users choose for standard or cheaper crossing, even if you have to go travel in a bigger distance and travel times might be higher than those of other routes (Estradas de Portugal, 2009).

Can you complete all these crossings have a demand with seasonal movements, achieving maximum in August (with the exception “25 de Abril” bridge that hits during the month of July) and that all record the month of February as the lowest utilization. The peak in the month of
August is fully justified by the Portuguese population preference as month vacation and is also related to the closure of some service industries and enterprises, which overlook the premises of this month, forcing employees to go on holiday in this period.

The fall in February may be assign to the closure of undertakings which is usually held at the end of each year, but in practice, it is only really closed in this month. Another situation that contributes to the reduction of demand is the economic situation of families at the time of the year. The spending during the festive Christmas season, as well as new year's Eve, it is only reflected in the month of February, making that other means of transport in addition to the car are more interesting to use.

Concludes that there is an equivalent in terms of distribution crossings with greater or lesser flow in one direction or another, i.e. the bridges of “Lezíria” and “Vasco da Gama” present bigger traffic values in North/South direction, and the other two crossings reach their highest values in the opposite direction.

One of the main reasons, perhaps the most obvious is that the cost of these crossings be less than the rest of the analyzed. “Marechal Carmona” bridge is inserted in a national road and the cost of its crossing is null. The “25 de Abril” bridge is the second cheapest crossing, including the advantage during the month of August, is free. To reinforce this assertion, they indicate that many of the clients that use the bridges more North of Lisbon to go for your holiday destination, to the “Algarve”, in return, prefer to go through the bridge toll not paid. Another reason for the increased use of 25 de Abril bridge is the fact that who walks through the crossing situated further north, the “Lezíria” bridge, you will have to pay more in tolls, even travelling less kilometers.

In Addition to the mentioned, people want to go for their vacations and maybe they do not care for the travelling costs. However, after their stay, they are no longer willing to make these visible payments, trying to reduce the costs of travel, preferring to return by “25 de Abril” bridge, or even by “Marechal Carmona” bridge even involve an increase in travel time or, where appropriate, an increase of the journey.

Case Study: Proposals for redesign the “Praça de Portagem de Plena Via de Benavente”

In this chapert it is attempted to introduce measures which benefit the design of the “Praça de Portagem de Plena Via de Benavente”. These proposals are based on the change of design assumptions of this infrastructure, whose parameters design varied because political decisions, i.e. at the date of traffic studies, there is the assumption that the new Lisbon Airport would build in “Ota”, being a pole traffic generator for the A10 motorway, which is where the Toll Plaza in study is implemented. With the amendment of this design, the conditions search using this road, for the year horizon, are not the same assumed when their conception of the project.

It seemed interesting to estimate new traffic demand for the year horizon on the basis of traffic values registred since the openning of this infrastructure, using the growth rates of cars seen in recent years.

This change has led to an estimated of 2.953 vehicles per day for the year horizon, contrasting with the estimated 19.600 vehicles per day in traffic study design.

Another of the assumptions which are proposed is to change the taxes used for the different methods of payment that are admitted by the “Brisa” in Toll Plazas design (BEG: 2006). And to give a more realistic proposal, the author performed a measure onsite to verify the values
that are proposed. The “Brisa” Values are more conservative and may be used for the design of new Toll Plazas. On the other hand, the use of values closer to reality will lead to an improvement in the cost of construction of a structure of this nature (Klodzinski, 2001).

Refers that these parameters, where used in faced the methodology recommended by the “Brisa” to determine geometric measures of a Toll Plaza. With the amendments proposed, the toll in the case study is less longer due to payment methods used with income allocated also proposed, and that this would lead to a reduction in the costs of construction and the consequent reduction in the cost of maintenance and operation.

One of the aspects that could have had a different conception is planning that led to the construction of the “Praça de Portagem de Plena Via de Benavente”. The definition of constructive process is crucial to the deadline of the construction of works. Thus, in order to improve the runtime, suggested changes to processes using parts made of reinforced concrete, which for the type of structures involved in this work, it would be a technical solution to gain benefits for the critical project activities, improving their runtimes.

In what regards the total length of the toll plaza, a lower value was achieved which allows you to obtain a benefit to the construction costs. The increase proposed in dimension in relation to the width of the edge of the tab central resulted from the future possibility to convert into extra movement track (one in each direction) allowing for a possible conversion of the “Praça de Portagem de Plena Via de Benavente” in infrastructure where fare collection is made of an automated way, using only the metallic postdates installation support for vehicle identification equipment.

Conclusions

The toll plazas design has evolved over time, always connected with the evolution of technology and the need for improvement in terms of road safety and environmental problems encountered over the past few years.

This evolution is related to the invention of new methods of collecting searched by their exploring entities, be they private or public nature.

Currently in Portugal, toll plazas design defined parameters necessary for its scalability, such as the estimate of the volume of traffic, the
calculation of TMDA and VHP, rates and taxes from each payment method to install, the definition of each element widths that comprise a toll, the definition of geometry (available or not) with lengths calculations of convergence and divergence, etc.

The whole characterization of parameters referred transmits some complexity in the design of the toll plazas. In addition, the facts mentioned, the construction of infrastructures whose features are necessary for the proper functioning of a toll. The inclusion of a control access to the building (air or ground), the construction of a building whose aim is to ensure the proper functioning of the toll, width required to install the islands of the different methods of payment is required to stop to pay the fee, the inclusion of a cover over the area of influence of the toll area, currently are features that are required for the construction of a toll plaza.

All the aspects mentioned in the preceding subparagraph, draft or features, entail costs for the entity responsible for their operation, as well as transmit to whom circulates in toll roads, a physical barrier image imposed in the middle of a motorway.

Current toll plazas cause entropy in the road network, are more polluting, oblige the staging/standby times, cause high levels of noise something towards concentration of vehicles in a small space have numerous points of conflict trajectory for whom access payment Islands, which increases the likelihood of an accident, and that meet the required payment methods in the concession contract, in this case the manual, extends the operating costs.

The future of these infrastructures will demand improvement of all aspects less positive meet their current characteristics.

At the moment is the change in the design of toll plazas throughout the world.

Environmental issues, safety and continuous optimization procedures for managing the operation of motorways run by the authorities responsible for their operation, the technological advancement, affiliated with the telecommunications area has been the dominant factors have been for this progress and have made an important contribution to that tolls will become more efficient in all aspects that compose it.

This development has contributed to the creation of new payment methods, such as the Go-box implemented in Austria, or improvement of existing methods, as is the case of the “Via Verde”, whose initial system characteristics limit the speed of travelling of vehicles and today, it is possible to circulate at the legal speed allowed on a highway, and the receiver grabs the signal transmitted by identifier installed on the vehicle.

There is already functioning of infrastructures financed stems from the collection of tolls whose payment method is fully automatic. As explained in case Austrian toll collection system in this country not installing a toll zone in the middle of the highway. This methodology is the most important factor that extracts the purpose of the entity responsible for management of the motorway network, which is to cause the least possible entropy road system. It is considered that the system implemented in Austria, or others who are already in operation in other countries, whose principles are identical functionality (example: Tis-pl in France), represent the future of toll plazas worldwide. In Portugal, with the opening tolls with automated systems in 2007 and in particular the system free-flow of the Via Verde, began to change the design of the toll plazas. Today, the entity
responsible for giving the concession of the new network of motorways, is planning to introduce a new automatic toll system, now called SIEV. The Portuguese State already created a body responsible for monitoring, through Decree-Law 111/09 of 18 May of 2009, which regulates the powers of this public body whose purpose is to explore and manage electronic identification system. However, given the current political landscape and the alleged social problems arising from the deployment of this system, the legislation on the introduction of the new system is pending. It is understood that the SIEV in its initial phase will work similarly to the Via Verde, however, by the adoption of directive 95 15 of May of 2009, interoperability between the two systems will be the next step.

After the approval of specific legislation for the determination of the proper functioning of SIEV and resolve social problems, toll plazas in Portugal will be identical to those existing toll plazas in Austria, i.e., Toll Plazas will work fully with electronic methods and the payment of the fare won’t be notice at the time of the crossing.

The commencement of operation of SIEV make toll plazas design easier, since this will be an integral part of a profile of current highway, and the planning of its construction will not cause a major impact on highway construction, its implementation resembles an Assembly whose most informative Panel drafted will connect telecommunications network equipment to each operator. At this stage it is still not known as work in the medium term, the SIEV, and its design end can pass through the inclusion of a chip on vehicles, during its manufacture. Interesting believes in future studies, whose nature leaves a little from the scope of civil engineering at the level of improvement of environmental conditions that these new models of toll introduce square, specifically the careful analysis of emissions of gaseous pollutants and sound levels recorded. It is understood that, as is happening in the high-speed rail network European interoperability between systems from different countries is a prerequisite for its design, the toll payment systems will one day be interoperable. When this happens, you can scroll through the European road network with an identifier that is recognized in all toll infrastructures.

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