

Integrating environmental impacts in an intercity corridor level pricing scheme

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Abstract

A significant part of the transport sector externalities occurs in intercity corridors, which account for 65% of the total of the kilometers travelled in for example, Portugal (for 2017). A thorough analysis of intercity corridors characteristics has been receiving less attention compared to urban roads. The objective of this work is to propose a methodology to tackle intercity corridors issues with respect to environmental impacts. It will focus on suggesting smart and dynamic toll systems, integration of impacts in pricing schemes, and optimization of public transport fares, coupled with a scheme based on the “polluter pays” principle. This vision paper presents the main objectives and methodology of an ongoing research in which the final objective is to lead to a more efficient usage of the infrastructures. The optimization is mainly focused on an environmental perspective, which can be important for decision-makers to improve specific intercity corridor measures/policies.

Keywords: Intercity corridors; external costs; toll design; fare optimization.

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1. Introduction and objectives

It is estimated that, in 2016, the transport sector was responsible for 27% of the greenhouse gases emitted in the European Union (EU) (EEA, 2019). For example, in 2014, the external costs associated with transport sector accounted with around 2% of the Portuguese Gross Domestic Product (GDP) (Tafidis et al., 2018). A significant part of the transport sector externalities occurs in intercity corridors, which account for 65% of the total of the kilometres travelled in the Portugal, considering data from 2017 (EMISIA, 2019). The EU believes that a more efficient usage of the infrastructures is crucial to reduce transport externalities (EC, 2011) by promoting policies related to the “polluter pays” principle (Transport & Environment, 2017). This vision paper presents the main objectives and methodology on an ongoing doctoral research programme. The goal of this paper is to propose methodologies to solve some issues regarding intercity corridors such as the lack of smart and dynamic tolls, integration of impacts and optimization of public transport fares. These methodologies may be applied to intercity corridors to reduce the externalities associated by finding optimal solutions that allow the minimization of impacts in terms of emissions, safety, fuel consumption and others.

The concept of smart pricing has been under study as a new way to perform traffic assignment, being the implementation of road pricing usually considered an effective measure to reduce environmental externalities (Vonk Noordegraaf et al., 2014, Cavallaro et al., 2018, Wen and Eglese, 2016). Dynamic pricing involves a trade-off between multiple objectives including efficiency, safety, pollution, reliability, economy, supply and demand (He et al., 2016, Chen et al., 2018). When assessing a multi-objective routing problem with environmental goals, the variables under study are not static, for example, emissions may vary by a factor of 1,4 while the potential number of exposed individuals can vary by a factor of 10 (Bandeira et al., 2018). In addition, to consider community exposure, it is necessary to not only take into account the individual impacts, but also the impacts at system level. Bandeira et al. (2018) has shown that choosing a supposedly eco-friendly route may have adverse effects in terms of system emissions due to the worse performance of the remaining vehicles. The impacts on Carbon Dioxide (CO₂) emissions by congestion-based road pricing (used in urban environments) have been widely studied and are already implemented in cities such as Milan, London and Stockholm (Rotaris et al., 2010, Morton et al., 2017, Daunfeldt et al., 2009). While some studies show that the three implemented cases have been able to reduce the negative externalities associated with traffic (Croci, 2016), other authors state that this scheme did not improve the air quality in some places like Milan (Percoco, 2013). Distance-based schemes pursue to internalize the external costs of transport, by implementing a price per kilometre approach, which may also vary depending on the specifications of the vehicle, or their capacity (Cavallaro et al., 2017, Ma et al., 2015, Brent and Gross, 2018). Dynamic road pricing based on optimizing the levels of congestion and emissions was also studied, for instance based either on formulating prices as a dynamic system optimal control problem, with traffic volumes and/or environmental factors working as constraints (Zhong et al., 2012), or on designing a dynamic toll with the objective of minimize travel costs for users and emissions at network level (Friesz et al., 2013).

There are studies that show that toll policies may impact the traffic flow. For instance, a study focused on conducting an ex-post analysis of road pricing changes in Portuguese motorways, showed that 50% of the average daily traffic exchanged the motorway with toll for alternative routes or modes (Bandeira et al., 2012). Moreover, by studying the elasticity of traffic demand and external costs, it was shown that the system elasticity changes with price changes in the fixed tolls, prevailing a correlation of 75% between traffic flow and toll prices (Fontes et al., 2015).

Toll optimization may be a good solution for a greater usage of public transport, as it was shown in a test case conducted in Singapore, where an increase of 1\$ in the toll, led to an increase ranging between 12 and 20% of public transport users, showing also bigger impacts in low income zones (Agarwal e Koo, 2016). The implementation of fair toll prices is in general seen as a tool to reduce and disperse traffic flow, with potential improvements of congestion and air quality levels (Coria and Zhang, 2017). Moreover, travel time value of public transport passengers is an important variable in the decision-making process. For instance, it was shown that users that can use their trip time in a more useful way have a lower perceived travel time cost (Kouwenhoven and de Jong, 2018).

Railway systems are an important component of the social and economic system and are often seen as a key component in the implementation of transport policies (Catalano et al., 2018). There are also some negative impacts, such as the noise generated by rail transit systems, which is a growing concern in around urban areas (Connolly et al., 2015, Kouroussis et al., 2014). In order to fostering the usage of intercity trains, it is important to understand what leads people to use this mode of transport. A study conducted in United States of America showed that people are more propitious to use trains if they travel less than 3,2km to access the train station. It also showed parking facilities near the train station is equally important (Losada-Rojas et al., 2019).

The behavioural inertia is also a factor to be taken into account when tackling intercity movements because the solutions are often dependent on user choices. A study conducted in the US showed the anti or pro car attitude

differs, depending on the quality of the public transport of the region under study. For example, a stronger anti-car mentality is found in West Coast residents, but counter-acted by the quality of public transport services (Hess et al., 2018).

The average emission factors may mislead policymakers, since they do not consider the marginal impact of changing demand for intercity travelling. For instance, the average emission factors for intercity rail is 10% lower than those for air travelling, and 30% lower than private vehicles while the marginal factor is 60% and 80% lower, respectively. These marginal factors may be elasticity values regarding the changing in demand (Bigazzi, 2019). Each intercity movement has different costs associated divided by private and external costs. The external costs comprise the costs related to emissions, noise, congestion and safety, while the private costs are the actual and perceived costs by the users. Some costs are real costs like the energy costs and tolls, and public transport fares, while others are perceived, for example, the travel time costs (van Hesse et al., 2019).

In essence, the existing system shortcomings found are:

- Road transport has high socioeconomic negative impacts;
- Infrastructure usage is not currently taxed in an integrated and effective way; thus, innovative and fair taxes and tolls should be considered;
- Most of the taxes and tolls with environmental concerns are implemented solely at urban level.

Bearing these issues in mind, the main gaps found in the literature review are related to:

- Dynamic road and public transport pricing in intercity corridors: according with the authors best knowledge, this was never been examined from an intermodal perspective;
- Lack of integration between the various traffic externalities, with special focus on environmental, private and travel time costs.

Therefore, the purpose of this work is to propose a methodology for an efficient pricing scheme that takes into account the externalities associated with intercity movements. The central research questions are as follows:

- i) To evaluate how an optimal traffic distribution in intercity corridors may contribute for the reduction of transport-related externalities;
- ii) To estimate how new smart and dynamic tolls and fares may contribute to optimal traffic solutions.

In order to succeed, the following topics will be addressed:

- Estimation of travel time costs for all the modes of transport and elasticity values on public transport fares;
- Explore how new data sources and Information and Communication Technologies (ICT) may contribute to a better characterization of the demand;
- Determination of 1) optimal traffic flows in alternative routes; 2) public transport for minimization of externalities;
- Evaluation of how new smart and dynamic tolls and fares may contribute to optimal traffic solutions;
- Evaluation of the impacts of the new smart and dynamic tolls have in the externalities based in vehicles characteristics.

The methodology proposed in this work intends to pave the way to new innovative and a fairer way to tax intercity corridors

2. Environmental impact integrating pricing methodology

This chapter presents the proposed methodology for developing an efficient pricing scheme.

2.1. Optimal traffic distribution for the reduction of externalities

The first research question involves determining how an optimal traffic distribution in intercity corridors may contribute for the reduction of externalities by quantifying the externalities associated with an intercity corridor through modelling and real-world measurements. New data sources and ICT can contribute for a rigorous characterization of demand to know how the exposed population is affected by the negative externalities of transport in a spatiotemporal scale. Additionally, the value of travel time for various means of transport and the elasticity of such values based on public transport tickets or operation costs of the vehicles will be needed.

For this purpose, a land-use and transport integrated model will be used. We chose VISUM (PTV Group, 2019a) for such task, since it is a transport modeling software that allows the representation of all the different and complex interactions between soil use and offer/demand of all the modes of transport in an urban or regional scale. The process of location and interaction between activities generates a set of matrices, which form the basis for calculating trips by the transport model that will be used to simulate impacts of road-pricing and Public Transport fares on travel behaviour. Fieldwork will be performed to collect traffic volumes and speed data to support model validation and calibration. A shortcoming is that VISUM model includes a volume-delay function to represent the

reduction of speed with the increase of congestion, however, information on average speed is often not enough to perform an accurate assessment of traffic-related impacts in the presence of high variability in speed profiles (Bandeira et al., 2011). Thus, a microscopic model, such as VISSIM (PTV Group, 2019b), will be applied to calibrate and adjust the output of the macroscopic modeling platform previously developed. The suggested approach to the hybrid modeling platform is displayed in the following figure.

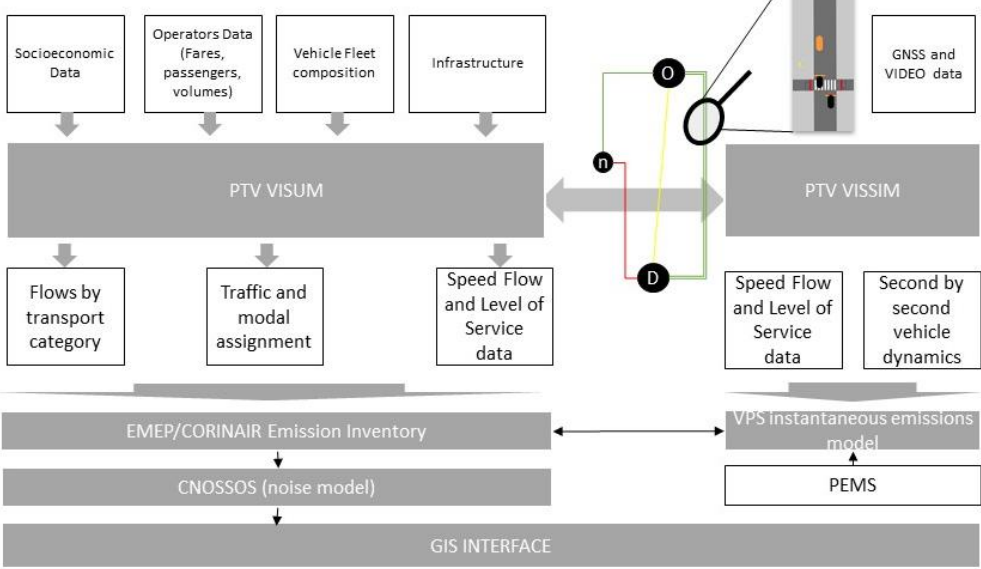


Figure 1 Approach to the hybrid modelling platform.

Besides, a Geographic Information System (GIS) interface will be developed for providing visualization and post-processing of specialized model results. This platform will be relevant for integration and manipulation of multiple data layers (e.g., traffic-related models, community exposure and socioeconomic costs), useful for the optimization process.

2.1.1. Estimation of key variables

Road-traffic emissions modelling will be based on a two-phase hybrid methodology. In phase 1, macroscopic models based on outputs of the integrated land-use model (link-based data on volumes and average speed) will be used. Then, in a second phase, specific corrective factors will be developed to adjust previous results. The main objective is to reflect the inherent heterogeneity and stochasticity of driving profiles, especially in road-segments with high number of singularities and/or traffic congestion levels. The macroscopic models will be used because they allow a better understanding of the various situations under study, with the microscopic models being used if specific road segments have an high number of singularities.

Regarding rail transport emissions, these will be estimated from energy consumption using average fuel-based emission factors and electrical production emission factors based on simulation of energy consumption and emissions from rail traffic. This approach will allow a macroscopic estimation of the emissions from rail traffic. Noise estimations will be performed using “The Common Noise Assessment Methods in Europe” model (Kephelopoulou et al., 2012). Field measurements with sound level meter will be carried out in selected points of the network to calibrate and validate model results. This model will be used because it allows a macroscopic view for the noise estimations, based on the approach made in Sampaio et al., (2019).

To tackle the external emission cost, an approach focused on quantification of the transport-related impacts on human-health, environment and economic activity. Analyses will include PM, NO_x and CO₂ costs, the main negative environmental externalities generated by the transport sector. Since exposure assessment costs are related to the population being exposed to traffic-related impacts (excluding GHG), determining human activity exposed is very important because the true impact that a pollutant may have in the population, thus their external costs, may change, increase or decrease, depending of the people exposed (Sampaio et al., 2019). Determination of the exposed population will be important to calibrate the average external costs found in the literature (van Hessen et al., 2019).

2.2. Achieving optimal traffic solutions

For the second research question, that it related with the estimation of how new smart and dynamic tolls and fares may contribute to optimal traffic solutions, it will be needed to determine optimal distributions of traffic flows through alternative routes and public transport for negative externalities minimization, assess how different fares systems for the various mobility services may lead to optimal traffic distributions based in different demand levels and assess the impacts that the innovative fares systems based on vehicle characteristics, location and time of the day to quantify CO₂ emissions, air pollution, noise and traffic congestion.

To solve this question, it is proposed to firstly formulate a dynamic system optimal problem to be solved as an optimal control problem. For a certain demand, optimal flow distribution will be assessed, i.e., a solution for which external costs are minimized will be obtained. Secondly, the dynamic optimal emission tolls and PT fares can be determined by solving an optimal control problem with the objective to minimize the system emissions subject to conditions related to the dynamic user equilibrium. The main objective of this solving method is that in each iteration from user's viewpoint, the most attractive travel option from individual perspective (including costs of wear, energy, travel time and pricing) is the one with lower external social costs. Finally, different and innovative methodologies of road pricing should be tested, using all the models, data and knowledge collected by this point.

2.3. Interaction between the research phases in the proposed methodology

In Figure 2, the interaction between the research phases is illustrated.

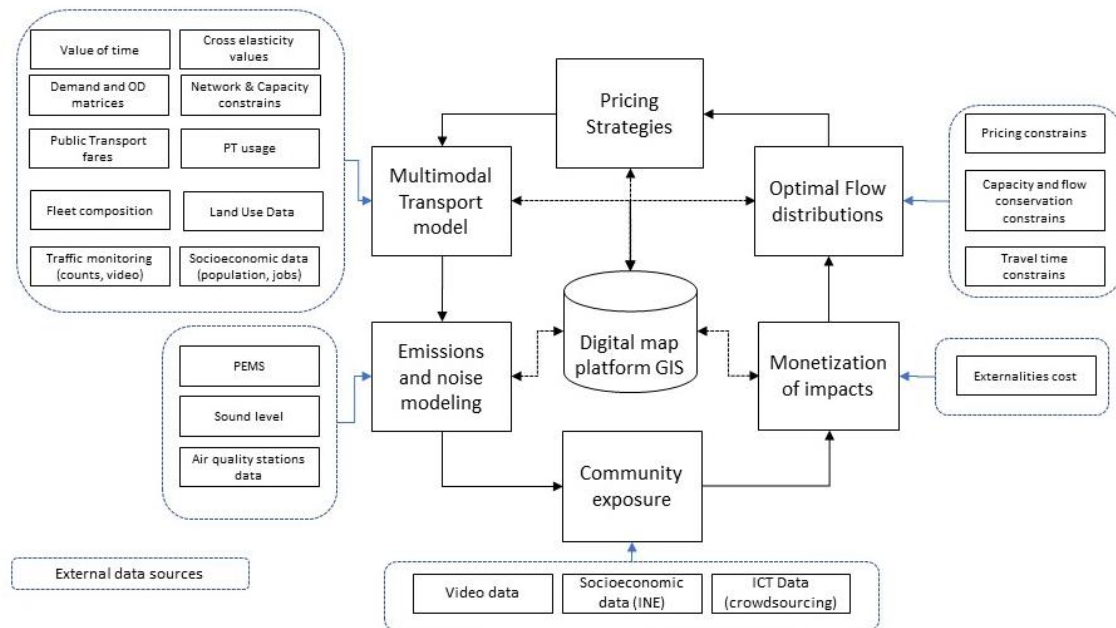


Figure 2 Interaction of the research phases.

The methodology plan is divided into research phases. First phase is composed by the multimodal transport model, where some external data sources will be needed such as value of travel time, public transport usage and fares, fleet composition of the study area, socioeconomic data, among others. The goal is to have information of the variables needed and the development of the multimodal transport model that will be the base for the methodology. Then, emissions and noise modelling will be performed, using real data gathered from Portable Emissions Monitoring Systems (PEMS), sound level meter and air quality stations to calibrate the models that will be used. The community exposure will also be taken into account, mainly to adjust the levels of emissions and noise level regarding the number of people exposed. These data will be gathered using video camera records, ICT information and socioeconomic records. After developing the model, and estimate the values for the various impacts, monetization of impacts will be performed, where the External Costs will be estimated using van Hensen et al. (2019). Optimal flow distributions and the study of pricing strategies will be executed has the final step of the research plan. A digital map platform based on Geographic Information Systems is the final deliverable,

incorporating all research phases, allowing the study of new innovative and a fairer way to tax intercity corridors.

3. Example of expected results

A simplified example of the result that it is intended to be achieved with this methodology will be discussed in this chapter.

Considering a trip movement of a user between an origin and destination points, the user has three alternative options: using a National road (108 km), a Motorway (86 km) or taking an Intercity Bus (86 km). In this example based on real data, the following costs (figure 4) were estimated. The private costs in this example comprise the travel time, toll/ticket and fuel costs. External costs are related with emissions of pollutants. A regular intercity bus was modelled with an occupancy rate of 50%, while the car modelled was a diesel car with small engine with only one passenger.

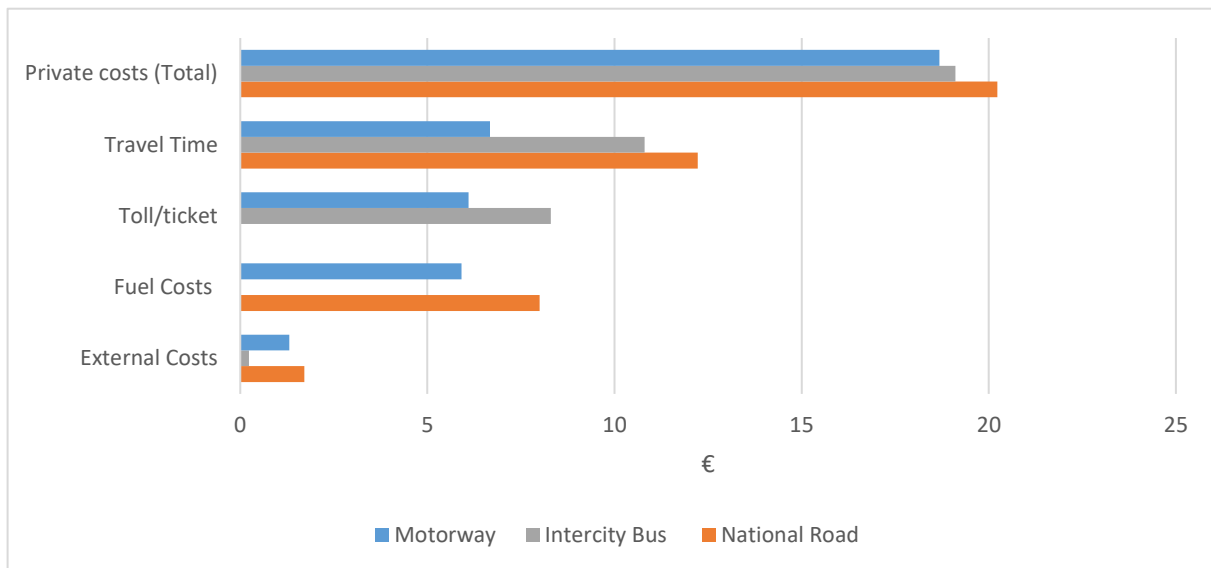


Figure 3 - External and private costs for each option from A to B.

These results based on real data show the option with lower external costs is taking the intercity bus, but it has higher private costs than the motorway option. An optimization should be made in order to ensure that the option with less private costs is the intercity bus, by for example decreasing the fare. This simple example neither takes into account the capacity of each option, or the actual passengers flow, nor all the externalities associated, being just a toy example of how the optimization of fares may work.

In this proposed methodology, an optimization of fares will be possible so that the option with lower external costs is also the one with lower private costs.

4. Conclusions

The objective of this paper is to propose a methodology that may solve some issues regarding intercity corridors, such as lack of innovative ways of toll designs and pricing with environmental concerns (which already happens in some urban city centers), and optimization and integration of the public transport fares to make more environmentally friendly modes of transport and more attractive routes to users. Overall, smart and dynamic fares may be an effective solution to address such gaps. The innovative ways to address corridors pricing should focus in the assumption that an optimization of prices will lead the users to a more environmentally friendly option for different day periods, or different weekdays. Routing and transport mode choice may vary depending on these particularities; thus, a trade-off between external and private costs should be evaluated in order to conduct to an optimal solution for the user and the overall environment. The suggested methodology in this work may be a solution for integrating environmental impacts in an intercity corridor level pricing scheme.

Some ethical issues may arise when discussing polluter-pays principle. The inhabitants of cities in the countryside have very few possibilities of travelling to another city by public transport; for them, the private car and the existence of good infrastructures (such as a motorway) seem the only good available option in terms of travel time and safety. However, if fares increase based on pollution, this can create general inequality between places with

very good public transport offer and places which only have as a good option the motorway. As this study takes into account also the options available, travel time and safety, it will allow optimal and fair solutions.

Some pros of this methodology have been presented along the document, but the main one is that its macroscopic modeling will allow to adapt it to different situations, and two different case studies will be considered in an initial phase. Some cons or constraints should also be considered. For instance, the actual costs may be different than the perceived costs, and behavioral inertia, a focus in the private economical and behavioral part may also be needed to be reinforced. The study of innovative ways to address corridors pricing may lead to a more efficient usage of the infrastructures, with a special focus on an environmental perspective, which can be important for decision-makers to improve specific intercity corridor measures/policies.

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