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IS CONGESTION PRICING AN URBAN MOBILITY SOLUTION TO BRAZILIAN CITIES?

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Abstract: The congestion pricing is a measure of travel demand management to discourage car use with low public and political acceptability. In the Brazilian context, the Urban Mobility Policy considers this measure to mitigate the congestion. In this paper, we present an exploratory analysis to identify the characteristics considered important by Brazilian transport experts to the implementation of the congestion pricing. The residents assessed these characteristics to identify the preference and acceptability of this scheme in Belo Horizonte (Brazil). We obtained the data from a Web-based survey from experts and residents. With the results, we simulated scenarios reducing the number of private cars in order to evaluate the real benefits of congestion price in a real network. According to Brazilian transport experts, the congestion pricing can be an efficient and well-accepted demand management measure, if the profit subsidizes the public transportation systems (bus and rail) and the infrastructure to non-motorized transportation, with active public participation in the decision-making. Considering the residents' results, we identified favorable public acceptability considering the benefits of public transport investment from the revenue obtained out of the congestion charges. However, availability for payment has a high rejection rate, although implementation strategies are perceived as advantages. The simulation indicates the reduction of travel time (seconds/km), delay time (seconds/km), queue length (vehicle) and density time (vehicle/km) indicating congestion reduction and, consequently, improving the urban mobility. The contribution of this paper is one methodology considering the Brazilian context to evaluate the congestion-pricing scheme from experts and residents point of view. Also, the results could support the discussion about the implementation of the congestion charging in Brazilian cities.

Keywords: Congestion pricing; public acceptability; simulation; Brazil; Urban Mobility Policy

INTRODUCTION

The increase of car use and the inefficiency of public transportation in Brazil impacts on urban mobility, aggravating traffic congestion and environmental degradation. In Brazil, 99,742,877 vehicles composed the fleet (54% cars and 24% motorcycles) in September 2018 (Brazil, 2018). The car is a fast, convenient, and comfortable vehicle. However, the massive use of car causes environmental problems (Garling & Schuitema, 2007).

Transportation demand management (TDM) programs may include congestion pricing to discourage car use. Although considered an important policy to reduce congestion, the acceptability is low (Jakobsson et al., 1999), stimulating the adoption of diversified and combined TDM measures by managers and urban planners (Eriksson et al., 2006).

In this paper, we consider congestion pricing (or congestion charging) as a mechanism of traffic control and transportation demand management. According to Goh (2002), congestion charging is the best way to reduce negative externalities related to urban traffic, and the success of this measure depends on the acceptability of the population, commitment of the governments, cost/benefit analysis of the implementation, and the improvement of public transportation.

Also, public and political acceptability are considered essential to ensure the success of TDM through congestion pricing (Giuliano, 1992; Bartley, 1995; Schlag & Teubel, 1997; Schade and Schlag, 2003; Sikow-Magny, 2003; May et al., 2010, Rentziou et al., 2011; Eliasson &Jonsson, 2011; Grisolía et al., 2015). The opposition and resistance of active groups were decisive in some cases, such as in New York (Schaller, 2010), Manchester (England) and Edinburgh (Scotland) (Ryley &Gjersoe, 2006). In Stockholm, a popular referendum approved the congestion pricing with 51% acceptance and, in Milan, with 79%. In Manchester and Edinburgh (UK), the population was against the implementation of congestion charging in central areas of these cities (Ozer, 2012). According to Gu et al. (2018), low public acceptance is the most significant barrier to congestion pricing.

In the Brazilian context, Law 12,587/2012 establishes legal support to implement taxes to the use of road infrastructure, making possible the consideration of congestion pricing as a measure for the improvement of urban mobility (Brazil, 2012). Also, this Law determines that the revenues shall be invested in transport infrastructure projects to provide public and non-motorized alternatives and to subsidies the public transportation fare (Brazil, 2012). Despite the legal support and the indication of the congestion charging as a mobility solution for São Paulo, Rio de Janeiro, and Belo Horizonte (included in the mobility plan), the effectiveness of this measure as an instrument of transportation demand management in Brazil is unknown. Brazilian cities have not investigated the expected results yet not from the experts' viewpoint and not even the public acceptability of the congestion charging.

In this context, in this paper, we analyse the adoption of congestion pricing in a Brazilian city, identifying and classifying the characteristics that contribute to a favorable evaluation of this solution from Brazilian transportation experts. Also, we present the results of an acceptability analysis from the citizens of Belo Horizonte concerning the congestion pricing. Finally, we simulate scenarios to evaluate the benefits of this measure in a real network. We intend to contribute with one methodology considering the Brazilian context to assess the congestion-pricing scheme from experts and residents point of view. Also, we intend to add to the discussion about the implementation of the congestion charging in Brazilian cities.

ACCEPTABILITY OF THE CONGESTION PRICING

Public and political acceptances are considered essential to ensure the successful implementation of the congestion pricing. Grisolía et al. (2015) reported some elements concerning the acceptability of the urban toll: (i) the opposition is based on the lack of reliability of the government in relation to the application of the revenues; (ii) there is a prospect of increased acceptability with increasing perception of the effectiveness of the congestion pricing to reduce the negative effects of car use; (iii) popular acceptance may be greater if there is clear information on the use of revenue; (iv) public and political acceptability depends on the distribution (and perception) of the benefits and consequences of the congestion pricing; and (iv) certain characteristics of urban tolls such as collection, period of validity and area may influence acceptability.

Eriksson et al. (2006, p. 16) define public acceptability as the "level of assessment (positive or negative) of travel demand management measures that can be implemented in the future." The acceptance may increase after the congestion charge implementation, as verified in Stockholm, Sweden, despite to be a challenge to urban planners (Eliason & Jonsson, 2011).

The public acceptability has been examined in several studies. Schade & Schlag (2003) evaluated the level of congestion pricing acceptability and the factors that explain this acceptability in four European cities. They interviewed 952 drivers in Athens (Greece), Como (Italy), Dresden (Germany), and Oslo (Norway) and the results indicated a low acceptance in the road pricing system, being influenced by factors related to the social norm, personal expectations, and perceived effectiveness.

Garling & Schuitema (2007) investigated the effectiveness of TDM measures in reducing private vehicle use and discussed factors related to public acceptability and political viability. Rentziou et al. (2011) analysed the factors that may influence the acceptability of the congestion pricing in Athens (Greece). The survey included 1,114 interviews to the travellers to the central area of Athens. The interviewees expressed their opinion about the congestion level, travel model, and the possibility of allocating revenues in a new modal alternative after the implementation of the congestion pricing. Among the results, socio- demographic and travel characteristics, the perception of the consequences of congestion increase, and the allocation of revenues collected are the factors influencing the community acceptance.

Eliason & Jonsson (2011) identified the decisive factors for acceptability, namely: (i) effective reduction of congestion; (ii) environmental factors; and (iii) the low dependence of the car in concomitance with a quality public transport system. The authors used data from a referendum held in Stockholm (Sweden) to analyse respondents' attitudes. Hensher (2013) related the acceptability and stated intentions of the TDM action. Hensher & Liu (2013) proposed a methodology to analyse the challenges of the implementation of congestion pricing.

Cools et al. (2011) examined the effects of congestion pricing on people's tendency to adopt different transportation modes. As a lesson for policymakers, the results indicated that the congestion charge must exceed a minimum threshold to change travel behaviour and that the benefits of the fare should be clarified according to the different needs of the users. Effectiveness, justice, and the social norm have a significant direct impact on perceived acceptability.

Grange & Troncoso (2011) conducted an empirical analysis using linear regression to evaluate the impact of the car restriction on the traffic flow in Santiago, Chile. The authors considered two restriction scenarios: a permanent one, prohibiting the circulation of 40% of cars without a catalytic converter and another one for environmental emergencies (declared when air pollution reaches critical levels). The results indicated that the permanent restriction reached only 4% of the vehicles, generating no reduction in the flow. The emergency restriction reduced the number of cars (5.5%, on average), being lower than the authors' expectations.

Grisolía et al. (2015) investigated the factors to increase the acceptability of congestion pricing in Las Palmas (Spain) using focus group, exploratory factorial, and stated preference results. The results indicated a low willingness to pay to save travel time, despite the concern for environmental aspects. The population agrees to pay €2.22 if the revenue is invested in green areas and on the improvement of public transport by bus. Finally, the authors predict a strong rejection in the initial phase of implementation, with a considerable reduction of traffic in the area (approximately 74% of the vehicles). The low acceptability - ex-ante - is an indicator of a potential behavioural change in the market share.

Chorus et al. (2011) investigated the factors of acceptability regarding the congestion pricing among German politicians, and Ciommo et al. (2013) evaluated the acceptability of different stakeholder groups (freight and passenger transport operators, road concessionaires and private vehicle owner associations).

This brief review of the literature indicates the concern of acceptability as a key factor for the success of the congestion pricing measure. The scholars used different methodological approaches: descriptive analysis (Grísolia et al., 2015), agent-based model (Taeihagh et al., 2014), latent variables model (Sugiarto et al., 2015), discrete choice models (Chorus et al., 2011; Cools et al., 2011; Basso et al., 2011; Hensher, 2013; Grísolia et al.,2015), analysis of attitudes and theory of planned behavior (Jakobsson et al., 1999; Schade & Schlag,2003; Eriksson et al., 2006; Eliasson & Jonsson, 2011; Ciommo et al., 2013; Xianglong et al., 2016), exploratory factor analysis (Schade & Schlag, 2003;Grísolia et al., 2015), cost-benefit analysis (Eliasson,2009; Raux et al., 2012), user balancing model(Eliasson & Mattson, 2006), probit model (Hensher,2013), regression model (Schuitema et al., 2010; Grange& Troncoso, 2011), and theory of cognitive dissonance(Schade & Braum, 2007).

Table 1 summarises these approaches. Most of the analysis was carried out in European cities. Germany and Spain have the highest number of approach applied to analyse the congestion charge. In Stockholm, there are a high number of technical publication, do not included in this revision. In Latin America, we have found analyse only for Chile (Santiago). Also, we observed a combination of methods to analyse the acceptability as stated by Ciommo et al. (2013). Thus, this matter is necessary and incipient, and we intend to minimise this theoretical gap through the methodological approach adapted to the Brazilian context. We don’t identify studies including traffic simulation of the acceptability scenarios as we proposed in this paper.

RESEARCH APPROACH

We propose a methodology composed of four steps to analyze the acceptability of congestion pricing in the Brazilian context. The methodological structure is detailed throughout the next sub-sections.

Definition and analysis of attributes related to congestion pricing

Firstly, we identify the attributes considered to evaluate the urban mobility considering congestion, TDM-measures, and source of public revenues to implement

Table 1. Methodological approaches and countries where public acceptability was analysed

Methodological approach	Australia	Belgium	Chile	China	England	Germany	Greece	Italy	Indonesia	Norway	Spain	Sweden	Virtual environment
Agent-based													•
Cost-benefit					•							•	
Descriptive analysis											•		
Discrete choice	•	•	•			•					•		
Exploratory factor						•	•	•		•	•		
Latent variables									•				
Probit model	•												
Regression model			•									•	
Theory of cognitive dissonance						•							
Theory of panned behaviour				•		•	•	•		•	•	•	
User balancing												•	
Agent-based model													•

Q: annual water availability; *D*: annual domestic abstraction; *P*: Precipitation rate (mm/h).

these measures through the literature review.

Schlag and Teubel (1997) point out that information, awareness, perceived effectiveness, rights, individual transformed into behavioral intentions, but it depends on each particular situation: the possibility of acting accordingly to the intentions, and cost/benefit assessment. This decision happens, first, at the individual level and, later, at a collective level, influencing and reinforcing social norms. Thus, according to Schlag and Teubel (1997), it is possible to define the basic principles for the public acceptance of the congestion pricing, namely: (i) the congestion pricing targets should be addressed to public concerns and include environmental benefits as well as the reduction of the congestion level; (ii) road pricing has to be seen as the most effective solution among possible other travel demand management measures; (iii) the system must be easy to understand and use, and the operation must be complete and reliable since the launching of the solution, free from fraud and evasion, both deliberate and intentional; (iv) the system needs to ensure equity in terms of personal cost-benefit results, social comparisons among road users, and possible disadvantages among neighbouring cities; and, (vi) the implementation needs to be transparent and count on popular participation, so that people have confidence in the effectiveness of the measure, the use of revenues, impartiality, anonymity, and the preservation of privacy.

However, to meet the requirements listed above, Schlag and Teubel (1997) consider the creation of a smart marketing strategy to disseminate the congestion pricing through compelling media, with a focus on population, including public transparency in the management of the system. The principles presented by Schalg and Teubel (1997) and the literature review provided subsidies to the definition of characteristics of the congestion pricing in the Brazilian context. These characteristics are presented as attributes in **Table 2**.

claims, revenue allocation, and equity are decisive for the public acceptance of road pricing measures. According to these authors, acceptance can be

We highlight that Law 12,587/2012 supports the attributes considered in the survey, which prioritizes non-motorized modes and public transportation (Article 6, subsection III). Also, the urban toll revenue can subsidize public transportation, according to article 9, §1 and §5.

Also, we considered travel demand management measures (TDB-measures) interfere in people's mobility patterns and encourage the use of collective public transportation to assess the point of view of the specialists. The options (exclusive tracks or lanes to public transportation; restriction and control of parking spaces; transformation of parking areas into public infrastructure for cyclists; increases on the extension of sidewalks and/or parklets (replacing car parking spaces with structures for leisure and social spaces); vehicle restriction (time-window settlement and spatially restricted areas); and congestion charging with popular participation in the definition of revenue expenditure) were compatible with Law 12,587/2012 (Brazil, 2012), with the PlanMob Reference Book (Brazil, 2015), and with alternatives adopted in the major cities of the world to reduce the attraction of automobiles to the congested central areas. The options were ranked considering the respective effectiveness to improve urban mobility.

We consider the experts' point of view to evaluate these attributes related to congestion pricing. We developed a questionnaire with two-section questionnaire: (i) profile of the interviewees, and (ii) assessment of the attributes related to travel demand management. We used the psychometric Likert scale to assess the attributes listed in **Table 1**, considering five levels: completely disagree, partially disagree, indifferent or neutral, partially agree and completely agree. We used the Cronbach's alpha test to evaluate the accuracy of the responses.

We used the exploratory factorial analysis (EFA) for the analysis of the variables. This method is a statistical technique designed to define a common structure among the variables examined, reducing the number of attributes analyzed (Child, 2006). We evaluated the data by the Kaiser-Meyer-Olkin (KMO) test and the Bartlett Sphericity test. The KMO test measures the proportion of variance among variables that have a common variance. The data are suitable if the proportion is low (Kaiser, 1974; Hutcheson and Sofroniou, 1999). The Bartlett test for Sphericity compares the correlation matrix to the identity matrix, checking if there is a redundancy between the variables considered to summarize some factors. The Bartlett's Test of Sphericity must result in a value lower than 0.05 (Tabachnick and Fidell, 2007).

Table 2. Attributes related to the acceptability of congestion pricing in the Brazilian context

ID	Description of the attributes
01	The congestion reduction is a major challenge for public authorities regarding urban mobility.
02	The best solution to promote the reduction of congestion is to increase road capacity
03	The best solution to reduce congestion is to invest in public policy to discourage car use.
04	The best solution to reduce congestion is to invest in improvements in public transport services and road infrastructure for the bus system.
05	The best solution to reduce congestion is to invest in rail transport.
06	It is important to invest in solutions to reduce the congestion.
07	The management of urban mobility focused on improving the average speed of vehicles has social and environmental impacts.
08	The cars are primarily responsible for the high emission levels of greenhouse pollutants and local pollutants.
09	The high concentrations of pollutants from cars are among the main causes of respiratory and cardiovascular problems.
10	The congestion pricing is a good solution to reduce congestion.
11	The congestion pricing is a good solution for reducing the emission of pollution caused by cars.
12	The congestion pricing is a favorable measure for users of public transportation by bus since it can facilitate the reduction of bus travel times.
13	The congestion pricing operates as a positive redistribution of the economic system of road space in that car users pay for the use of urban roads, with the possibility of reversal of revenues collected in benefits for mobility.
14	Revenues from congestion pricing should be invested in public transport by bus.
15	Revenues from congestion pricing should be invested in non-motorized transport.
16	The revenue obtained from the congestion pricing shall be invested in rail transportation.
17	The public acceptability of congestion pricing depends on the legal commitment of the application
18	The popular participation in the decision-making process for the implementation of congestion pricing is essential to ensure the success.

Acceptability analysis of the residents

We developed a second questionnaire to obtain the data necessary to analyse the residents' acceptability of the congestion pricing in the Belo Horizonte metropolitan area (BHMA). We assessed the perception of people who travelled to/from the central area of Belo Horizonte.

The questionnaire is composed of five sections:

- Section 1 - characterization of the respondents: information about the frequency of car and motorcycle use; age; gender; household average income; neighbourhood of residence; reason for the main daily displacement; neighbourhood of destination; time, travel time, and mode of transport of the main daily trip. We analysed these data through descriptive statistics.

- Section 2 - travel frequency to justify the congestion pricing zone: information about trip frequency; mode of transport; traffic assessment; and the opinion on the importance of reducing the number of cars and motorcycles within the central area. We also analysed these data through descriptive statistics.

- Section 3 - urban mobility perception: six multiple-choice statements were presented to capture respondents' perceptions about urban mobility. The interviewees were asked to choose the statement that better suited their way of acting and thinking.

- Section 4 - congestion pricing in the central area (possible toll zone): the respondents were invited to choose an option out of a hypothetical strategy, considering: the charging process, the use of revenues collected, and the expected results, presented in **Table 3**. The development of strategies was based on Schade and Schlag (2003). In addition, the interviewees were asked about the impact of the congestion charge on their displacement and their emotional feeling to cope with the possibility of urban tolls in the central area. We then analysed these data using the descriptive statistics.

- Section 5 - attitudinal analysis: six statements based on the results of the experts' survey. We analysed these data with descriptive statistics and used the Cronbach's alpha test to evaluate the accuracy of the responses.

Table 3. Hypothetical scenarios to the collection, revenues, investment, and policy results.

Strategy	Collection	Revenue	Results
A	Monday to Friday, from 6 a.m to 8 p.m and same fee	50% of investment in public transportation 30% of investment in non-motorized transportation 20% subsidize public transportation fare	Reduction in congestion, travel time all day, improvement in environmental conditions and Investments in public transportation, bicycle path, sidewalks, and reduction on the public transportation fare
B	Monday to Friday, full fee between 6-9 a.m and 5-8 p.m 50% fee reduction between 9a.m to 5p.m	40% of investments in public transportation and non-motorized transportation 40% subsidize the public transportation fare	Reduction in congestion and travel time Improvement in environmental conditions Investments in public transportation, bicycle path, sidewalks, and reduction on the public transportation fare

Traffic impacts of congestion charging scheme

We considered result of acceptability identified from last step to perform a traffic simulation in order to identify the benefits of this scheme in a real network. We chose Aimsun in version 8.1 (TSS, 2015) as a traffic simulator. Also, we selected the part of the network from Belo Horizonte presented in **Fig. 1**. This area includes the avenues of Contorno, Afonso Pena and Getúlio Vargas, classified as arterial avenues, Professor Moraes avenue, Cláudio Manoel streets and section of av. Bernardo Guimarães, classified as collector roads, and other local roads.

We obtained the traffic demand through an origin-destination (OD) matrix from a 2012 OD-survey. We used an Aimsun tool called "Static OD Traversal" to generation the OD matrix of the study area, which allows the creation of a crossover matrix for subnetworks. We performed an adjustment of the traversal matrix through the Aimsun Static OD Adjustment Scenario tool from the volumetric counting data of 31 sensors present in the study area. The simulated scenario was the morning peak, set for the hours of 7 a.m. to 8 p.m. The study area is located in the south-central region of Belo Horizonte, a mixed, residential and commercial district, which promotes a balance in the displacements of the desired lines identified from the OD matrix to individual motorized trips (**Fig. 2**) show demand levels of the same order in both directions of the main road system. We also considered the public transport lines, itineraries, frequencies, bus stop and the average times of boarding and unboarding time.

We calibrate, and the parameters of the submodels to the simulator (Aimsum) represent the conditions found in the field. For this, we collected travel time data in some segments of the road network in the region selected. Half of the data set was used for the calibration

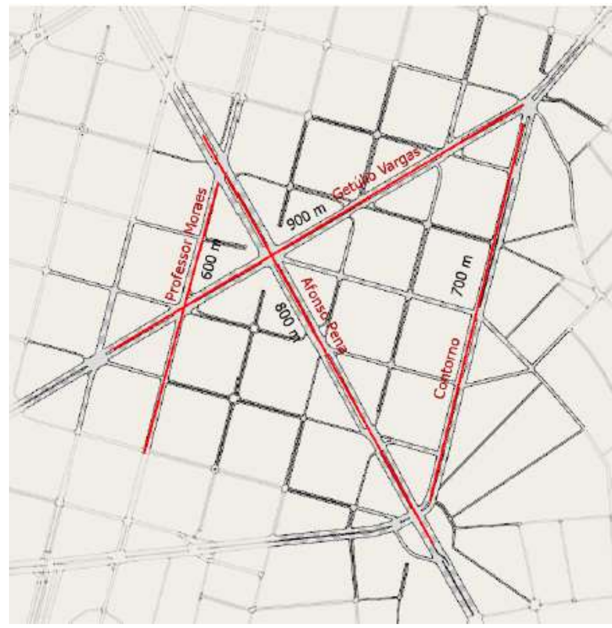

Fig. 1 The area of study.

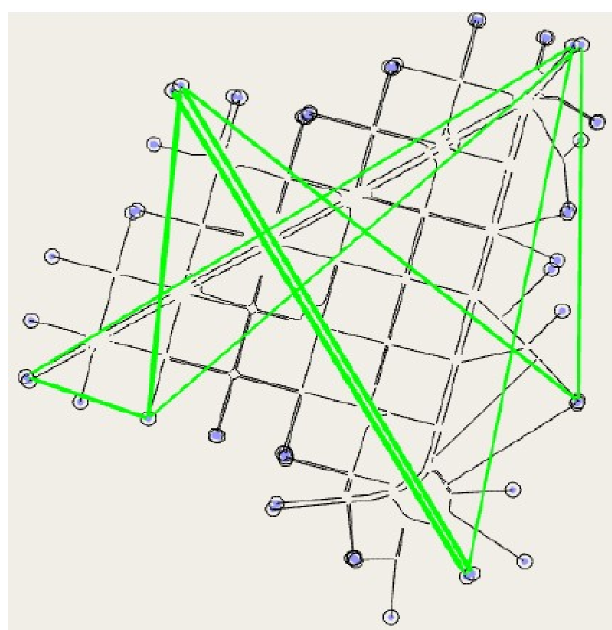

Fig. 2 Desired lines according OD-survey.

of the model parameters, while the second set of data was used to validate the parameters obtained in the simulation. These data was collected in two steps: one between 4-6 April 2017 and another between 18-20 April 2017. **Figure 3** shows the Box Plot graph with the travel time data used in the calibration. **Figure 4** shows the Box Plot graph with the travel data used in the validation step. We remove the outliers and obtain the average travel time.

We developed a Genetic Algorithm (GA) to perform the calibration of the behavioral parameters of the Aimsun. A GA consists of a search and optimisation technique based on the theory of evolution (Goldberg, 1989). The AG developed has the same general procedures used in other studies that performed the calibration of microscopic traffic simulators (Bessa Jr. et al., 2017; Bessa Jr. and Setti, 2018; Moreno et al., 2018).

The objective of this GA is to obtain behavioral parameters for that the travel time in road corridors (performance measure utilized in this study) had simulated and closely observed values. The search space and the default values of the parameters chosen for calibration are presented in **Table 4**, obtained from previous studies (Figueiredo et al., 2014; Giuffrè et al., 2015).

The solutions obtained for the problem through GA were composed of 20 individuals, and the stop criterion of the algorithm was the maximum number of generations equal to 20, with five replications using different seeds of random numbers. The crossover with a selection criterion of elitism type and rates of predation and mutation of 30% and 20%, respectively, were applied every two generations. The fitness function was the mean absolute normalized error (MANE) between the travel times of the corridors, observed and simulated, as shown by Equation 1.

$$MANE = \frac{1}{N}\sum_{i=1}^{n}\frac{|y_i - x_i|}{x_i} \quad (1)$$

where: n is the total of road corridors, by way; y_i is the i-th average travel time obtained by simulations; x_i is the i-th average real travel time.

We used the default parameters of the calibration parameters (**Table 4**) and found a MANE value of 0.32 for the microsimulated network. The application of the best solution found with AG in the traffic microsimulation AIMSUN (also presented in **Table 4**) provided a MANE value of 0.20, or 38% less than when using the default values of the parameters.

We performed a validation process by testing the best solution obtained in the calibration step considering the travel times found in the second data collection. The MANE value found was 0.13, a value 54% lower than found from the default parameters (0.28). The results of the parameters calibrated and validated for the Brazilian reality represent, in general, a more aggressive driver, in comparison to the default parameters of the simulator.

RESULTS

We sent the questionnaire with the attributes related to congestion pricing and TDM-Measures by e-mail to Brazilian Transportation Engineering specialist with the survey electronic link. The return rate was approximately 50%, with the participation of 348 specialists. The profile of the respondents is: 69% are between 30-59 years old, 54% have postgraduate level, and 68% use the car as their main mode of transport in daily commutes.

Table 5 presents the descriptive statistics from the attributes relates to the acceptability of congestion pricing. In general, the experts have a positive view of the attributes evaluated (column mode), except for the attribute two the best solution to reduce congestion is to increase road capacity. Up to 75% of the respondents (3rd quartile) believe that the congestion pricing is a good solution to reduce congestion and pollutants (attributes 10 and 11). Still, 50% of respondents agree that the congestion reduction is a major challenge for public authorities in the face of urban mobility (attribute 1), the public acceptability of congestion

Table 4. Default values, search space and solution of the GA for the parameters of calibration.

Parameter	Behavioraul Model	Default	Search Space Minimum	Search Space Maximum	Value obtained by **AG**
Number of vehicles	Car-Following	4	1	6	1
Maximum distance between vehicles (m)	Car-Following	100	50	150	138.88
Maximum diference of the velocity (km/h)	Car-Following	50	25	75	34.27
Reaction time (sec)	Reaction time	0.75	0.50	2.00	0.64
Reaction time on “STOP” (sec)	Reaction time	1.35	0.70	3.00	0.84
Reaction time on traffic light	Reaction time	1.35	0.70	3.00	1.25
Maximum velocity for cars (km/h)	Vehicle characteristics	110.0	50.0	180.0	74.47
Maximum acceleration for cars (v/s)	Vehicle characteristics	3.00	2.00	4.00	3.65
Acceptance of speed for cars (X/X)	Vehicle characteristics	1.10	0.50	2.00	0.64
Minimum distance between vehicles and cars (m)	Vehicle characteristics	1.00	0.50	2.00	0.56

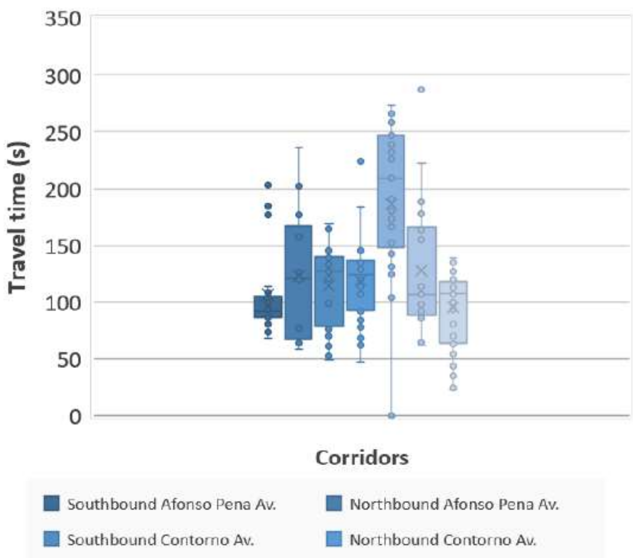

Fig. 3 Travel time used in calibration step.

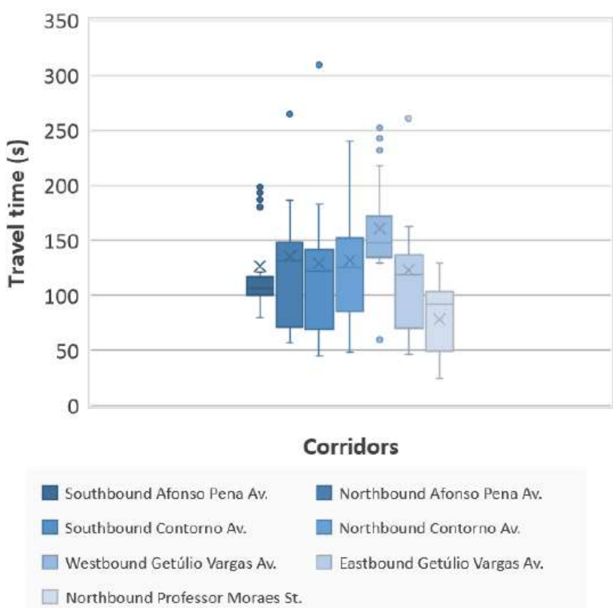

Fig. 4 Travel time used in validation step.

pricing depends on the legal commitment of the application of revenues collected (attribute 17), and the popular participation in the decision-making process for the implementation of congestion pricing is essential to ensure the success (attribute 18). The Cronbach's alpha was calculated, and the result of 0.79 indicates that the consistency of the answers is acceptable.

We obtained 0.8 out of the Kaiser-Meyer-Olkin (KMO) test and -294.81 out of the Bartlett Sphericity test, indicating that the data are suitable to be analyzed through a factorial exploratory method. Six latent variables, which explained 64.3% of the accumulated variance, were considered. **Table 6** shows the factor loadings and the communalities of each attribute, eigenvalues, variance and accumulated variances regarding each factor. The communalities indicate the power of explanation of the attribute by the factors: the attributes 1 and 16 are explained in 70%; the attribute ten is explained in 80%. Other main communalities results are highlighted in **Table 6**.

Considering these results, we took into account the following attributes to analyse the attitudinal behaviour of the residents, ranked concerning the respective importance:

- Attribute 10: The congestion pricing is a good solution to reduce congestion;
- Attribute 8: The cars are primarily responsible for the high emission levels of greenhouse pollutants and local pollutants;
- Attribute 5: The best solution to reduce congestion is to invest in rail transport;
- Attribute 1: The congestion reduction is a major challenge for public authorities in the face of urban mobility;
- Attribute 4: The best solution to reduce congestion is to invest in improvements in public transport services and road infrastructure by bus;
- Attribute 18: The popular participation in the decision-making process for the implementation of congestion pricing is essential to ensure its success.

The results of the factorial analysis indicated a consensus that the congestion pricing is a solution to reduce congestion, with the car being responsible for the high levels of pollution. The investment in public transportation (railway or bus system) is a solution for the improvement of the urban mobility, and the popular participation is essential for the implantation of the congestion pricing. The acceptability of the urban toll depends on the legal commitment concerning the expenditure of revenues towards the improvement of thepublic transport system. In summary, the revenues from congestion pricing can subsidize an efficient public transportation system.

Analysis of the attributes related to congestion pricing and TDM-measures

We collected information using a Web-based survey and face-to-face survey from October to November 2016 with residents who travelled to and from the central area of Belo Horizonte. We obtained 674 valid responses. Considering the origin and destination of the interviewees: 88% lives in Belo Horizonte, and 95% have Belo Horizonte as their main destination. Also, 60% have Belo Horizonte central area as a destination (zone considered to congestion pricing). We present the

Table 5. Descriptive statistics for the attributes related to the acceptability of congestion pricing (1 = completely disagree; 2 = partially disagree; 3 = indifferent; 4 = partially agree; 5 = totally agree).

Attribute	Minimum	1st quartile	Median	3rd quartile	Maximum	Mode
1	1	4	5	5	5	5
2	1	1	2	2	5	1
3	1	4	4	5	5	4
4	1	4	4	5	5	4
5	1	4	5	5	5	4
6	1	4	4	5	5	5
7	1	4	4	5	5	5
8	1	4	4	5	5	4
9	1	4	4	5	5	4
10	1	4	4	4	5	4
11	1	3	4	4	5	4
12	1	4	4	5	5	4
13	1	4	4	5	5	5
14	1	4	4	5	5	5
15	1	4	4	5	5	5
16	1	4	4	5	5	4
17	1	4	5	5	5	5
18	1	4	5	5	5	5

Table 6. Descriptive statistics for the attributes related to the acceptability of congestion pricing (1 = completely disagree; 2 = partially disagree; 3 = indifferent; 4 = partially agree; 5 = totally agree).

Attribute	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communalities
1				-0.82			0.70
2		0.48					0.36
3	-0.72						0.56
4					-0.74		0.69
5			0.82				0.74
6				-0.79			0.67
7		-0.53					0.50
8		-0.79					0.64
9		-0.76					0.63
10	-0.89						0.80
11	-0.83						0.75
12	-0.79						0.67
13	-0.81						0.69
14					-0.70		0.67
15					-0.63		0.67
16			0.78				0.70
17						-0.45	0.57
18						-0.71	0.57
Eigen values	3.73	1.87	1.55	1.58	1.57	1.26	>1.00
Variance	20.7%	10.4%	8.6%	8.8%	8.7%	7.0%	
Accumulated variance	20.7%	31.1%	39.8%	48.5%	57.3%	64.3%	>60.0%

respondent's profile information in **Table 7**: population interviewed use car or motorcycle (54%), income from 3,520 to 8,800 (1US$ ≈ R$3.2) (39%), displacement due to work (78%) and travel time between 16 to 30 minutes (32%). Considering the travel frequency to congestion pricing zone proposed, in general, the respondents travel 4 to 5 times per week to the central area (46%). Despite the fact that cars and motorcycle are the main transportation mode in trips to the Central Area of Belo Horizonte, 46% of respondents use of public transportation.

We present the urban mobility perception in **Table 8**. Environmental concerns and an effective public transportation system could attract motorized transport users to other modes. On the contrary to common sense, only 3% consider the car to be a symbol of status, and respondents do not corroborate with tax-exempt policies for reducing vehicle and fuel prices. These results support the acceptance of the urban congestion price, since the literature indicates that the greater the awareness of environmental causes or the perception of the importance of air quality, the greater the agreement with this measure (Jaensirisak et al., 2005; Janssens et al., 2009; Fürst and Dieplinger, 2014).

We present the results regarding the public acceptability in **Table 9**. The strategy B is the most acceptable (full charges for entering the congestion pricing zone at peak hours – from 6 a.m to 9 a.m and from 5 p.m to 8 p.m – with a 50% fee reduction between 9 a.m and 5 p.m), with acceptance of 41% of the respondents. The strategy A, the most restrictive, had 38% of acceptability among respondents, with a greater acceptance of public transport users. We highlight that strategies A and B have the preference of 78% of the respondents and are considered advantageous for 50% of them. However, the interviewed users of motorized transport perceive strategies A and B as disadvantageous in relation to the current situation, and 79% prefer the current situation (strategy C).

These results corroborate with the reflections of Garling and Schuitema (2007), who affirm that isolated measures are not effective in reducing the use of the private vehicle. Anas and Lindsey (2011) argue that improving public transportation is an important success factor for congestion pricing schemes. Moreover, this scheme is more likely to be accepted in cities with good public transportation systems or with significant investments before the implementation, as happened in London. Unfortunately, the poor evaluation of the public transportation in Belo Horizonte and the high dependence on private vehicles (2.05 inhabitant/car) donot represent a favorable situation for the success of this measure.

We also present the acceptability and the availability of payment if strategies A or B were implemented in **Table 9**. Although strategies A and B had a higher percentage of acceptability (78%), 68% of the respondents stated that they would not pay, 44% would maintain their current transportation alternative, and 24% would choose other modes. Out of the 32% of the respondents that would accept to pay, 24% agree that the daily fare should not be higher than R$10. We emphasize that users of non-motorized and public transportation have stated that they 'would eventually pay' the congestion pricing when using car or motorcycle for displacements within Central Area.

The results indicate that, despite the high percentage of respondents favoring the implementation of congestion pricing (78%), when faced with a possible daily fare, acceptability related to payment drops to 32%, with 24% paying no more than R$10. These results indicate that, in theory, the congestion pricing is a good solution. In practice, with the payment of the fare, few citizens are favorable to this scheme.

Traffic impacts results

The results of traffic impacts are presented in **Fig. 5** (density), **Fig. 6** (queue length), **Fig. 7** (delay time) and **Fig. 8** (travel time). For them, the impact of the reduction of car demand was evaluated, with simulated scenarios with the following levels of automobile demand: i) 100%, which represents the demand observed in the field (of the data set used in the Aimsun calibration); ii) 76% (from 24% of reduction of car demand due the use other transportation modes); iii) 52% (a hypothetical scenario with reduction of 48% of demand)); and iv) 34% (a hypothetical scenario with reduction of 66% of demand).

It is evident the benefits with the reduction of car demand in the traffic. Although the decrease in travel time, the reduction of the queue length (**Fig. 6**) and delay time (**Fig. 7**) imply in an improvement of the traffic conditions.

CONCLUSION

This paper presents an analysis of the acceptability of congestion pricing in Brazilian cities. We carried out interviews with experts and residents to obtain information to do the analysis.

The main variables regarding the favorable position towards congestion pricing, from specialists' viewpoints, regarding the Brazilian transportation structure, were identified in this study. Among other important

Table 7. Belo Horizonte residents' profile

Information		Main mode of transportation: Car or motorcycle	Non-motorized modes	Public transportation	Total	Percentage
Gender	Female	181	21	128	330	49%
	Male	183	49	112	346	51%
Age	18 to 25 years	38	14	71	123	18%
	26 to 35 years	117	33	100	250	37%
	36 to 45 years	100	17	37	154	23%
	46 to 60 years	79	5	28	112	17%
	> 60 years	30	1	4	35	5%
Income	< R$1,660	50	13	93	156	23%
	R$1,661 to R$3,520	66	13	64	143	21%
	R$3,521 to R$8,800	162	34	65	261	39%
	R$8.801 to R$16,600	70	9	17	96	14%
	>R$16,601	16	1	1	18	3%
Reason for displacement	Study	32	13	52	97	14%
	Work	300	49	175	524	78%
	Other	32	8	13	53	8%
Travel time	< 15 minutes	66	22	6	94	14%
	16 to 30 minutes	146	30	40	216	32%
	31 to 45 minutes	43	2	61	106	16%
	> 60 minutes	17	2	75	94	14%
Evaluation of urban traffic in relation to 5-years	Remains the same	120	15	74	209	31%
	Improved	61	7	40	108	16%
	Got worse	183	48	126	357	53%
Weekly travel frequency to Central Area	1 to 3 times	100	20	49	169	25%
	4 to 5 times	122	30	161	313	46%
	Rarely	142	20	30	192	28%
Transportation mode to Central Area	Car or motorcycle	281	9	10	300	45%
	Non-motorized modes	9	46	10	65	10%
	Public transportation	74	15	220	309	46%
Total		364	70	240	676	100%
Percentage		54%	10%	36%	100%	–

Table 8. Perceptions of respondents related to urban mobility.

Statement evaluated	Percentage
I worry about air pollution and the noise produced by vehicles.	68%
I would reduce the use of my car/motorcycle if public transport served me better.	67%
The city centers should be, primarily, for pedestrians and public transportation.	63%
I believe that cars/motorcycles should have less space on urban roads.	36%
I cannot stop using my car/motorcycle because I cannot do everything I have to do using public transportation.	4%
Vehicles and fuels should be cheaper, so more people can have/move around by car/motorcycle.	7%
Nothing makes me stop using my car/motorcycle because it is very important to me.	3%

Table 9. Acceptability and evaluation of urban congestion pricing strategies.

Evaluation		Car or motorcycle	Non-motorized modes	Public transportation	Total Percentage
Strategy	Strategy A	37%	16%	48%	38%
	Strategy B	57%	9%	34%	41%
	Strategy C	79%	3%	17%	21%
TOTAL		54%	10%	36%	100%
Evaluation of the strategies in relation of current situation	Disadvantage	86%	2%	12%	32%
	Not important	60%	6%	34%	18%
	Advantage	33%	17%	50%	50%
TOTAL		54%	10%	36%	100%
Acceptability of payment	I use the same mode of transportation	-	17%	83%	44%
	I use other transportation modes	100%	-	-	24%
Value of congestion charge	< R$10	65%	5%	30%	24%
	R$11 to R$20	73%	15%	30%	24%
	R$21 to R$30	70%	15%	15%	1%
	R$31 to R$40	100%	-	-	1%
TOTAL		37%	41%	22%	100%

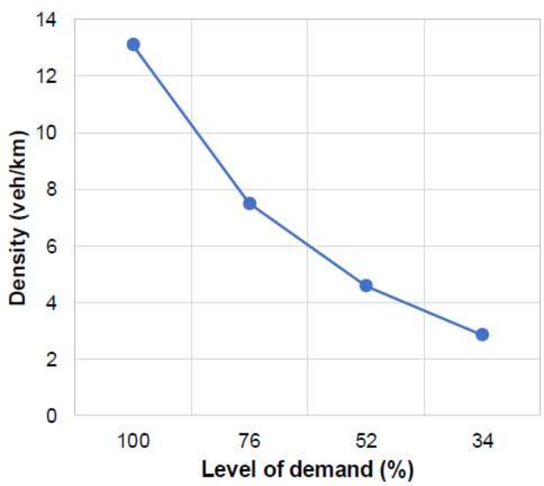

Fig. 5 Evaluation of the reduction of the demand for automobiles in the average values of the density.

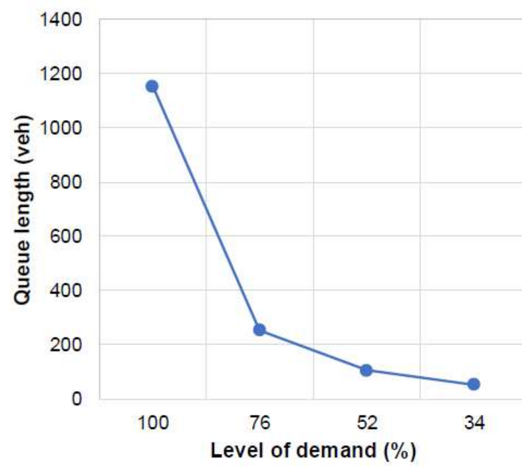

Fig. 6 Evaluation of the reduction of the demand for automobiles in the average values of the queue length.

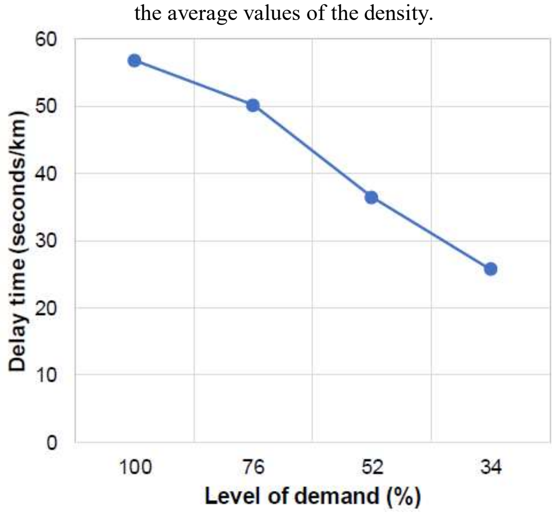

Fig. 7 Evaluation of the reduction of the demand for automobiles in the mean values of the delay time.

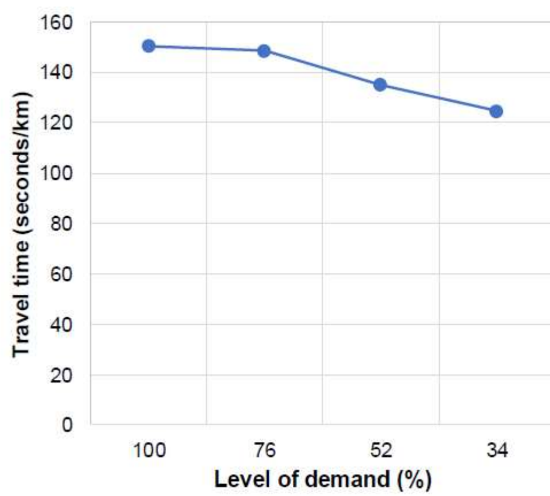

Fig. 8 Evaluation of the reduction of the demand for automobiles in the average values of travel time.

conclusions, it is worth noting the importance of directing more investments in mechanisms to minimize congestion, reduce traveling times, and improve environmental quality and economic efficiency of cities. Experts have expressed their opposition regarding investments in transport infrastructure (such as tunnels, viaducts, trenches) to increase road capacity, and have agreed that urban mobility management, focused on the improvement of vehicle speed, has social and environmental impacts. In general, considering the experts' viewpoint, the urban toll is a better solution to reduce congestion than to reduce the emission of pollution caused by cars.

The results also indicated that the adoption of congestion pricing could be a favorable measure for public transportation users since it reduces travel time and brings improvements to service quality. Thus, congestion pricing can be an economic system of positive redistribution of road space, in which users of cars/motorcycles pay for the use of urban roads, with the possibility of reversing revenues in benefits for urban mobility, being acceptable by experts. Still, the experts consider that the monetary resources obtained from the congestion pricing scheme should be invested in the improvements of services and infrastructure of public transportation by bus (considering the method of successive intervals) and in the implementation of railway transportation system (considering factorial analysis). The investment in non-motorized transport is the best option for users of this mode of transportation.

For the implementation of congestion pricing to promote demand management, the transparency and participation of the population in the process, as well as the legal commitment of the governments in the issues and decisions concerning the investment of the revenues are crucial matters.

Thus, we conclude that demand management tools must be associated and that urban toll implementation cannot be an isolated solution. Therefore, we must invest in improvements of public transportation and non-motorized modes and in a more restrictive parking policy in the central areas of cities to enhance the success of the congestion-pricing scheme.

Still, in this paper, we presented the acceptability of residents of the Belo Horizonte Metropolitan Area in relation to congestion pricing. Considering the literature reference and Law 12,587/2012, we developed a questionnaire to identify the travel frequency of respondents to the central area (possibly toll zone), the acceptability of congestion pricing, the availability for payment, and the prioritization of solutions for the improvement of urban mobility.

The results presented in this paper indicate that the congestion charging in the central area of Belo Horizonte is a challenge for urban planners and administrators. In this case, there is a significant percentage of the respondents who declare that they do not accept payment. In contrast, respondents consider reducing congestion as a major challenge for urban mobility enhancement. These results also corroborate with the literature: acceptability can be considered low, and there is behavioral change when the residents perceive the benefits of the implementation of congestion pricing revenues in the improvements of public and non- motorized transportation. However, before the implementation of congestion pricing, there should be investments in public transportation and non-motorized systems that meet the aspirations of the population and allow the modal shift of users of private transport.

Finally, we simulate the traffic impacts with the reduction of car demand, considering the Central Area of Belo Horizonte. The results demonstrate the benefits of this measure to reduce the congestion (considering the queue length and delay time).

Considering the results, we conclude that transport demand management is essential for cities due to its influence on the main transportation mode of residents, especially if non-motorized modes and public transportation systems are effective. Considering these transportation alternatives, the congestion pricing could reduce urban traffic (related to car and motorcycle) and, consequently, the congestion.

However, the congestion pricing is an unpopular solution given that no one would like to spontaneously pay for the use of a 'public' road space, which has always been available for citizens free. Also, we have identified that, in Brazil, the participants agreed that, in order to increase the acceptability, transparency, and participation of the population throughout the urban toll implementation process, it is important to have the public authorities committed with the effectiveness of alternative transportation schemes to replace cars for daily commutes.

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