CONGESTION COST IN MASS TRANSIT SYSTEMS; PRICING AND INVESTMENT POLICY IMPLICATIONS –CASE STUDY: BOGOTÁ´S BRT SYSTEM

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ABSTRACT

This paper estimates the effect of congestion inside Bogota´s BRT system in the loss of welfare, based on Pigou's externality theory. We developed a methodology to assess the optimal comfort condition according to users' perception and comparing it to the actual situation in Transmilenio which is critical. The social cost of not being at the optimal state of comfort is USD$6,700 per hour for the entire system. In the specific case of mass transit we do not think that an internalization charge should applied. Instead the result allowed us to define the necessary level of investment for reducing the "congestion cost" to maximize welfare. Demand implications, benefits and other possible effects related with these solutions are analyzed.

INTRODUCTION

Traditionally, the analysis of congestion in transport systems has focused primarily on the delays and loss of speed for private transport, leaving aside the effects of congestion on other transport modes, such as mass transit systems. Transit congestion has not been considered as a social cost while appraising transport system solutions (Prud'homme, Koning, Lenormand, & Fehr, 2010); besides the congestion charge schemes for private vehicles may increase the cost of congestion in public transport. One of the main disadvantages of mass transit systems is the lack of comfort; this is related to the in-vehicle high passenger density as a consequence of overcrowding in certain time periods. This situation results in the users' benefit reduction, due to deterioration of the quality of service, users may will to wait for a less congested vehicle or may be forced to board an overcrowded one, this situation represents an extra journey cost for individuals and this is the transit congestion cost. It is possible to maximize the social welfare by investing in reducing this cost, improvements of different nature can be considered as possible alternatives for reducing the congestion cost to the optimal. In this paper, an investment policy formulation tool for mass transit congestion cost reduction is developed and proposed.

THE COST OF CONGESTION

Pigou's social cost theory states that, in certain markets, the excessive consumption of a service or good may imply a marginal increase in individual's cost (Ic in Figure 1). This situation creates an inefficient resource allocation due to the lack of internalization of the cost that each single individual generates to the rest of the society, so there is a marginal social cost caused by the excessive consumption (MaSC in Figure 1). Then, for a determined demanded quantity there is always a difference between de Ic and MaSc which is the externality linked to the consumption. These statements have been widely applied in congestion theory in transport systems.

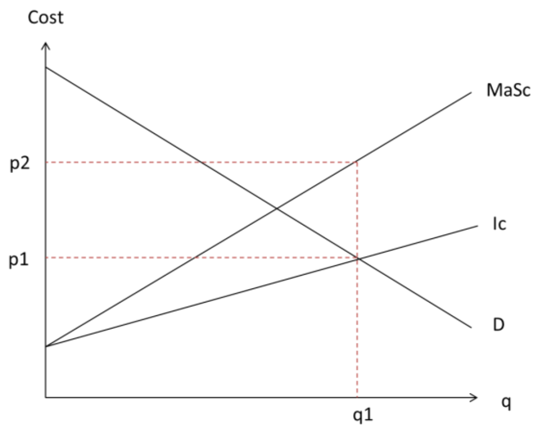

Figure 1. Pigou's traditional curve.

It is well known which the effect of congestion on urban private transport is; the traffic theory says that ever since the amount of vehicles trying to use a road at the same time increases the mean spatial speed decreases. This means that every single car that wants to incorporate to the flow makes all the other cars go slower, Figure 2A shows a typical volume-speed curve; it is the plot of a monotone decreasing function. This phenomenon has a direct effect on the travel cost for the individuals, because it represents an increase on the travel time due to the delays generated on the congested road (Figure 2B).

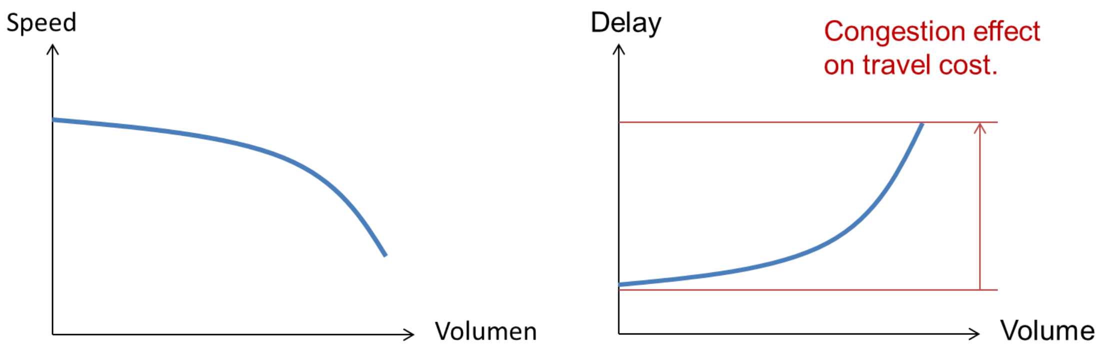

Figure 2. A. Volume-Speed curve B. Volume-Delay curve

Even higher is the effect of congestion if it is seen from a broader perspective, the extra cost caused by a single user to the society will be the individual travel cost plus the cost that he/she generates to the users that are using the infrastructure simultaneously (marginal social cost). Since the individual only perceives he's own cost, there's an externality that is not reflected on the cost function he computes to take decisions. That's why a correction to this market failure should be applied; this means that an external actor might charge the user for using the road when congestion occurs, this is called congestion charge.

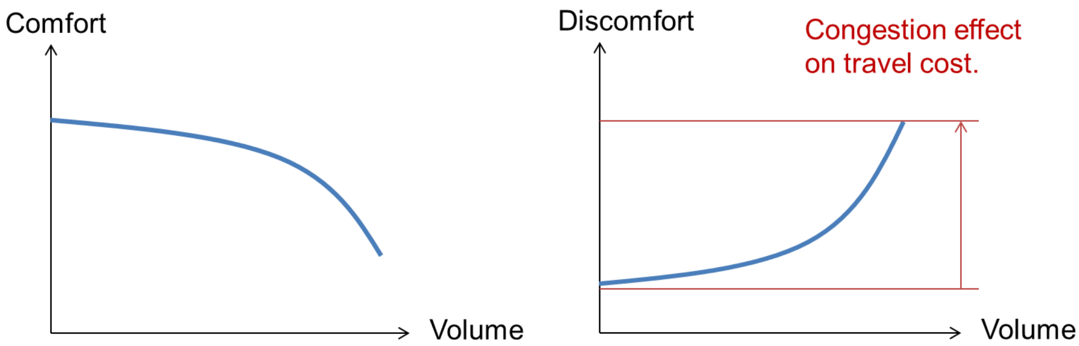

Figure 3. A. Volume-Comfort curve B. Volume-Discomfort function

In the case of urban public transport, the effect of congestion inside the system is not as evident as in the case of private transport. Let us think about a mass transit system, with segregate right of way (no physical interaction with private vehicles), if the volume of passengers trying to use the system's services at the same time increases: which would be the effect on individual cost for each user? The main effect would be that individual would be forced to travel in a less comfortable situation; this means that the comfort decreases while de volume of passengers increases (Figure 3 A). As it happens in the case of private transport congestion cost, the increase in volume of users brings an increase in individual cost; the comfort loss (discomfort increment, Figure 3 B). Analogously to private transport, this has social cost effects and a similar analysis to the non-internalized costs may be carried out.

Prud'homme (et al, 2010) conducted a stated preferences survey in the Paris' metro system to estimate the cost of congestion inside the vehicles during the peak hour of a weekday; Based on the collected data passengers' willingness to pay for a less congested travel situation was estimated and a potential congestion cost reduction by implementing a congestion charge was determined. This methodology may represent a transport policy formulation tool regarding congested transit systems.

CONTEXT

TransMilenio is the Bogotá's Bus Rapid Transit (BRT); it was conceived as a high capacity system and as the main component of the local transit network. Nowadays it has 84 km of segregated bus lanes, an important feeder line system, 114 stations including 7 terminal stations. Infrastructure has not evolved from 2005 to 2010, it has not grown. The size of the bus fleet has grown 2.2% and daily demand grew from 1'300,000 to 1'700,000 passengers (30%) in the last five years (EMBARQ, 2009). In Figure 4 the evolution of demand along the past 10 years is presented.

The Colombia's capital BRT has high levels of congestion in two periods that take place in the morning and afternoon, related with work and academic schedules . The passenger density inside the vehicle in peak hours, has led to the deterioration of the quality of service (Cámara de comercio de Bogotá, Universidad de los Andes, 2011). TransMilenio currently carries, nearly 170,000 passengers in the morning peak hour, the current fare is of USD$0,972 for the entire day. Daily, the system carries approximately 1.7 million passengers, meaning that 10% of all trips are made in the highest demand period (6:30 a.m. to 7:30 a.m.). This creates an extreme passenger density situation inside the vehicles, in average 6.5 passengers per square meter (EMBARQ, 2009).

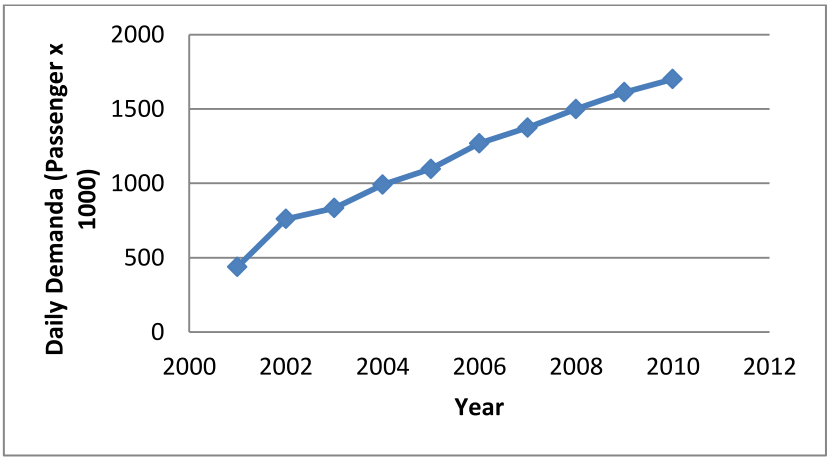

Figure 4. Evolution of daily demand (Source: Own Elaboration based on TransMilenio data)

This situation has generated an institutional and public image crisis to the system. TransMilenio has the great challenge of recover the high service standard and user satisfaction indexes that, in the early years of operation, made the system an international mass transit reference.

METHODOLOGY

To estimate the social cost of congestion in Bogotá's mass transit system it is necessary to construct the mean individual cost function for the morning peak hour users. This function will depend on the passenger density inside the vehicle the user is going to travel in; it is possible to express this function in terms of total demanded quantity by assuming that the relation between total area supplied and passenger density in the period of analysis is linear. The relation between passenger density and individual mean cost is determined by estimating individuals willingness to pay (WTP) for a less congested situation. It is worth saying that in peak hour average occupation of buses is homogeneous in most of the system.

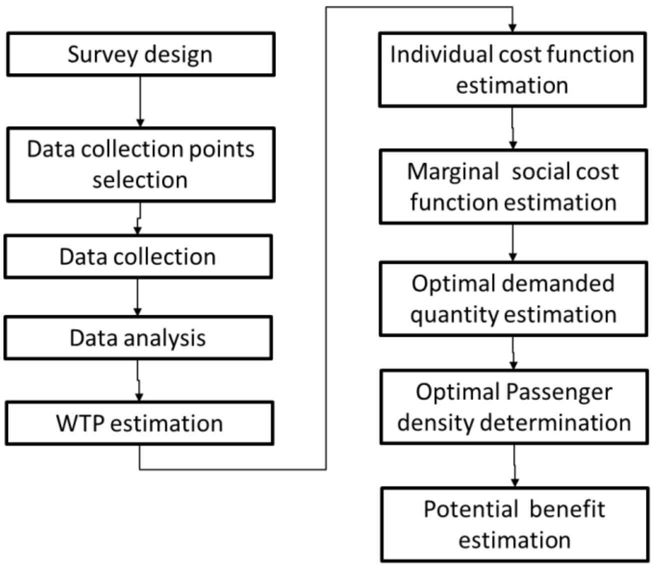

Figure 5. Methodology conducted

For the analysis, it was necessary to find the stations which represent the general situation of congestion. Naturally, in the morning peak hour, congestion occurs in the vehicles that go towards the city's CBD, along the main system lines. To choose the stations another criteria was the possibility of using different "services" to get to destination. Transmilenio offers normal and express routes and in some cases the possibility to use different corridors to access some destinations.

To estimate the WTP, a stated preference survey was conducted in the most representative system stations, securing that all demand strata were properly represented in the sample. To avoid biases respondents were asked for their WTP in time units, rather than WTP in monetary units. Individuals were asked for how long they were willing to wait for a better situation of passenger density inside the vehicle, along with some information that helped to identify the socio-economic characteristics of the respondents such as gender, age and income group. The income group was determined by geo-referencing the location of respondent's home to avoid wrong information. The questionnaire included the origin and destination stations for the estimation of in-vehicle trip distance. This information also allowed us identifying the users that were transferring from one line to another in the moment they were enquired.

Respondents were asked for their willingness to pay (in time) for three different passenger density trip situation (4 pas/m^2, 3 pas/m^2 and 2 pas/m^2). Individuals were asked if they would wait 5 extra minutes for the first situation; if the response was positive they were asked if they would wait 10 minutes, and so on. At the moment the respondent answered that he or she would not be willing to wait longer, a similar questionnaire showing the second and third situation were presented. This process allowed us to determine the maximum time that each user was willing to wait for each congestion situation. Images of each situation, used in the survey are presented in Figure 6.

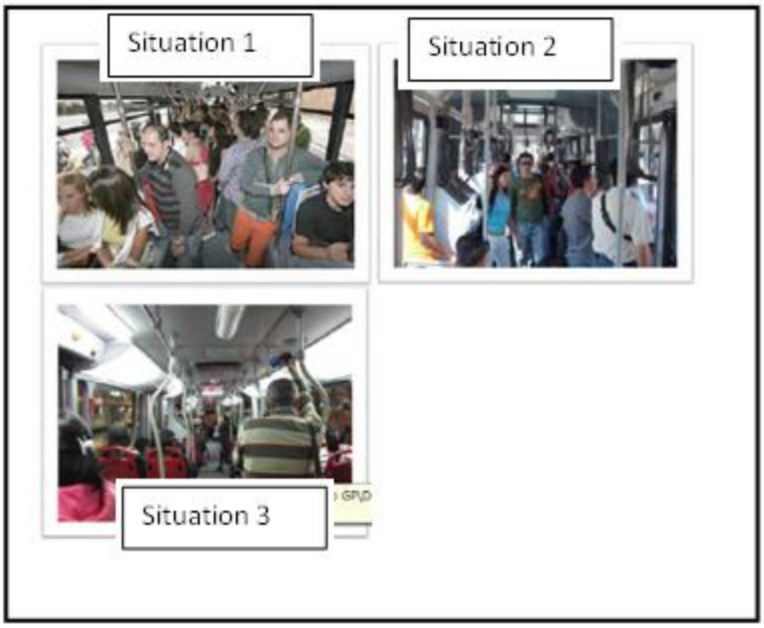

Figure 6.Passenger density situation images used in the survey

Note that the survey does not allow for irrational behaviour in the individual responses, since is not possible for a respondent to give an answer in which he or she has a higher WTP for the most congested situation.

Through an econometric model the WTP is estimated as a function of passenger density (d), this represents the congestion cost (Cc) for an individual and it is part of the generalized individual cost function for transit users (Ic in Equation 1). In-vehicle density can be expressed as a function of demanded travel quantity (Equation 3), ever since transport supply could be assumed as constant along the analysis period. By replacing Eq. 3 in Eq. 2,

Cc can be expressed as a function of **q**, this means that congestion cost depends on the demanded travel quantity.

$$\text{Ic} = (\text{Fare}) + (\text{Travel Time} \times \text{Value of Time}) + \text{Cc} \qquad (1)$$

$$\text{Cc} = \text{WTP} = \text{f(d)} \qquad (2)$$

$$\text{d} = \text{g(q)} \qquad (3)$$

Since every single user of the system increases the individual cost for the others, there is a marginal social (**MaSc**) cost that depends on **q**. The **MaSc** function is calculated by using Equation 4. The demand curve (D) was determined based on previous studies on elasticity to cost, Figure 7 shows de plot of these functions.

$$\text{MaSc} = \text{Ic} + \frac{\partial \text{Ic}}{\partial \text{q}} \times \text{q} \qquad (4)$$

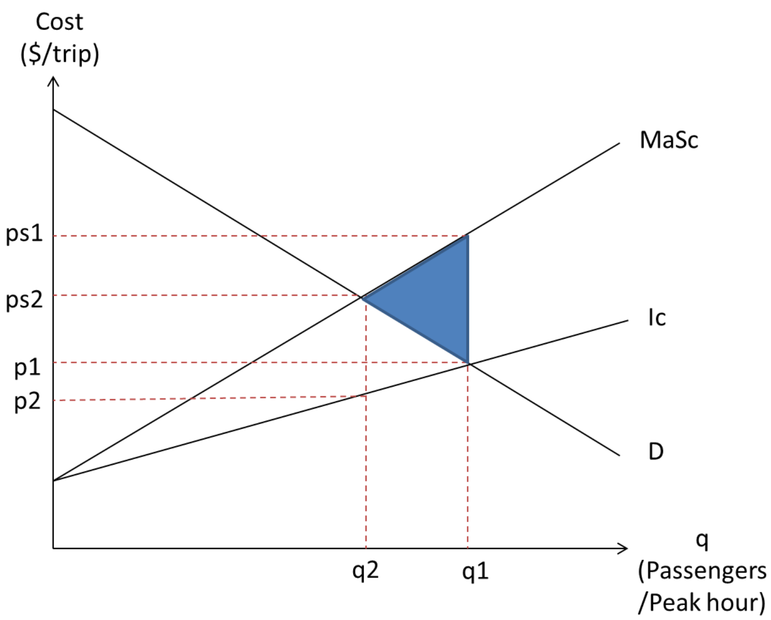

Figure 7. Individual Cost, Marginal Social Cost and demand functions

The difference between p1 and ps1 is the un-internalized cost of a single trip at the current equilibrium demanded travel quantity q1 (the second term in Eq. 4). Remaining close to the private transport situation, implementing a congestion charge in this case may be considered as a measure aiming the reduction of congestion social cost. It is possible to determine the optimal passenger density by estimating which would be the travel demanded quantity if this charge is added to the current fare (q2, ps2), however this would lead to a reduction of system affordability for the lower income groups bringing undesired effects in terms of equity and accessibility due to passenger travel budget restrictions,. An alternative solution to the congested situation is related to investment policy, looking for the improvement of the system which may lead to congestion cost minimization. This may be done by providing a level of comfort that secures the optimal passenger density in each vehicle of the system during the peak period, the social benefits of this alternative possibility should be equal to the benefits that a congestion charge could bring (Shadowed area in Figure 7, Equation 7), ever since it is the optimal congestion cost reduction for the system. There might be an increase in the travel demanded quantity due to the reduction of the generalized individual cost; therefore it is necessary to increase the supplied total area, a new equilibrium would occur at q3 and p3 (Figure 8)

$$\textbf{Congestion Charge benefit} = \int_{q2}^{q1} \textbf{MaSc} - \textbf{D}\, \textbf{dq} \quad (5)$$

$$\textbf{Investment policy benefit} = \left(\int_{0}^{q1} \textbf{MaSc}\, \textbf{dq}\right) - \left(\int_{0}^{q3} \textbf{MaSc}^{*}\, \textbf{dq}\right) \quad (6)$$

$$\int_{q2}^{q1} \textbf{MaSc} - \textbf{D}\, \textbf{dq} = \left(\int_{0}^{q1} \textbf{MaSc}\, \textbf{dq}\right) - \left(\int_{0}^{q3} \textbf{MaSc}^{*}\, \textbf{dq}\right) \quad (7)$$

$$\textbf{Ic}^{*} = \textbf{D} \quad (8)$$

Equation 6 represents the benefits attained by reducing MaSc by improving the comfort in the buses, it is the reduction of total Social Cost. The solution of the set of equations (7) and (8) will determine the demanded travel quantity in the improved system scenario (q3), furthermore the optimal density can be estimated by computing the Equation 3.

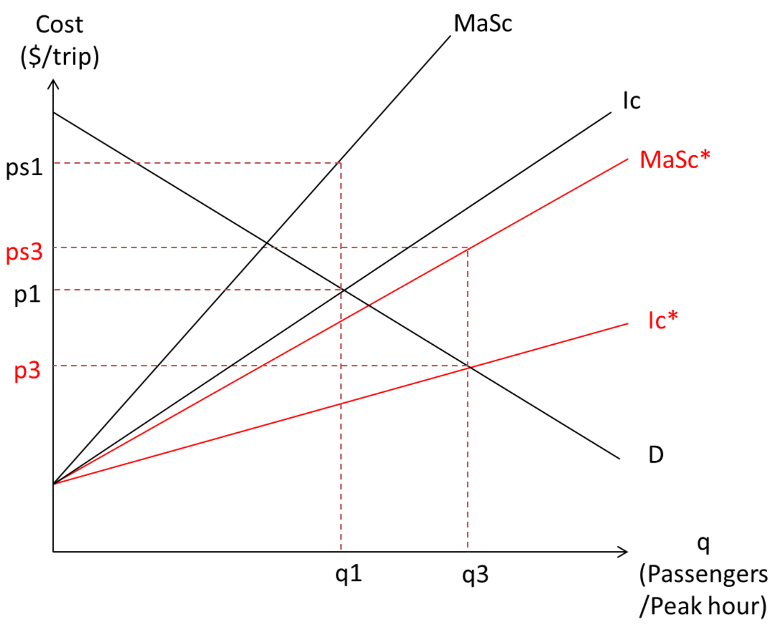

Figure 8. Congestion cost reduction by improving quality of service

The result of this process is the estimation of the optimal congestion cost reduction in a mass transit system achieved by improving the quality of the service provided, taking into account the possible demanded travel quantity increases due to the generalized cost reduction that it brings.

RESULTS AND ANALISYS

A total of 3,273 valid observations were obtained from the stated preferences survey conducted in 8 of the TransMilenio stations. The main descriptive statistics are presented in Table 1. The sample income group distribution is presented in Figure 9. The higher the income group number is the higher the mean home income is, this distribution is quite similar to the distribution reported by Embarq (2009) for system users.

Table 1. Main descriptive statistics

Total Respondents	1,091	
Male	54.50%	
Female	45.50%	
Age	30.4	(11.2)
Estimated in vehicle distance (km)	10.2	(4.65)
Standard deviation in parenthesis		

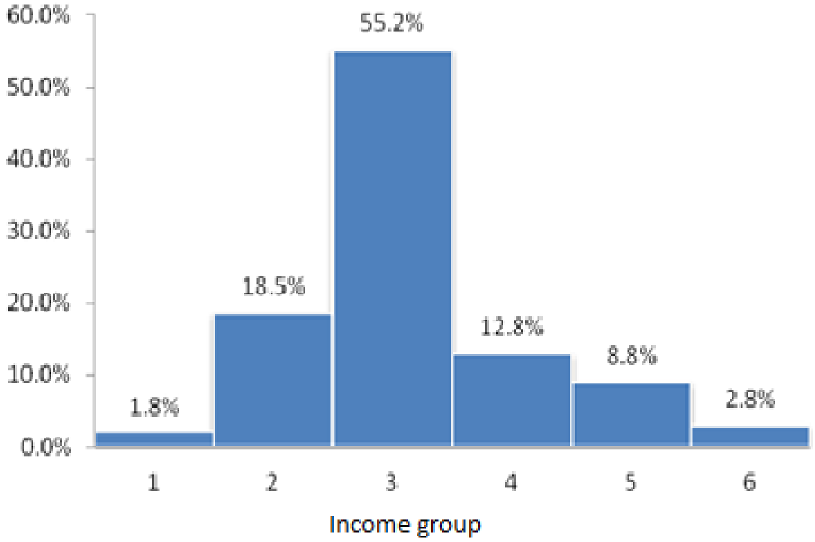

Figure 9. Sample income group distribution.

To estimate the WTP in time units of TransMilenio users to travel in a less congested situation different econometric models were estimated (Exponential regression, powered regressions, linear regressions, logit discrete choice model). The linear regressions dropped better significance results, the variables included in these regressions were:

Gender: 1 if male, 0 otherwise

Age

Distkm: In vehicle trip distance (kilometres)

Hr: Approximated trip starting time

Transfer: 1 if the respondent was transferring in the enquiry station, 0 otherwise

Income group: Values from 1 to 6, 1 representing the lowest income users 6 the highest

Difd: Difference between the actual passenger density and the hypothetic reduced density.

In the estimation of WTP (in minutes) as a linear function of all variables mentioned above. Difd and Transfer are the statistically relevant variables (at a 90% of significance).

Table 2. Linear regression including all variables

VARIABLES	wtp
Gender	-0.0308
	(0.194)
Age	-0.000708
	(0.00869)
distkm	0.0137
	(0.0207)
Hr	0.00276
	(0.00183)
Transfer	-0.404*
	(0.229)
Income group	0.0123
	(0.0982)
difd	4.061***
	(0.118)
Constant	-8.162***
	(1.481)
Observations	3,273
R-squared	0.268

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3 shows that in these regressions the only variables that are significant at a level higher than 90% are those related to the density difference and transfer. Variables that were expected to affect the user's WTP, as the in-vehicle trip distance and the income, probably resulted not significant because the congestion level is so high that individuals desire a better situation regardless of the length of the trip. It is likely that the variable income group has no influence on the willingness to pay in time because most individuals are regular users of the system in the morning peak hour travel whose trip purpose is work or study, making it mandatory to reduce the waiting time.

Table 3. Time WTP linear regressions as function of Difd and transfer combined with the other variables

VARIABLES	wtp	wtp	wtp	wtp	wtp	wtp
Gender	-0.0345					
	(0.193)					
Age		0.000738				
		(0.00861)				
Distkm			0.0139			
			(0.0207)			
Hr				0.00278		
				(0.00182)		
Income group					0.0144	
					(0.0981)	
Transfer	-0.384*	-0.381*	-0.379*	-0.407*	-0.380*	-0.383*
	(0.226)	(0.227)	(0.226)	(0.226)	(0.227)	(0.226)
Difd	4.061***	4.061***	4.061***	4.061***	4.061***	4.061***
	(0.118)	(0.118)	(0.118)	(0.118)	(0.118)	(0.118)
Constant	-5.940***	-5.982***	-6.102***	-8.031***	-6.005***	-5.959***
	(0.440)	(0.503)	(0.477)	(1.426)	(0.530)	(0.427)
Observations	3,273	3,273	3,273	3,273	3,273	3,273
R-squared	0.267	0.267	0.267	0.268	0.267	0.267

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The table above shows that in addition to gender variables age, distance, time and stratum are not significant, their coefficients are relatively low (representing a marginal change less than 10% compared to the variable transfer and less than 1% compared with variable Difd). This allows us to assert that these variables are not relevant to the analysis.

Besides the fact that this variable has on the WTP (in time), represented by the coefficient, and is considerably lower than the variable Difd (about 10%). That is why a final model was estimated, whose independent variable is the Difd and the constant was constrained to zero, since it is assumed that users are not willing to pay for no density reduction. Estimates of this regression are significant at greater than 99%; the resulting r2 is 0.70 higher than that value obtained with all other models previously estimated of which did not exceed the threshold of 0.27. This is the model that best estimates the users' willingness to pay (in time) to travel to a lower density is presented in Table 4.

Table 4. Time (min) WTP estimation as a function of density difference

VARIABLES	wtp
Difd	2.422***
	(0.0276)
Observations	3,273
R-squared	0.702

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The regression coefficient obtained can be interpreted as the time (in minutes) that an average user is willing to wait to ride in a vehicle with a passenger less per square meter, the sign of the coefficient indicates that the higher the density difference between the actual situation and the hypothetical situation the longer willing to wait (Equation 9).

$$\text{wtp (difd)} = 2.422 \times \text{difd} \qquad (9)$$

It is necessary to estimate the willingness to pay of users in terms of money for the purpose of performing the microeconomic analysis and identify the implications on the generalized cost of travel on the mass transit system of Bogotá. For this, the time WTP estimation was transformed into money using the value of time for each income group (VOT) reported by Steer Davies Gleave (2011) (see Table 5), this provides the average willingness to pay weighted by income group VOT for TransMilenio users in the morning peak hour. This was estimated by performing a linear regression between the willingness to pay, money transformed (wtpp), and the density difference of the compared situations.

The results of the estimation of the willingness to pay in money (Colombian pesos of 2012) are presented in Table 6. As in the case of the willingness to pay in time, the positive sign of the coefficient associated with Difd indicates that users are willing to pay to travel in a less congested situation. The estimated value of USD$0.115/pas/m2 (statistically significant at 99% confidence) represents what users would pay for travel more comfortable, but also what would be perceiving if he/she traveled more uncomfortable.

Table 5. VOT for each income group

Income group	VOT (USD$/hr)
1	0.83
2	1.70
3	2.53
4	4.50
5	4.50
6	4.50

Table 6. Money WTP estimation as a function of density difference

VARIABLES	(1) wtpp
difd	0.115*** (0.00158)
Observations	3,273
R-squared	0.617

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

This WTP takes into account the effect of the TransMilenio users' income group distribution; it is weighted by the proportion of users and VOT of each one. The willingness to pay in Colombian pesos of users for each demand strata is presented in Table 7.

Table 7. Money WTP estimation as a function of density difference for each income group

VARIABLES	(1) wtpp	(2) wtpp	(3) wtpp	(4) wtpp	(5) wtpp	(6) wtpp
Difd	0.0382*** (0.0031)	0.0672*** (0.0018)	0.1011*** (0.0016)	0.1956*** (0.0060)	0.1749*** (0.0067)	0.1859*** (0.0120)
Observations	60	606	1,806	420	288	93
R-squared	0.714	0.693	0.701	0.720	0.702	0.722

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

However, the willingness to pay in time (Table 8) for each income group shows some uniformity among strata. This means that the only difference between them is due to the value of time, confirming the results of the initial regression warning that the income group was not statistically significant. This uniformity in the willingness to pay expressed in time may be due to similar situations of congestion for all users of the system.

Table 8. Time WTP estimation as a function of density difference for each income group

VARIABLES	(1) wtp	(2) wtp	(3) wtp	(4) wtp	(5) wtp	(6) wtp
Difd	2.748***	2.372***	2.395***	2.608***	2.332***	2.479***
	(0.227)	(0.0643)	(0.0368)	(0.0795)	(0.0896)	(0.160)
Observations	60	606	1,806	420	288	93
R-squared	0.714	0.693	0.701	0.720	0.702	0.722

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The willingness to pay in money can be used, as shown in Equation 4, for microeconomic analysis of congestion costs. Wtpp function was estimated based on the field survey carried out, assuming that the distribution of TransMilenio users income group in the morning rush hour is similar to that obtained in the sample.

$$\mathrm{wtpp}\ (\mathrm{difd}) = 0.115 \times \mathrm{difd} \qquad (10)$$

As depicted in the previous section, the individual congestion cost can be expressed as a function of demanded travel quantity (q), if it is assumed that the relation between density (d) and q is linear, this function can be estimated as follows:

$$\mathrm{d} = \mathrm{g(q)} = \alpha \times \mathrm{q} = \frac{\mathrm{d\ current}}{\mathrm{q\ current}} \times \mathrm{q} = \frac{6.5}{170{,}000} \times \mathrm{q} \qquad (3)$$

$$\mathrm{d(q)} = 3.82353 \times 10^{-5} \times \mathrm{q}$$

$$\mathrm{Cc} = \mathrm{WTP} = 0.115 \times \mathrm{d} \qquad (2)$$

$$\mathrm{C(q)} = 0.115 \times \mathrm{d(q)} = 0.115 \times (3.82353 \times 10^{-5} \times \mathrm{q}\ )$$

$$\mathrm{C(q)} = 4.39 \times 10^{-6} \times \mathrm{q}$$

$$\mathrm{Ic} = (\mathrm{Fare}) + (\mathrm{Travel\ Time} \times \mathrm{Value\ of\ Time}) + \mathrm{Cc} \qquad (1)$$

$$\mathrm{Ic} = 0.972 + 43 \times 0.04715 + 0.115 \times 10^{-6} \times \mathrm{q}$$

$$\mathrm{Ic} = 3.000 + 2.068 \times 10^{-6} \times \mathrm{q}$$

The average travel time was reported by Camara de Comercio de Bogotá and Universidad de los Andes (2011) as 43 minutes (complete travel time, including origin waiting time and transfer time), and the mean value of time was calculated based on the income group VOT and reported by Steer Davies Gleave (2011) and the TransMilenio users' income group distribution obtained in the survey.

The marginal social cost function is estimated as shown below:

$$Ma\mathrm{Sc} = \mathrm{Ic} + \frac{\partial \mathrm{Ic}}{\partial \mathrm{q}} \times \mathrm{q} = (3.00 + 2.068 \times 10^{-6} \times \mathrm{q}) + (2.068 \times 10^{-6}) \times \mathrm{q}$$

$$\mathrm{MaSc} = 3.00 + 4.136 \times 10^{-6} \times \mathrm{q} \qquad (4)$$

For the determination of the travel demand function for TransMilenio system, an elasticity of -0.67 was estimated (2003). As the analysis to be carried out will evaluate changes in the generalized cost of a trip (GC), the demand curve to be determined must include the effects of each of the components of the GC. To simplify the analysis we assume that elasticity CG-quantity equals the price-quantity elasticity. The slope of the demand curve is calculated as follows:

$$\frac{\partial \mathrm{q}/\mathrm{q}}{\partial \mathrm{GC}/\mathrm{GC}} = -0.67$$

$$\frac{\partial \mathrm{GC}}{\partial \mathrm{q}} = \frac{\mathrm{GC}}{-0.67 \times \mathrm{q}} = \frac{\mathrm{F} + \mathrm{TT} \times \mathrm{VOT} + \mathrm{Cc}}{-0.67 \times \mathrm{q}} = \frac{0.972 + 43 \times 0.04715 + 0.115 \times 6.5}{-0.67 \times 170{,}000}$$

$$\frac{\partial \mathrm{CG}}{\partial \mathrm{q}} = -3.290 \times 10^{-5}$$

The constant of the demand function is determined calculating the vertical axis intersects. Equation 8 represents the demand function that is used in the analysis.

$$\mathrm{a} = (3.00 + 4.136 \times 10^{-6} \times 170{,}000) - (-3.290 \times 10^{-5} \times 170{,}000) = 9.335$$

$$\mathrm{D: q} = -3.290 \times 10^{-5} \times \mathrm{q} + 9.335 \qquad (11)$$

The result of the microeconomic analysis is shown in Figure 10, it can be seen that to achieve the optimal congestion cost reduction (CCB) it is necessary to reduce the in-vehicle passenger density, if it is to be done by using a congestion charge this charge should be USD$0.67, added to the current fare USD$0.97 user would have to pay USD$1.64. However, the optimal congestion cost reduction is about USD$6,681 per hour, and this is the reduction objective that should be reached by the authorities by improving the system service.

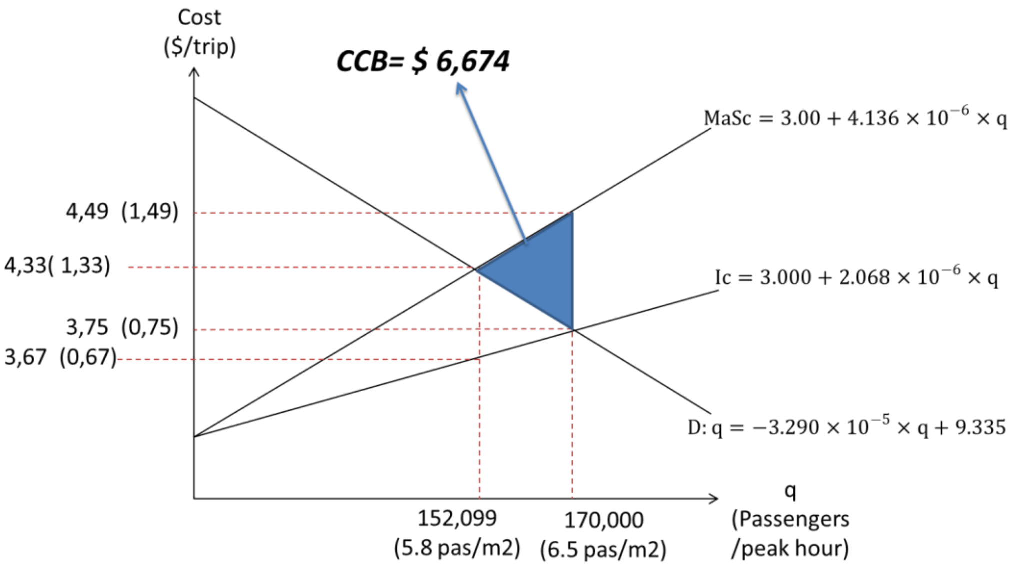

Figure 10. Peak hour congestion costs, current situation.

To obtain the equivalent benefit of a congestion charge, as it is the optimal, the system should be able to transport 172,700 passengers in the peak hour at 5.7 passengers per square meter (results are shown in Figure 11), this represents an increase of about 15.9% of the supply of TransMilenio in that period. Every single user of the system, that already used the mass transit, will perceive a 12% reduction in individual congestion cost. The required capacity improvements could be reached by optimizing system elements such as traffic lights, junction upgrade or using higher capacity buses.

It must be said that this analysis is limited to the effects of such a measure would have only in the mass transit system. External effects should be evaluated in future studies, this way a broader view would be provided to appraise this kind of policy.

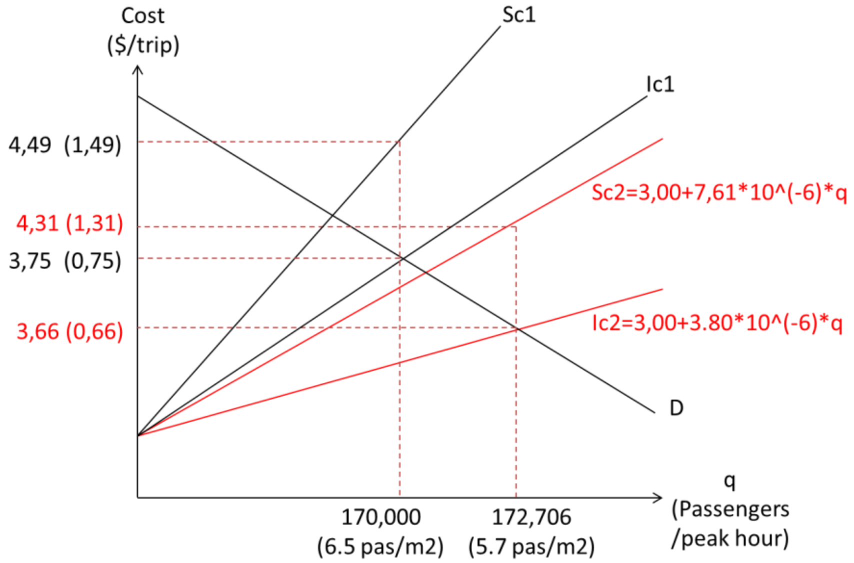

Figure 11. Cost functions in both scenarios.

CONCLUSIONS

Congestion costs in a mass transit system can be optimized by applying Pigou´s theory of internalisation of externalities, usually applied for private transport. In the case of Bogotá optimal density passenger vehicle is 5.7 pas/m2.

To reach this optimal situation there is two alternatives. The first one would be to implement a USD$0.67 congestion Charge, which would bring about USD$6,700 welfare increase in peak hour for the overall system. However, this would not be a sustainable, neither one promoting equity measure, as it would prevent citizens to use public transport.

The second option would be to increase the capacity of the system in order to reach the optimal occupation. In this case comparing cost of increasing capacity should be compared to welfare benefits.

The intervention of the authorities to mitigate the effects of congestion, and get equivalent benefits to be gained by implementing a congestion charge, is a measure that requires a higher level of investment but avoid undesired effects on accessibility and equity due to lower income groups individuals’ budget restriction.

The effect of other variables on costs caused by congestion should be evaluated; in the set of variables included in this study only the desired density was significant at a confidence level of 95%.

Finally this analysis should also be considered when evaluating congestion charge schemes for private transport. Existing appraisal of those schemes do not consider increase in congestion within public transport, brought by a shift from private to public modes as an additional cost.

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