Towards a More Sustainable Passenger Transport: Management of Disutility Related to Environmental Impacts

RAYMUNDO, H. [a b*], REIS, J. G. M. [a]

a UNIP – Paulista University, São Paulo
b National Association of Public Transportation - ANTP.
**Corresponding author, helcioru@ uol.com.br*

Abstract

Passenger Transport (PT) imposes disadvantages (disutilities) to its users. One of these disutilities is the environmental impact caused by greenhouse gases emissions from PT vehicles, specifically CO_2, the main cause of global warming. This paper aims to show ways to manage this disutility, drawing from Brazilian experience, using two freely available planning tools: (i) reduction in the consumption of fossil fuels in Public Transport vehicles by the substitution of buses, and (ii) changes of modal-split (modal share).

Keywords: passenger transport; disutilities; management of environmental impacts; public transport; modal-split

1. Introduction

Passenger Transport (PT) imposes disadvantages to those who use it, even being the only provider of all human displacements (Raymundo, 2015). These disadvantages, also known as disutilities, are related to (EMPLASA. 1981): (i) passengers: time wasting, money spending, discomfort and insecurity; and (ii) society: consumption of urban areas devoted to PT infrastructure and noise, water, soil and air pollution. However, the challenge of the 21st century for transportation systems is to increase availability and passenger use while reducing environmental impacts.

The environmental impacts in the air caused by greenhouse gases (GHG) emissions of PT vehicles, specifically CO_2, is considered the main cause of global warming, since air pollution probably represents one of the most important environmental concerns in society today (Bickerstaff and Walker, 2001). PT vehicles (automobiles, motorcycles, buses and trains) play an important role in this scenario because they consume 50% of the energy of all world transport and are responsible for 20% of global warming caused by CO_2 emissions (Seigfeld and Pandis, 2006).

Even using more environmentally efficient automobiles, motorcycles, buses and trains, the economic and social growth will boost PT demand. A 50% growth of PT demand is expected until 2050 (IEA, 2009), which will inevitably worsen global warming. Furthermore, there is no guarantee that efficiency improvements in the consumption of all kinds of energy sources, even electric, can compensate for the increased demand. Therefore, experts propose policies trying to reduce 50% of CO_2 emission levels of PT by 2050 in relation to the values currently observed in 2013 (IEA, 2009; Skinner et al., 2010; IEA, 2015).

The aim of this paper is to suggest ways to manage the disutility related to environmental impact measured by CO_2 emission from PT vehicles, using Brazilian experience[1] by means of:

- Consumption reduction of fossil fuels in Public Transportation vehicles by the substitution of buses, or their engines, (Suzuki et al., 2010; Comissão de Transporte e Meio Ambiente da ANTP, 2011; Raymundo and Reis, 2015); and
- Changes of modal-split (modal share), in which Public Transportation could assume part of the trips, independently of their origin and destination, the purposes, the social-economic level of the passengers and the availability of modes of transport (Cihat, 2012; ANTP, 2017 a). To accomplish this simultaneously, a methodology is proposed (Raymundo, et al., 2014), consisting in the utilization of two freely available planning tools (ANTP, 2017 b; ANTP, 2017 c): (i) Urban Bus Emissions Simulator (UBES[2]); and (ii) Environmental Impacts of Urban Mobility Actions Simulator (EIUMAS[3]).

2. Methodology

The proposed methodology allows a set of steps, to simulate the combined effect of CO_2 emission reduction in Brazilian cities by the substitution of bus fleets and changes in its modal-split.

Previously to the development of the proposed methodology, it was necessary to understand how the mentioned planning tools work, their methodology, their adopted hypothesis and "boundary conditions", and their possibilities and limitations (Raymundo et al., 2014).

This attention to detail allowed us to apply the proposed methodology for each tool in just three phases, as follows (Jahangirian et al., 2010):

- PHASE 1 - To collect, to inform or to adopt the required information;
- PHASE 2 - To perform the simulations (scenarios), generating results and, if it is needed, to apply the necessary adjustments and to redo the simulations; and
- PHASE 3 - To consolidate the results of each scenario and their respective analysis.

3. Urban Bus Emissions Simulator (UBES)

UBES (ANTP, 2017 b) assists decision-makers to estimate the emissions reduction potential of pollutants from the replacement of diesel-powered buses by new units powered by clean energy or other technological alternatives.

The emission reductions consider: (i) average annual bus mileage; (ii) quantity of current diesel buses to be replaced (or just "modified", changing the fuel type), grouped by type (Mini-Micro; Midi-Basic; Padron; Articulated and Biarticulated)[4] ; and (iii) motorization types, directly linked to vehicle age

[1] Brazil is a leading country when it comes to environmental issues, mainly in Public Transportation, by both progressive legislation/practices and the presence of prominent researchers in their scientific production [see Suzuki et al., 2010).

[2] UBES was developed by ANTP - Associação Nacional de Transportes Públicos (Nacional Association of Public Transport), a Brazilian pro-public transport NGO founded in 1977, a respected producer of academia contributions to Brazilian and Latin American enterprises, available at:<http://www.antp.org.br/simulador/simulador-de-emissoes-de-onibus-urbanos/> (in Portuguese) (see ANTP, 2017 b).

[3] EIUMAS was also developed by ANTP, in partnership with WWF®-Brazil, available at: <http://www.antp.org.br/simulador/impactos-ambientais/?fieldState=SP&fieldCity=1&fieldPercentage=30&fieldOptionFrom=3&fieldOptionTo=2#> (in Portuguese) (see ANTP, 2017 c).

[4] Diesel buses classified in different types meet the needs of the fleet replacement, allowing the calculation of CO_2 emission of the original fleet and of the replacement fleet.

(Euro 2, 3 or 5, equivalent to Proconve 4, 5 and 7)[5] , which permit the application of the corresponding Emission Factors (g/km) for each pollutant.

Annual emissions of each vehicle type (for each of the pollutants) are calculated by multiplying the average annual bus mileage (variable for each vehicle type), by the quantity of the original diesel fleet and by their respective "Emission Factors", according to the formula:

$$Ep = Akm \times Qv \times Ef \quad (1):$$

where, 'Ep' refers to annual emissions of pollutant X, 'Akm' to average annual bus mileage, 'Qv' to quantity of vehicle type and 'Ef' to the emission factor of the pollutant X for each vehicle type. The majority of information is provided by UBES for scenarios of the replacement fleet (buses to be replaced and their technology), considering:

- The alternatives available in Brazil: Euro 5 - Proconve 7 buses (EUR5); diesel with 20% biodiesel (B20); natural gas or bio-methane (GAS); diesel engine consuming ethanol with 5% of detonating additive (E95); hybrid bus (HBR); electric battery bus (ELB); and trolleybus (TRO);

- The replacement fleet establishment for each vehicle type, according to the following suggestions: (i) buses manufactured until 2005 and part of the fleet manufactured from 2006 to 2011 should be replaced by EUR5, B20, GAS, E95, HBR, ELB or TRO; (ii) part of the fleet manufactured from 2006 to 2001 should be maintained; and (iii) buses manufactured from 2012 should be replaced by EUR5 or B20 (ANTP, 2017 b);

- The identification and characterization of each bus type by the Emission Factor (linked to vehicle age); and

- The Emission Factors (g/km) for current diesel buses, referring to properly maintained buses operating on typical diesel fuel (D'Agosto, 2012): Mini-Micro (790), Midi-Basic (1,168), Padron (1,643), Articulated (2,042) and Biarticulated (2,312), and the average Emission Factors for new buses showed in Table 1.

UBES provides results performed in three steps: (i) Step 1 – to inform or confirm the current quantity of the diesel fleet to be replaced and to inform or confirm the average annual bus mileage in a given city; (ii) Step 2: to decide how the replacement of the fleet for each vehicle type will be carried out (scenarios) and (iii) Step 3: to present the final results for each simulation (scenarios).

Table 1. CO_2 Emission Factors for New Buses (g/km) – Source: (CETESB, 2015)

Fuel	Mini-Micro	Midi-Basic	Padron	Articulated	Biarticulated
EUR5	790	1,168	1,643	2,072	2,312
B20	665	984	1,384	1,745	1,947
GÁS	n.a.	1,154	1,624	n.a.	n.a.
ELB	0	0	0	0	0
HBR	470	695	978	1,233	1,376
E95	n.a.	0	0	n.a.	n.a.
TRO	0	0	0	0	0

[5] Euro 1 to 6 means European Emission Standards for new Light Duty Vehicles. In Brazil, the equivalent is Proconve - Programa de Controle da Poluição do Ar por Veículos Automotores (Motor Vehicles Air Pollution Control Program), in which Euro 2 corresponds to Proconve 4, Euro 3 to Proconve 4 and Euro 5 to Proconve 7 and so on (see Raymundo and Reis, 2015).

4. Environmental Impacts of Urban Mobility Actions Simulator (EIUMAS)

EIUMAS (ANTP, 2017 c) estimates environmental impacts produced by a given city when its modal-split is changed. It allows users to select a city[6] and change the proportion of trips from a transport mode to another one. The results are presented in terms of: (i) time change for displacement; and (ii) energy consumption and urban space consumed, in addition to local emissions and emissions of GHG (CO_2). In this paper, only the results of CO_2 emissions will be used.

The calculation process is done by the estimation of the magnitude level for the impacts that may be caused. Thus, EIUMAS cannot be used to set technical projects of implementation of actions, which require specific additional studies, using mathematical and economic models.

The EIUMAS simulations are performed in three steps: (i) Step 1: to choose the city to be simulated; (ii) Step 2: to estimate, for each scenario, the transfer of x% of the trips from one mode (walking, cycling, motorcycle, bus and automobile) to the other modes, one by one; and (iii) Step 3: to present the results in reduction or increase of CO_2 emissions.

5. Simulations

It was decided to perform the simulations for the city of São Paulo, because, as was previously said, UBES and EIUMAS have been developed under the conditions of this city. Moreover, São Paulo is a city, like any other big urban agglomeration, which combines all the adverse consequences of fast growing, high levels of automobiles per inhabitant, an insufficient underground network for the city size and other deficiencies in Public Transport (Leahy, 2013).

5.1. UBES

Considering the current situation of São Paulo's bus fleet, emitting about 1.40 million tons of CO_2 annually, and adopting an average annual bus mileage of 70,000 km, three scenarios were considered:

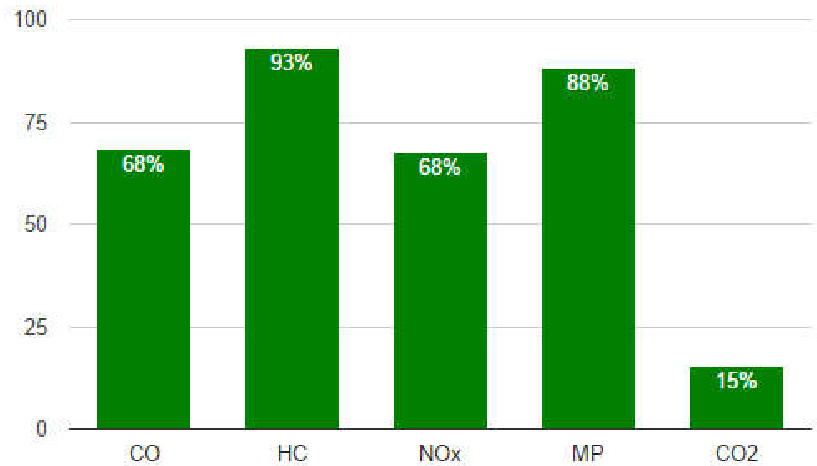
- SCENARIO 1 (conservative), like the one suggested by UBES, e.g. focusing mainly on the replacement of diesel fleet to B20 for vehicles manufactured before 2011 and maintaining buses manufactured after 2012 in EUR5;
- SCENARIO 2 (intermediate), consisting in ELB for Mini-Micro and in maximizing the successful experience with B20, E95, TRO and HBR carried out in the city in recent years, adopting: Mini-Micro (B20 for buses manufactured from 2005 to 2011 and ELB beyond 2012); Midi-Basic (E95 from 2005 to 2011 and ELB beyond 2012); Padron (E95 from 2005 to 2011 and TRO beyond 2012 - equivalent to the current fleet); Articulated and Biarticulated (all HBR); and
- SCENARIO 3 (radical), with 100% of ELB (electrical battery vehicles).

Thus, performing Steps 1, 2 and 3 of UBES, previously shown in item 3, one obtains:

- SCENARIO 1 - the replaced fleet would produce an annual CO_2 emission of 1.11 million tons, compared to the current situation of 1.31 million tons, or a 15% reduction;
- SCENARIO 2 - the replaced fleet would produce 0.15 million tons of CO_2, an 89% reduction; and
- SCENARIO 3 - the emission reduction is 100% (1.31 million tons of CO_2).

The following figure shows the results of SCENARIO 1, in its original format, in terms of a graph and a comparative table.

[6] The EIUMAS basic source of information is the ANTP database "Sistema de Informações da Mobilidade Urbana" (Information System of Urban Mobility), especially designed to permit the appropriate follow-up of some economic and social aspects of urban transit and transport in Brazilian cities with more than 60 thousand inhabitants (see ANTP, 2017 a).



EMISSÕES E REDUÇÕES DA FROTA TOTAL POR POLUENTE	CO	HC	NOx	MP	CO2
Diesel (t/ano)	1505.43	247.81	8097.43	143.50	1308210.61
Alternativas energéticas (t/ano)	474.70	17.42	2629.50	16.77	1107882.88
Redução (t/ano)	1030.73	230.39	5467.93	126.74	200327.73
Redução (%)	68.5%	93.0%	67.5%	88.3%	15.3%

Figure 1 *– Original UBES – Results of Scenario 1 (in Portuguese) (source: ANTP 2017 b)*

5.2. EUMAS

Steps 1, 2 and 3, previously shown in item 4, were performed, simulating CO_2 reductions, carrying out in a progressive way degrees of trip transfers ranging from 10% to 90%, with intervals of 10%, in the following format: (i) from motorcycle to walking, motorcycle to cycling and from motorcycle to bus (Table 2); and (ii) from automobile to walking, automobile to cycling and from automobile to bus (Table 3).

Another simulation was tested, adopting trip transfers from walking, cycling, motorcycle and bus to automobile, resulting in additions in CO_2 emissions (Table 4).

Table 2. Percentage of CO_2 Reduction – Trip Transfer from Motorcycle

Level of Transference	From Motorcycle to Walking	From Motorcycle to Cycling	From Motorcycle to Bus
10%	0	0	0
20%	1	1	0
30%	1	1	0
40%	2	2	0
50%	2	2	0
60%	2	2	0
70%	3	3	1
80%	3	3	1

90%	3	3	1

Table 3. Percentage of CO_2 Reduction – Trip Transfer from Automobile

Level of Transference	From Automobile to Walking	From Automobile to Cycling	From Automobile to Bus
10%	7	7	3
20%	14	14	6
30%	20	20	9
40%	27	27	12
50%	34	34	15
60%	41	41	18
70%	48	48	21
80%	55	55	24
90%	61	61	27

Table 4. Percentage of CO_2 Addition – Trip Transfer to Automobile

Level of Transference	From Walking to Automobile	From Cycling to Automobile	From Motorcycle to Automobile	From Bus to Automobile
10%	8	0	0	2
20%	16	1	0	4
30%	23	1	0	7
40%	31	1	1	9
50%	39	1	1	13
60%	47	2	1	16
70%	54	2	1	18
80%	62	2	1	23
90%	70	2	1	20

The following figure illustrates the complete results shown in Table 4, related to the simulation of 90% of trips transferred from walking to automobile, in terms of percentage of CO_2 addition and other indicators.

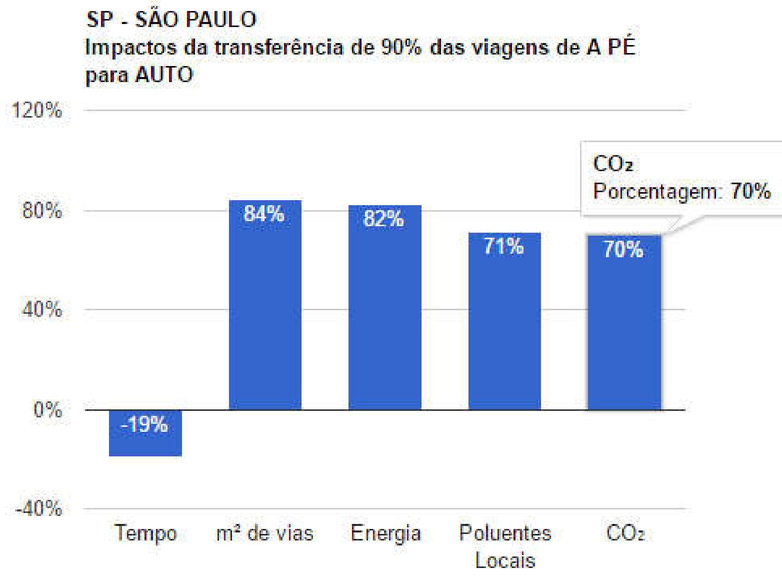


Figure *2 - Original EUMAS – (in Portuguese) (source: ANTP 2017 c)*

6. Results and Discussions

From UBES, three aspects can be highlighted:

- Even in SCENARIO 1, probably representing low investment and a short deployment term, with little technical difficulty, a 15% reduction of CO_2 emissions was achieved;

- It is encouraging to note that SCENARIO 2 shows a CO_2 emission of 0.15 million tons, resulting in an expressive reduction of 89%; and

- In SCENARIO 3, the consequence of a complete fleet renewal with the introduction of electric battery buses, indicates, obviously, the biggest contribution to CO_2 emission with a 100% reduction. Certainly, this could impose investments impossible to be completely obtained and applied in the short term, and, most importantly, economically and socially infeasible.

Thus, it could be said that the merit is in testing, by trial and error, various possibilities to "find out" the best alternative in each city that combines low investments and short term implementation of the replacement fleet that would minimize CO_2 emissions.

Conversely, the simulations performed by EIUMAS revealed findings, such as:

- The modal-split transfer trips from motorcycle to walking, motorcycle to cycling and from motorcycle to bus gave little help in reducing CO_2 emissions (from zero to 3%);

- The modal-split transfer trips from automobile to walking, automobile to cycling and from automobile to bus helped considerably the reduction of CO_2 emissions (from 3% to 61%); and

- The modal-split transfer trips from walking to automobile, cycling to automobile, motorcycle to automobile and from bus to automobile reinforce the harmfulness to society, resulting in additions in CO2 emissions, especially when it refers to the cases of walking to automobile (from 8% to 70%) and of bus to automobile (from 2% to 20%).

7. Conclusions and Outlook

This paper allows us to conclude that the two planning tools tested, even with limitations, represent a suitable disutility management instrument regarding CO_2 emissions. In short, it can be said that it is a quick and inexpensive way to assess the magnitude of environmental impacts, resulting from management in transport supply (change of the bus fleet) and in transport demand (change of modal-split).

Hence, this paper has contributed to reveal levels of CO_2 emissions in Brazilian cities (reductions or additions), which could be adopted in every city of the world.

According to simulations of bus replacement fleets combined with new modal-splits, it may be possible to encourage, with scientific support, more non-motorized transport modes and less automobile usage.

References

- Associação Nacional de Transportes Públicos - ANTP., 2017 a. Sistema de Informações da Mobilidade – Apresentação. <http://www.antp.org.br/sistema-de-informacoes-da-mobilidade/apresentacao.html> last accessed January 2017 (in Portuguese).
- ____, 2017 b. Simulador de Impactos de Ônibus Urbanos – Apresentação. <http://www.antp.org.br/simulador-de-emissoes-de-onibus-urbanos/apresentacao.html> last accessed January 2017 (in Portuguese).
- ____, 2017 c. Simulador de Impactos Ambientais – Apresentação. <http://www.antp.org.br/simulador-de-impactos-ambientais/apresentacao.html> (in Portuguese).
- Bickerstaff, K., Walker, G., 2001 Public understandings of air pollution: the 'localization' of environmental risk. Global Environmental Change 11, 45–67.
- Cihat, P., 2012. The Demand Determinants for Urban Public Transport Services: A Review of the Literature. Journal of Applied Sciences, 12: 1211-1231.
- Comissão de Transporte e Meio Ambiente da ANTP., 2011. Transporte e Meio Ambiente no Brasil. In: 18º Congresso de Transporte e Trânsito da ANTP. < http://files-server.antp.org.br/_5dotSystem/download/dcmDocument/2012/11/21/D21774B2-348A-484A-96EF-1CE2FFA9FBC2.pdf> last accessed January 2017 (in Portuguese).
- Companhia Ambiental do Estado de São Paulo - CETESB., 2015. Emissões Veiculares no Estado de São Paulo - 2015. <http://cetesb.sp.gov.br/wp-content/uploads/sites/35/2013/12/RelatorioEmissoesVeiculares-2015-subst-201016.pdf> last accessed January 2017 (in Portuguese).
- D'Agosto, M. A.,2012. Alternativas tecnológicas para ônibus no Rio de Janeiro. Rio de Janeiro: PET/Coppe/UFRJ. (in Portuguese).
- Empresa Metropolitana de Planejamento da Grande São Paulo – EMPLASA, 1981. Manual PAITIP: Programa de Ação Imediata de Transporte Integrado de Passageiros. (in Portuguese).
- International Energy Agency - IEA, 2009. Transport Energy and CO_2 – Moving Toward Sustainability. <https://www.iea.org/publications/freepublications/publication/transport2009.pdf> last accessed January 2017.
- ______________________________.,2015. Data from Co_2 Emissions from Fuel Combustion (2015 preliminary edition) - Recent trends in OECD CO_2 emissions from fuel combustion. <http://www.iea.org/publications/freepublications/publication/CO2_OECD_Factsheet_2015.pdf> last accessed January 2017.
- Jahangirian, M., Eldabi, T., Naseer, A., Stergioulas, L. K., Young, T., 2010. Simulation in manufacturing and business: A review. European Journal of Operational Research, 203(1), 1-13.
- Leahy, J., 2013. Unrest highlights São Paulo's transport challenge. Technical Report, Financial Times Special Report Emerging Voices – Brazil: Infrastructure 2013. <https://www.ft.com/content/002f7028-ed43-11e2-8d7c-00144feabdc0> last accessed January 2017.

- Raymundo, H., Vendrametto, O., & dos Reis, J. G. M., 2014. Knowledge Management in Public Transportation: Experiences in Brazilian Bus Companies. In: IFIP International Conference on Advances in Production Management Systems (pp. 603-610). Springer.
- Raymundo, H., 2015. Minimizing the Disutility of Urban Passenger Transport from the Customers Point of View. In: VII International Scientific Conference in Road Research and Administration, Road Research and Administration "C.A.R." 9 – 11 July 2015, VII Edition, Book of Proceedings "C.A.R. 2015".
- Raymundo, H., Reis, J. G. M., 2015. Renovação da Frota de Ônibus Urbanos: Redução de Consumo de Energia e de Impactos Ambientais. In: 5th International Workshop in Advances in Cleaner Production (in Portuguese).
- Seifeld, J. H., Pandis, S. N., 2006. Atmospheric chemistry and physics: from air pollution to climate change. John Wiley & Sons, New York.
- Skinner, I., Van Essen, H., Smokers, R., Hill, N., 2010. Towards the Decarbonisation of EU's Transport Sector by 2050', Final Report.
- Suzuki, H., Dastur, A., Moffatt, S., Yabuki, N., Maruyama, H. 2010. Eco2 Cities: Ecological cities as economic cities. World Bank Publications.