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

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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 CO₂ emission from PT vehicles, using Brazilian experience¹ 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 (UBES²); and (ii) Environmental Impacts of Urban Mobility Actions Simulator (EIUMAS³).

2. Methodology

The proposed methodology allows a set of steps, to simulate the combined effect of CO₂ 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 (National 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 CO₂ emission of the original fleet and of the replacement fleet.
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:

\[ Ep = Akm \times Qv \times Ef \] (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.** CO₂ Emission Factors for New Buses (g/km) – Source: (CETESB, 2015)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Mini-Micro</th>
<th>Midi-Basic</th>
<th>Padron</th>
<th>Articulated</th>
<th>Biarticulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUR5</td>
<td>790</td>
<td>1,168</td>
<td>1,643</td>
<td>2,072</td>
<td>2,312</td>
</tr>
<tr>
<td>B20</td>
<td>665</td>
<td>984</td>
<td>1,384</td>
<td>1,745</td>
<td>1,947</td>
</tr>
<tr>
<td>GAS</td>
<td>n.a.</td>
<td>1,154</td>
<td>1,624</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>ELB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>HBR</td>
<td>470</td>
<td>695</td>
<td>978</td>
<td>1,233</td>
<td>1,376</td>
</tr>
<tr>
<td>E95</td>
<td>n.a.</td>
<td>0</td>
<td>0</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>TRO</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

(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.

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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.

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\(^6\) 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).
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**

<table>
<thead>
<tr>
<th>Level of Transference</th>
<th>From Motorcycle to Walking</th>
<th>From Motorcycle to Cycling</th>
<th>From Motorcycle to Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20%</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>30%</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>40%</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>50%</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>60%</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>70%</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>80%</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 3. Percentage of CO₂ Reduction – Trip Transfer from Automobile

<table>
<thead>
<tr>
<th>Level of Transference</th>
<th>From Automobile to Walking</th>
<th>From Automobile to Cycling</th>
<th>From Automobile to Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>7</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>20%</td>
<td>14</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>30%</td>
<td>20</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>40%</td>
<td>27</td>
<td>27</td>
<td>12</td>
</tr>
<tr>
<td>50%</td>
<td>34</td>
<td>34</td>
<td>15</td>
</tr>
<tr>
<td>60%</td>
<td>41</td>
<td>41</td>
<td>18</td>
</tr>
<tr>
<td>70%</td>
<td>48</td>
<td>48</td>
<td>21</td>
</tr>
<tr>
<td>80%</td>
<td>55</td>
<td>55</td>
<td>24</td>
</tr>
<tr>
<td>90%</td>
<td>61</td>
<td>61</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 4. Percentage of CO₂ Addition – Trip Transfer to Automobile

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

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 CO₂ addition and other indicators.
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 CO₂ 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 CO₂ 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**


