A Sustainable Mobility Index to Assess the Public Transport Quality in the City of Rio de Janeiro

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ABSTRACT: Nowadays issues related to the conditions of urban mobility in the largest Brazilian cities become quite important. Particularly in Rio de Janeiro there are some serious structural challenges to overcome: overcrowding and difficult access to bus stations, subway and trains; inadequate traffic signaling system and traffic congestion provoked by a great number of single-occupant vehicles. This article aims to analyze the actions that the municipal government could promote to improve urban mobility. How and for what reasons a city that has heavily invested in several modes of transport in the last years still has problems in these services? This question is discussed from two points of view: the legal framework available to the government for development of public transport policies and the use of a Sustainable Mobility Index (SMI), proposed in this research as a tool for assessment of the public transport quality. Specifically, the SMI is used to study the case of the VII Administrative Region of the City of Rio de Janeiro (São Cristóvão and neighborhood districts), an area selected due to the multiplicity of urban occupation (housing, education, sport facilities, leisure infrastructure, health services, trade companies, industries, many connections to other districts) and its privileged geographical situation near downtown, with several access routes forming a great potential for intermodal logistics. A correct use of such good features depends basically on government decisions and public investment but, as put in evidence by the SMI calculation, São Cristóvão still suffers from the faulty planning of Rio de Janeiro transport system.

Keywords *Public Transport System, Sustainable Urban Mobility, Sustainable Mobility Index, São Cristóvão District, Rio de Janeiro*

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1. INTRODUCTION

The city of Rio de Janeiro has a wide range of urban transportation system. Subway, trains, buses, bike paths, cable cars and water transportation. Recently, these modes have been awarded with public investments, with expansion of the subway, modernization of railways, construction of dedicated lanes for buses and bicycle paths and the number of boats for the water transport has also increased. However, the improvement in the quality of urban mobility is not perceived by the population. Traffic jams, overcrowding of the public transport and poor services are parts of the public transport difficulties. This article analyzes the case of the São Cristóvão District (VII Administrative Region of the City of Rio de Janeiro), from the perspective of sustainable urban mobility using an index which includes social, environmental, economic and institutional dimensions. This area, that comprises the neighborhood districts of Benfica, Mangueira and Vasco da Gama, has a good transport capacity (train and subway) and also features several bus lines that make connection to several regions of Rio de Janeiro and nearby cities. The Administrative Region possesses several urban equipment, such as public parks, hospitals, shopping malls, leisure infrastructure, museums and educational institutions.

2. URBAN MOBILITY

The expression urban mobility has been often used, in many and distinct ways. The popularization of the term is positive, because the debate does not end within the government, but it also helps to involve ordinary citizens with problems that affect everyone, regardless the social class. However, the trivialization of this expression may have a negative aspect as well, especially when authorities treat urban mobility according to very simplified strategies. The improvements in urban transport tend to fail when deployed without a serious planning of the transport system and without the awareness and participation of the people directly affected.

In a survey conducted in several European cities (Eurforum, 2007), many problems about urban mobility were raised and the challenges ahead in the future. Despite the differences between these cities and the Brazilian ones, it seems that they all have similar concerns: uneven growth in transportation, huge traffic jams due to increasing use of private cars and imbalance between the transport modes, with harmful effects on the environment and public health by vehicles powered by fossil fuels.

The understanding of urban mobility in a systemic way is essential for a discussion about the subject. According to the Eurforum (2007), the goals to be pursued in the planning of sustainable urban mobility must be: accessibility, sustainability, integration of transport modes, public management, reduction of pollutant emissions and noise, road safety for all users of the transport system, cost control in order to establish a fair pricing system, taxation so that the transport infrastructure be associated with the shortage of a fundamental good, verification of quality standards in accordance with pre-established indicators and competition among transport system operators.

Such goals imply the efficiency of land use versus public transport planning, since both issues have influence on one another. According to Campos & Ramos (2010), both the

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transport system can be an inducer of occupation of a given region, according to the land use conditions, and the land use can increase the use of public transport.

2.1 Legal Framework on Transport Planning

The Brazilian Constitution (Brazil, 1988) establishes the guidelines for the urban development policy, and hence the planning of public transportation, placing both under the responsibility of the cities. Following in the same direction, the City Statute (Brasil, 2001) is a federal law that enforces guidelines for development of city master plans and asks for mandatory preparation of urban transport plans in accordance with the population size of each municipality. The National Policy on Urban Mobility (Brasil, 2012) brought the most current tendencies on urban transport planning. At the state level (Brazil is subdivided into 27 states, each one with its own regional laws), in 2014 it has been launched the Master Plan for Urban Transport of the Metropolitan Region of Rio de Janeiro (PDTU RMRJ, SEAERJ, 2014), which outlines a diagnosis of transportation in the Rio de Janeiro metropolitan area and proposes some solutions for public transport in the region. At the municipal level, the Master Plan of the City of Rio de Janeiro (Rio de Janeiro, 2011) deals with the urban policy in the occupation of soil and land use, the planning of public transport and the connection between both issues.

3. THE VII ADMINISTRATIVE REGION (VII AR) OF RIO DE JANEIRO

The VII AR, especially the São Cristóvão District, currently lives an urban transformation that has been accompanied by academic studies due to its importance as a touristic and cultural center of Brazil. At the beginning of XX century, the region had many small industries but nowadays there are many buildings for residences and home of several trade companies. Despite these changes, the region has the same old problems since the municipal laws allow changes in the type of land use, but this change is not followed by the government itself. The recent modification in laws, through the Urban Structural Plan of the VII Administrative Region (Rio de Janeiro, 2004) and the Land Use and Occupation Law (Rio de Janeiro, 2013) introduced changes in kinds of land occupation and use in São Cristóvão and in the neighborhood districts, but there is no plan that could unite the land use and the public transport system.

4. METHODOLOGY

From the perspective of the urban sustainable mobility, this work analyses the actions implemented in the transport system of the city of Rio de Janeiro between the years 2010 and 2012. In that period, the city received many investments in urban transport, but the main question still remains: how the transport system, specifically in the VII AR, has evolved between 2010 -2012 from the perspective of urban sustainable mobility?

4.1 Indicator and Index for Sustainable Urban Mobility

According to Joumard et al. (2010), in the context of sustainable urban mobility, indicator is a variable based on measures that represent as accurately as possible a phenomenon needed to be checked. Thus, three aspects can be highlighted for a choice of an indicator:

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a) what should be measured and what impact on what activity? b) why this phenomenon should be measured? c) how it should be measured?

Index, on the other hand, is a decision-making parameter (Briguglio, 2003) with the following objectives: establishment of goals, standards and focus in the discussion and dissemination of information, promotion of integrated actions, monitoring and evaluation of targets and results. Index is considered a higher level of aggregation of a set of indicators or variables. The Sustainable Urban Mobility Index (SUMI), proposed by Costa (2008), has been widely applied in several Brazilian cities for the evaluation of urban mobility. This index is based on a hierarchy of several criteria that characterize urban mobility, establishing a weighting system for the relative importance of the different component criteria, according to the local reality, but keeping its calculation easy to understand and to be applied. The SUMI may be regarded as a tool that encompasses nine fields such as accessibility, environment, integrated planning, etc., and thirty seven topics or subdivisions of each field (accessibility, for instance, may refers to the transport system, universal accessibility, physical barriers and laws for people with special needs). Machado et al. (2012) proposed a new version of a Sustainable Mobility Index (SMI), adapting the model suggested by Costa (2008) by considering the availability of data for the metropolitan region of Porto Alegre (31 cities) and the possibility to collect them on an annual basis.

4.2 A Sustainable Mobility Index for the City of Rio de Janeiro

According to Gudmundsson (2004), the adoption of an urban mobility index in the planning of a transport system can be used as a measure of the transport system performance and a calibration toll of that system as well. An economic advantage can also be considered, since the transport system itself feeds back important information for self-evaluation. The adoption of an urban mobility index would tend the system to be more efficient, reducing the social and economic impacts of poorly formulated and isolated plans.

Another aspect is worth to mention: democratization of information, since a systematic data collection, used as input for the urban mobility index, could be accessible for the entire population, a relevant information for the society as a way of transparent monitoring and evaluation of the public transport policies.

The purpose of using an urban mobility index in this study is to assess the current status of the public transport system in VII Administrative Region of the city of Rio de Janeiro, to diagnose its shortcomings and point out ways that could solve some existing problems. It should be noted that an index is a tool that may be used to achieve such objectives, but it is not intended to be seen as the ultimate (and unreachable) ideal solution. The proposed methodology is a dynamic one because of the nature of the continuous process to calculate the index. As new elements are introduced, previously adopted indicators are reviewed in order to adapt the methodology and to conform it to the new characteristics of the problem.

A constant evaluation of the process may introduce new indicators but also discard others of little relevance. The Sustainable Urban Mobility Index introduced in this work follows the general procedure suggested by Machado et al. (2012), but considers the institutional

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dimension as a new field for the index calculation. The adoption of the institutional dimension has been suggested by Costa (2008), although not implemented by that author. The institutional dimension evaluates the existence of laws that encourage or require the integration of urban and transport master plans enforcing guidelines for a sustainable urban mobility.

5. CALCULATION OF THE SUSTAINABLE MOBILITY INDEX

The index considers four dimensions of sustainability: the social, economic, environmental and institutional ones. The typical characteristics of each dimension are the following: social dimension - information about conditions and changes of demography, public health, recreation and leisure, education, habitation, infrastructure and community services, community development, public security, situation of indigenous community and historic and archeological resources; economic dimension - information about conditions and changes of industrial production, commerce, services, fiscal and monetary data and human resources; environmental dimension - information about conditions and changes in the natural resources like soil, atmosphere, including climate and air quality, amount and quality of water, wild life and vegetation, natural reserves and habitats, mineral and metal resources and fossil fuels; institutional dimension - information about laws, technical standards, master urban plans and transport plans based on mobility principles; operational capacity of the public transport system and management tools, such as access to technical literature, expertise in preparation of projects, use of channels of communication with the users of the transport system.

5.1 Weights for the specific dimensions

Weights must be assigned to each dimension, according to criteria listed in Table 1.

Table 1. Weights for Dimensions of the Sustainable Mobility Index

Weight	Description
3	Very important, because it represents the actual conditions of sustainable urban mobility
2	Important, because it represents many conditions of sustainable urban mobility. Its main focus is in the conditions of the entire city
1	Not very important, because it represents few conditions of sustainable urban mobility

Once the weights have been assigned to each one of the four considered dimensions, these values are normalized within the range between 0 (zero) and 1 (one), so that the sum of the assigned weights results always equal to one (1). This normalization is accomplished by the weighted average given by equation 1 where SOC, ECO, ENV, INST refer to the social, economic, environmental and institutional dimensions, respectively.

$$\text{Normalized Dim. Weight 1} = \left(\frac{\text{Assigned Weight to Dimension X}}{\sum \text{Assigned Weights to SOC, ECO, ENV, INST}} \right) \quad (1)$$

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Table 2 shows the assigned normalized weights (Weight 1) for each one of the dimensions:

Table 2. Normalized Weights for Dimensions

Dimension	Normalized Weights (Weight 1)
Social (SOC)	0,30
Economic (ECO)	0,20
Environmental (ENV)	0,20
Institutional (INST)	0,30

5.2 Topics and Indicators

The indicators were chosen according to their adherence to the concept of specific topics and the possibility of access to available public statistical databases (Table 3). The assignment of weights for each one of the topics (Weight 2) has been made in a manner analogous to that used for the dimensions, following the classification shown in Table 4 that depicts the local conditions of the existing transport system. The sum of the weights for the topics belonging to the same dimension must be equal to 1.

Table 3. Topics, Indicators and Evaluation Criteria

Topic: indicator	Evaluation Criteria (summary)
SOC1: Master Plan and urban laws	Forecasting of integrated planning regarding occupation of soil and land use with public transport. Public transport planning using the concepts of sustainable urban mobility.
SOC2: Accessibility	Level of accessibility to all means of transport and also the road system (access ramps to sidewalks, sidewalks suitable to all types of users, among other features).
SOC3: Public Transport Integration	Percentage of intermodal stations. Measures the interconnection between the modes of transport.
ECO1: Budget spent in transportation (tickets)	Measures the family budget percentage spent on transport tickets, related to the minimum monthly wage. Average ticket value per month / minimum monthly wage.
ECO2: Efficiency of Collective Public Transport	Measures the index for passengers per km of journey made in public transport. The higher the number, more efficient transport system is.
EC03: Public Investments in Public Transport Sector	Public budget percentage of the municipality for investments in the public transport sector.
ENV1: Motorization Rate	Percentage of vehicles circulating in relation to the number of inhabitants.
ENV2: Consumption of Fossil Fuels	Measures the sale of fossil fuels (diesel and gas) in relation to the number of inhabitants.
ENV3: Infrastructure for non-motorized modes	Evaluation of existing infrastructure to bike transport (bike paths and similar, bike racks and appropriate facilities). It also evaluates existing conditions for walking (facilities, appropriate urban equipment, streets with sidewalks and trees). It also evaluates if the existing laws cover the subject and are applied to the locality.
INST1: Guidelines	Verifies if existing federal laws require that the cities prepare their Master Plans, which must be coordinated with the Transport Plans, and both must be prepared according to the principles of sustainable mobility.
INST2: Operating Capacity	Evaluates if Master Plan and Public Transport Plan were developed, and, if so, whether they are in accordance with federal laws.
INST3: Management Tools	Evaluation of four specific parameters to the management of transport systems: access to technical literature, preparation of projects, use of quality index and use of communication channel with the users of public transport.

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Table 4. Calculation of index for each topic and desired directions

Theme	Normalized Values			Expected Tendency	Weight 2
	2010	2011	2012		
SOC1: Master Plan and urban legislation	0.75	1.00	1.00	Increase	0.33
SOC2: Accessibility	0.25	0.75	0.75	Increase	0.33
SOC3: Integration of Public Transport	0.25	0.25	0.75	Increase	0.34
ECO1: Budget spent in transportation (tickets)	0.90	0.43	0.12	Decrease	0.29
ECO2: Efficiency of Collective Public Transport	0.08	0.76	0.76	Increase	0.29
ECO3: Public Investment on Public Transport Sector	0.81	0.08	0.69	Increase	0.42
ENV1: Motorization Rate	0.11	0.49	0.89	Decrease	0.29
ENV2: Consumption of Fossil Fuels	0.43	0.13	0.90	Decrease	0.29
ENV3: Infrastructure for non-motorized modes	0.00	0.25	0.25	Increase	0.42
INST1: Guidelines	0.25	0.75	0.75	Increase	0.20
INST2: Operating Capacity	0.00	0.25	0.25	Increase	0.40
INST3: Management Tools	0.33	0.33	0.33	Increase	0.40

5.3 Calculation of the Sustainable Mobility Index

Collected data are calculated in two different ways: the indicators ECO1, ECO2, ECO3, ENV1 and ENV2 are obtained using data acquired in the public data bank. These data are normalized in order to make meaningful the comparison between them. This process is achieved by calculating the average and the standard deviation of the data series. Once obtained, the data are normalized according to a normal distribution as given by equation 2:

$$f(x) = \frac{1}{\sqrt{(2\pi\sigma^2)}} \exp\left\{-\frac{(x-\mu)^2}{2\sigma^2}\right\} \quad (2)$$

where μ is the average of collected data and σ the standard deviation.

For the indicators SOC1, SOC2, SOC3, ENV3, INST1, INST2 and INST3 rating scales were created for each one of them, according to criteria shown in Table 2. The evaluation grades start from 0, when any of the required conditions was fulfilled, to 1, meaning that all conditions were fully accomplished.

It is also necessary to assign a expected tendency to each one of the indicators, depending on specific characteristics. Some of them are expected to decrease, such as budget spent in transportation, motorization rate and consumption of fossil fuels while others, as accessibility and efficiency of public transport, should increase over time. Table 4 shows the values calculated for the indicators, the expected tendencies and the assigned weights.

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A partial index calculation for every dimension is carried out multiplying the Weight 2 (Table 4) by the respective normalized values of the data series. For example:

$$\text{ISOCpartial} = \text{Weight 2} \times [(\text{SOC1} + \text{SOC2} + \text{SOC3})] \tag{3a}$$

$$\text{IECOpartial} = \text{Weight 2} \times [(-\text{ECO1} + \text{ECO2} + \text{ECO3})] \tag{3b}$$

$$\text{IENVpartial} = \text{Weight 2} \times [(-\text{ENV1} - \text{ENV2} + \text{ENV3})] \tag{3c}$$

$$\text{IINSTpartial} = \text{Weight 2} \times [(\text{INST1} + \text{INST2} + \text{INST3})] \tag{3d}$$

A final index determination for every dimension is obtained multiplying these partial values (equation 3) by the corresponding Weight 1 (Table 2), as indicated by equation 4:

$$\text{ISOC} = \text{Weight 1} \times \text{ISOCpartial} \tag{4a}$$

$$\text{IECO} = \text{Weight 1} \times \text{IECOpartial} \tag{4b}$$

$$\text{IENV} = \text{Weight 1} \times \text{IENVpartial} \tag{4c}$$

$$\text{IINST} = \text{Weight 1} \times \text{IINSTpartial} \tag{4d}$$

The Sustainable Mobility Index (SMI) is then given as the following sum (equation 5),

$$\text{SMI} = \text{ISOC} + \text{IECO} + \text{IENV} + \text{IINST} \tag{5}$$

The SMI values for the VII Administrative Region of Rio de Janeiro were the following: 0.342 for the year 2010, 0.498 for the year 2011 and 0.550 for the year 2012. As can be observed, the index has increased over those three years, reflecting some improvements in the public transport system, but it also emphasizes that the major value of 0.550 is still very low with respect to maximum possible value of 1.

6. CONCLUSION

There has been a mismatch between the improvements that are being implemented in the city of Rio de Janeiro and what has been done in many parts of the world in terms of sustainable urban mobility. There are some important topics that are not usually included into government plans such as integration of the transport modes, favoring non-motorized means of transport, infrastructure that allows cycling or walking safely and warning signals to keep pedestrians safe.

The suggested Sustainable Mobility Index (SMI), herein adapted to the reality of the city of Rio de Janeiro, highlights the growing motorization rate (indicated by topic ENV1) and the increasing consumption of fossil fuels (pointed out by topic ENV2), but it can encompass much more valuable and relevant information to be used in the development of public transport policies. The incorporation of an urban mobility index is necessary not only to assess the evolution and performance of a transport system, but also to control and bring it back to a well-planned route.

The city of Rio de Janeiro has many elements that may be explored to achieve a good urban planning, such as technical knowledge, legal framework and the existence of several modes of transport, especially in the VII Administrative Region. However, what population gets is the consequence of poor designed plans, with occurrence of daily traffic jams, overcrowded buses and subways cars, difficulties in accessibility, among other complaints. The large amount of bus lines circulating in the region, many with overlapping

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routes and lack of an efficient integration between other transport modes, are facts that can be observed every day.

The absence of a Master Plan for Urban Transport, including all the precepts of sustainable urban mobility, can be considered as the biggest problem of the public transport sector in the city of Rio de Janeiro, as well as in many other large Brazilian cities. Without a sound planning, there are no guidelines, targets or promises that could improve the transport system that the city population deserves.

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