Sustainable urban mobility: a comparative study and the basis for a management system in Brazil and Portugal

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Abstract

There is a clear need for the implementation of sustainability principles and guidelines in urban areas, as well as for strategies for controlling the elements that shape the urban environment. As a consequence, indicators become essential tools in providing the knowledge and information required for understanding particular aspects and problems of the cities. Therefore, the main objective of this work was to identify indicators that are suitable for monitoring the urban mobility conditions of selected cities in Brazil and Portugal. The first step taken in order to reach that objective was the selection and analysis of mobility indicators extracted from several national and international experiences of sustainability indicators. Those indicators were organized under a framework of Categories and Themes and also submitted to the evaluation of groups of experts in both countries, in order to determine their relative importance for monitoring urban mobility conditions. The final outcome of the analysis was a common set of mobility indicators for Brazilian and Portuguese cities, in addition to a more complete list of indicators that could better serve each country in particular.
Keywords: urban sustainable mobility, mobility indicators, multicriteria analysis, Brazilian cities, Portuguese cities.

1 Introduction

The increasing number of people living in cities, the continuous overload of infrastructure and urban facilities, and different kinds of environmental impacts are producing a fast deterioration of the quality of life in urban areas all over the world. Mobility problems exacerbate even more this picture, producing or worsening the overall conditions in urban areas due to problems such as: the spatial segregation of urban activities and services, the growing participation of non-sustainable modes in the transport split, the inefficiency of public transportation, noise, air pollution, and traffic congestion.

The lack of effective instruments for mobility control and monitoring in urban areas is also part of the problem faced when decision-makers try to implement sustainable policies. Most initiatives in this area, such as in Lautso [1], OECD [2] and EEA [3], are frequently focusing on mobility monitoring at the national level, and therefore they cannot be directly applied to urban mobility management. In contrast, a comprehensive picture of the indicators available for monitoring the urban environment in Brazilian and Portuguese cities is available in Costa [4], who built an inventory of urban indicators based on a search conducted in the official Internet pages of a substantial number of municipalities in both countries. The conclusions drawn by that author after the analysis of the inventory confirmed the lack of data and information for monitoring several aspects of the urban areas in both countries, particularly those related to mobility issues. The main aspects revealing these deficiencies are the absence, in the majority of the official municipal Internet pages, of: *i*) general statistical information (e.g., concerning urban infrastructure, health and education facilities, environmental aspects, etc.), *ii*) urban indicators able to provide summarized information about particular facts of the city, and *iii*) mobility indicators in particular. Notwithstanding the fact that conclusions based only on data extracted from Internet pages can be a limitation of that study, we believe that it reasonably reflects the information actually available in the cities surveyed.

The objective of the present work, which is an extension of Costa's study, is to identify indicators able to examine the mobility conditions of specific groups of cities in the two countries. In the case of Brazil, the study focus on medium-sized cities, which were selected according to IPEA [5]. In Portugal, the cities considered are those found in the *Atlas of Portuguese Cities*, which is a study produced by INE [6], although we did not include in our study the cities located in the insular territories.

The main reason for putting together, in a single study, cities of two countries coming from different contexts is exactly the possibility to learn from their individual experiences in the mobility management and in the promotion of sustainable development. The experience gathered in Portugal due to its status as a member of the European Union, where there are many efforts to deal with the sustainable mobility issues, can be of great value to Brazil, where the topic is not yet deeply explored. On the other hand, the Brazilian experience in managing the fast growth of medium-sized cities, associated with the knowledge of complex questions involving metropolitan areas, can be useful to Portuguese administrators and planners when trying to anticipate problems (and solutions) in the context of their own urban areas.

The theoretical background for this study is presented in the next section, in which we discuss the problem of sustainable urban mobility. In section 3 we conduct the selection and analysis of mobility indicators extracted from several national and international studies dealing with indicators of sustainability. The mobility indicators were then evaluated by a group of experts from Brazil and Portugal. The outcome of the evaluation was used in the development of systems of indicators directed to each country in particular and a common framework for both countries. The paper ends with an evaluation of the study results, followed by the conclusions.

2 Sustainable urban mobility

Mobility is an attribute of individuals and economic agents when performing a required displacement. It is constrained by the dimensions of the urban space and strongly affected by the complexity of the activities conducted in that space. In addition, it can be affected by user characteristics, such as income, age, and gender, and above all by the characteristics of the urban environment and transportation availability (ANTP [7]).

In general terms, many of the current mobility problems derive from the following aspects: the focus on private rather than on public transportation, with a strong concentration of investments in infrastructure for the automobile; the uncontrolled and unplanned urban growth, particularly in developing countries; and the continuous shift towards unsustainable transport modes. That combination of factors affects the overall urban quality of life in a negative way. Thus, part of the solution of the mobility problems is an attitude change, which can be made effective through the implementation of sustainability principles and concepts aiming at an improvement of the quality of life of urban citizens.

In such a context, a new urban mobility paradigm should consider: priority for public transportation and non-motorized modes, the reorganization of urban activities in order to have more compact cities and a reduction of long distance trips, and mainly a more balanced modal split integrated with the spatial distribution of urban activities.

Several authors (such as Costa [4], Greene and Wegener [8], Gudmundsson and Höjer [9], Moore and Johnson [10], World Bank [11]) have identified key factors affecting sustainable mobility. Briefly, mobility can be improved and made more sustainable by the following strategies: more efficient technologies, able to reduce energy consumption; the adoption of non-motorized transport modes (e.g., walking and cycling); strategies for urban growth control, focusing on the reduction of travel times and traffic pollution; the improvement of effectiveness and efficiency of transit systems; a balanced and integrated use of different transport modes; development of new technologies and evaluation of their assimilation by the community; reduction of travel needs by means of a reorganization of urban activities and mixed land use; better accessibility conditions for persons with special needs, such as handicapped, pregnant women, children and senior citizens; and fair transport fares.

The assessment of the benefits resulting from such strategies is not easily done, however, and that is one of the reasons why indicators are so important for planning. Indicators are essential at any planning level, since they provide information that can be used in the formulation of plans and policies directed to the quality of life improvement and to the implementation of sustainability concepts. They play a key role in providing more detailed information about the actual conditions found in urban areas and they are also useful for monitoring the progress obtained with specific actions aiming at sustainable mobility. In addition, the development of indicators specifically conceived for the urban context is fundamental for highlighting the obstacles that have to be removed and the alternatives that can be explored. In summary, indicators are not only helpful for understanding economic, social, and environmental issues, but also to improve the knowledge of particular features and details of urban areas.

One of the problems of indicators, however, is that they are very context-sensitive. So, in order to contribute for a selection of mobility indicators appropriate for Brazilian and Portuguese cities we carried out a review of national and international experiences in the field, which is summarized in the following section. The selection procedure is complemented by an analysis using MCE (Multicriteria Evaluation) techniques relying on experts of both countries.

3 Selection and analysis of urban mobility indicators

The search for sustainability indicators in the literature was necessary for building a theoretical framework for sustainable urban mobility. The elements and indicators extracted from the different experiences might thus constitute a reference for initiatives designed to promote the concept. At the start, the search was not limited to a certain scale or by geographical boundaries. The idea was to gather a significant amount of data and information so that the many elements and functions involved in the complex concept of sustainability could be identified and characterized.

All elements identified in the studied experiences were combined in five main **Categories**, each one of them with four subdivisions or **Themes**, as shown in Figure 1. Each theme was scrutinized with the help of key-words or key-sentences for the identification of the mobility indicators already available in the different systems. Parts of words were also used to make the search more effective. For example, instead of searching for the words pollution and pollutants we have searched for the first part of these words (not necessarily the root), which in this case is *pollut*.

The framework presented in Table 1 was thus a reference for searching for mobility indicators. Next, each item displayed in the Themes column received an identification number (**ID**) representing at the same the Category (by the letter) and the Theme (by the number). The ID was later used for grouping indicators coming from different systems into the current classification. The whole process, which is thoroughly explained in Costa [4], made possible the identification of 465 indicators dealing with mobility out of the 1350 indicators of sustainability found in the experiences investigated.

Given that some of the indicators selected were similar or not adequate to be applied at the urban level, a new selection was made to obtain a set of indicators valid for the evaluation phase. The final group of indicators presented to the

Brazilian and Portuguese experts for evaluation was then reduced to 115 indicators. Next, all elements of the three hierarchy levels (Categories, Themes, and Indicators) were finally evaluated by the experts, in order to determine their relative importance for monitoring urban mobility conditions. The evaluation was conducted with an AHP (Analytical Hierarchy Process) approach, and the final outcome of the process was the identification of weights associated to each element evaluated.

Table 1: A framework of Categories and Themes associated with the concept of sustainable urban mobility.

Category	ID	Theme
Transportation and Environment (E)	E1	Energy/Fuels
	E2	Environmental Impacts
	E3	Air Quality
	E4	Traffic Noise
Urban Mobility Management (M)	M5	Expenditures/Investments/ Economics Strategies
	M6	Management
	M7	Strategies to Improve Urban Mobility
	M8	New Technologies
Infrastructure and Transportation Technologies (I)	I9	Fleet
	I10	Infrastructure/Street System
	I11	Technologies and Transportation Services
	I12	Traffic
Spatial Planning and Transportation Demand (P)	P13	Accessibility to Urban Facilities
	P14	Urban Development/ Land Use
	P15	Urban Population
	P16	Urban Displacements
Socio-economic Aspects of Transportation (S)	S17	Costs/Prices/Tariffs
	S18	Socio-economics Impacts of Transportation
	S19	Traffic Safety
	S20	Transit

3.1 Evaluation of sustainable mobility indicators

All analyses conducted in this study were meant to identify the main elements (Categories, Themes, and Indicators of mobility) that should be part of a system of indicators for monitoring urban mobility conditions in Brazilian and Portuguese cities, according to the experts. Three groups of elements were identified in the process. Two of them had the most important indicators for each country. The third group, in contrast, had a set of indicators that were important for both countries and therefore it is flexible enough to be applied in either case.

The application of the AHP approach, which was developed by the mathematician Thomas Saaty at the Wharton School of Business (Saaty [12] [13] [14]), made possible to associate weights varying from zero to one to each element evaluated. The subjective evaluations of the experts were converted into weights through pairwise comparisons performed at all hierarchy levels and subsequently combined. According to Forman and Selly [15], the model allows the development of a hierarchical structure in which the relationships between the main goal and the elements, criteria, subcriteria, and alternatives, can be visualized.

The pairwise comparisons were all performed in spreadsheets developed by the authors specifically for this study and made available to all experts invited to participate in the evaluation panel. The experts were selected among professionals involved in urban and transportation planning either in Brazil or in Portugal. The spreadsheets contained not only the matrices needed for the pairwise comparisons, but detailed instructions and information for the entire evaluation process. That included, for instance, descriptions and comments regarding each element considered in the evaluation (i.e., Categories, Themes, and Indicators). The additional information was provided to ensure a clear understanding of what was being evaluated.

The experts were asked to conduct the pairwise comparisons having in mind the relative importance of the elements in each pair for the process of monitoring urban mobility, which was the goal. The evaluation process was divided in two phases. Five Categories and twenty Themes were evaluated in the first phase, with the same number of Themes per Category (i.e., four). The 115 Indicators were evaluated in the second phase, grouped according to the Themes they belong to, as indicated in Figure 1.

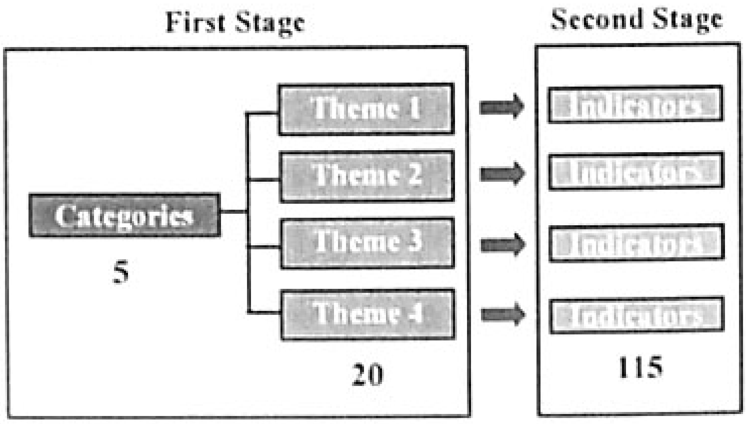

Figure 1: Elements of the hierarchy.

After the evaluation, some points should be highlighted with regard to the weights associated with the categories. In the case of Brazil, the categories Transportation and Environment, Socio-economic Aspects of Transportation, and Spatial Planning and Transportation Demand had the highest weights (0.297, 0.217, and 0.210, respectively), followed by Urban Mobility Management (0.173) and Infrastructure and Transportation Technologies (0.102). In the case of Portugal, the results were slightly different. The category Spatial Planning and Transportation Demand had the highest weight (0.363), followed by Transportation and Environment (0.221), Urban Mobility Management (0.173), Infrastructure and Transportation Technologies (0.129), and Socio-economic Aspects of Transportation (0.114). It is also interesting to compare the weights of the themes that were on the top of the ranking in each category in both countries, as shown in Table 2.

Table 2: Weights obtained for the themes evaluated.

Category	Brazil			Portugal		
	ID	Theme	Weight	ID	Theme	Weight
E	E3	Air Quality	0,311	E3	Air Quality	0,415
M	M5	Expenditures/Investments/Economics Strategies	0,284	M7	Strategies to Improve Urban Mobility	0,335
I	I12	Traffic	0,316	I10	Infrastructure/Street System	0,43
P	P13	Accessibility to Urban Facilities	0,313	P13	Accessibility to Urban Facilities	0,397
S	S17	Costs/Prices/Tariffs	0,264	S19	Traffic Safety	0,377

Table 3: Common indicators for the evaluation of sustainable urban mobility in Brazil and Portugal.

Category	Weight		ID	Theme	Weight		Indicator	Weight	
	BR	PT			BR	PT		BR	PT
E	0,297	0,221	E2	Environmental Impacts	0,257	0,223	Fragmentation of lands and forests	0,160	0,259
							Car use impacts	0,292	0,261
							Waste from road vehicles	0,278	0,305
			E3	Air Quality	0,311	0,415	Number of days air pollutants exceed healthful levels	0,109	0,180
							Emissions of acidifying gases from transport	0,110	0,118
							Transport emissions of greenhouse gases by mode	0,093	0,109
							Transport-related air emissions and emission intensities	0,188	0,234
							Population exposed to air pollution from transport	0,292	0,247
			E4	Traffic Noise	0,234	0,258	Noise pollution	0,340	0,197
							Population exposed to transport noise greater than 65 dB(A)	0,267	0,478
							Traffic Noise: exposure and annoyance	0,187	0,255
M	0,173	0,173	M5	Expenditures/Investments/ Economics Strategies	0,256	0,240	Investments in transport infrastructure	0,308	0,239
			M6	Management	0,236	0,183	Effective traffic management/Enforcement	0,226	0,357
							National transport and environment monitoring systems	0,477	0,436
			M8	Strategies to Improve Urban Mobility	0,271	0,335	City develops trip reduction plan	0,191	0,247
P	0,210	0,363	P13	Accessibility to Urban Facilities	0,313	0,397	Accessibility to the center	0,139	0,287
							Accessibility to basic services and markets by transport mode	0,325	0,339
							Access to transport services	0,249	0,190
			P14	Urban Development/ Land Use	0,222	0,211	Land use urban planning	0,184	0,193
			P15	Urban Population	0,267	0,079	Population density	0,352	0,362
							Population growth rate	0,228	0,317
			P16	Urban Displacements	0,199	0,313	Local mobility and passenger transportation	0,269	0,170
S	0,217	0,114	S19	Traffic Safety	0,244	0,377	Transport accident fatalities	0,225	0,235
							Safe and secure residential streets	0,185	0,321

The combination of the weights of the categories, themes and indicators, produced a final score, also varying from zero to one, to each indicator. This process was carried out three times: only for Brazil, only for Portugal, and for both countries simultaneously. The mean and the standard deviation of the final values were calculated in all three cases and subsequently used to identify the indicators that could be removed, because of their low weights, in the case of building a specific monitoring system for each of the two countries. The mean and the standard deviation were also used to produce classes of indicators with the highest weights in the cases of Brazil and Portugal (i.e., 52 and 39, respectively). This may be an indication that these indicators should be part of a system designed to be flexible enough for monitoring mobility in the context of both countries.

The indicators associated with environmental and socio-economic aspects of transport were on the top of the rank, according to Brazilian experts. For Portugal, the most important indicators belonged to the category Spatial Planning and Transportation Demand. However, a selection of the indicators that were important for both countries is required for the development of a common system for urban mobility monitoring. Most of the indicators in that condition belonged to the category Transportation and Environment and Spatial Planning and Transportation Demand. In addition, they were concentrated in eleven of the twenty Themes considered in this study. Furthermore, the Category Infrastructure and Transportation Technologies should not be included in a common system because of the low weights of its indicators. Therefore, the final structure of the proposed system for the management of mobility in Brazil and Portugal contained twenty-four indicators. They are shown in Table 3, along the Categories and Themes, and the associated weights found for both countries separately.

4 Final remarks

This work was meant to be a contribution for the identification of indicators for monitoring urban mobility conditions in Brazilian and Portuguese cities aiming at sustainability. We started the research by building a theoretical framework on sustainable urban mobility based on international systems of indicators. In that phase, we also tried to identify the main elements and attributes needed for the promotion of sustainable development. This framework was essential in the definition of the hierarchy of Categories, Themes, and Indicators for monitoring urban mobility conditions proposed next.

The development of such a structure and the assessment of the weights associated to individual elements helped in the identification of relationships among the elements and their relative contribution to the issue of sustainable urban mobility in Brazil and in Portugal. The relative importance of the elements was possible thanks to the involvement of Brazilian and Portuguese experts in the study. While the most important aspects in Brazil were related to environmental issues, mainly due to the pollution produced by transportation systems, the focus in Portugal was on spatial planning and transportation demand. These differences were not really a surprise, given that the two countries are in very distinct contexts, what certainly raises dissimilar issues concerning the environment and the territory management and organization.

Also noticeable is the relevance of the indicators in the category Socio-economic Aspects of Transportation in Brazil, mainly those dealing with transportation costs and fares. For both countries, the elements in the category Infrastructure and Transportation Technologies were not relevant if compared to the other elements in the other categories. We assumed it as an indication that the whole category should not be considered in a system to be applied in both countries.

On the other hand, we have to highlight the importance given to the indicators of accessibility to essential services as well as to transportation services in Brazil and in Portugal. Traffic safety, growth control, and the degree of population concentration in urban areas (as an important element for transportation demand estimation) were also seen as highly relevant in both countries.

The synthesis produced here can certainly help in the implementation of new tools (e.g., Decision Support Systems) for the evaluation, control, and improvement of urban mobility conditions in a more sustainable way. The identification of indicators of urban mobility and the assessment of their weights in the specific contexts of Brazilian and Portuguese cities is needed for the identification and quantification of the existing problems, which is the first step to find solutions to solve them and to improve the overall mobility of urban citizens.

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