DEVELOPMENT AND APPLICATION OF I_SUM - AN INDEX OF SUSTAINABLE URBAN MOBILITY

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ABSTRACT

This work describes the construction process of an Index of Sustainable Urban Mobility (I_SUM). Important aspects regarding its application as a mobility planning and management supporting tool are also discussed. The index is based on a hierarchy of criteria built essentially with data obtained from planners and technicians of eleven cities, what resulted in eighty-seven Indicators forming thirty-seven Themes, under nine Domains. Weights for the Themes and Domains were obtained through a panel of experts. A viability analysis of the index application was carried out in a city with around 220,000 inhabitants located in the state of São Paulo, Brazil. The analysis of the results has shown that a significant number of indicators could be calculated in the short term and with good quality data in the studied city. The main conclusion drawn from the application was the confirmation that I_SUM is flexible enough to be applied not only in a developing country medium-sized city, but also in cities with diverse characteristics. It is important to highlight the fact that the tool also gives the opportunity to assess the relative contribution of any specific aspects of mobility to the Social, Economic, and Environmental dimensions of sustainability. That I_SUM feature can be used to help in the formulation of either integrated or stand-alone policies per sector aiming at the development of the sustainable urban mobility. Moreover, it can help in the public participation process due to the possibility of building up scenarios based on hypothetical changes of the indicator values.

1. INTRODUCTION

Urban mobility problems vary from country to country and from city to city and they have produced some changes in the way cities and their circulation systems are planned. As a result, the traditional transportation planning approach based essentially on 'prediction and provision' is no longer an option. That is essentially caused by two transport demand-related troubles. On one side are the demand behavior uncertainties and on the other side is the difficulty in effectively meeting the needs of a growing demand. The alternative approach of 'mobility management' advocated by some (*1*) can also be a problem, considering that mobility is nowadays an essential condition for an active participation in the social and economic aspects of life (*2*).

A new planning paradigm is being gradually built, in which transportation planning, circulation planning and urban planning are now devised under a common approach, the mobility planning. This new approach is based on the concepts of sustainability, and sustainable development. According to Litman and Burwell (*3*), there is a growing interest in sustainability, which may be a simple concept with complex implications, and its relationships with transport planning. If the concept of sustainable transportation is seen as an extension of the concept of sustainable development introduced in the Brundtland Report (*4*), it could be defined as the development that meets the current transport needs without jeopardizing the ability of future generations to meet these needs (*5* and *6*). Additionally, the concept of sustainability is often associated to the economic, social, and environmental dimensions (*5*, *6*, *7*, *8*, *9*. *10*, 11 and *12*).

As a consequence of that new paradigm, the treatment of mobility issues has fostered the development of new planning procedures and tools, among which are improved versions of traditional urban indexes and indicators. Indicators are useful to describe the behavior of the several elements and functions that shape the urban environment. In general, the indicators have been developed so far to help assess economic, social, and environmental implications of alternative scenarios and policies. Other indicators focus on specific aspects of sustainability, such as accessibility, mobility and environmental capacity (*13* and *14*). However, as stated by Maclaren (*15*), indicators are simplifications of complex phenomena and they often provide only an indication of the condition or state of a given element. Thus, a better picture is only obtained through a combination of indicators, in order to capture the different dimensions and aspects of any particular problem, as observed by Gudmundsson (*16*) in Europe and in North America. It allows more understandable and integrated analyses, what helps decision-makers to recognize how specific policies and planning decisions affect sustainability goals (*11*).

I_SUM, which is the acronym for Index of Sustainable Urban Mobility, was designed to combine the main domains and themes needed for urban mobility monitoring. It was meant to be a supporting tool for mobility management and for the formulation of public policies. The hierarchy of criteria of I_SUM was essentially structured on the top of an indicator set. As suggested by Litman (*11*) the indicators were carefully selected to reflect diverse impacts and perspectives of mobility. They were also relatively easy to collect and to analyze. The main characteristics of the Index are:

- It follows a hierarchy of criteria based on concepts and elements identified by technicians and managers working at urban and transportation planning agencies of eleven important Brazilian cities or metropolitan regions, as described in (*17*) and (*10*).
- It follows a weighing system for the criteria. It establishes the relative importance of the elements and concepts based on the judgment of a small group of experts from different countries. It also takes into account the weights of the main sustainability dimensions (i.e., social,

environmental and economic) for each theme under analysis. That makes possible to assess the impact of any actions on the mobility system as a whole or on each separate dimension.

- It contains a structure of criteria aggregation that allows for trade-offs. In other words, a low score criterion can be compensated by a set of high-score criteria.
- It is a tool easy to understand and to apply. It does not require specific software or complex mathematical models for practical use. A simple spreadsheet can do the entire computation job.

The results of a viability analysis of the index application and the main conclusions of the study are presented in this paper, which is structured as follows. The next section brings the description of I_SUM, whit an emphasis on the method used for the index construction, as well as on its main characteristics as a tool for assessing and monitoring urban mobility. While referring to details of the application methodology in section 3, the results of that application are presented in discussed in section 4. The main conclusions are presented in section 5.

2. THE INDEX DEVELOPMENT

The index of Sustainable Urban Mobility, or I_SUM, was developed in several stages, as briefly described in the following subsections.

2.1. The Concept of Sustainable Urban Mobility

The first step for the definition of I_SUM consisted in the identification of concepts somehow connected to the issue of sustainable urban mobility that could be adopted in urban and transportation planning and management activities in selected Brazilian cities. The process involved the organization of several workshops with technicians, planners and decision-makers working for the public administration sector at the municipal or metropolitan level. The process was officially conducted by the Brazilian Ministry of the Cities under a training initiative named “Integrated Management of Urban Mobility” in eleven Brazilian cities of the five country regions between May 2005 and November 2006 (*10*).

The workshops were carried out with a constructivist Multicriteria Decision Analysis approach, what led to the identification of a set of Alternatives, Fundamental Points of View (FPVs), and Indicators. Those elements are useful to describe the problems, concerns, and potentialities for making effective the concept of sustainable urban mobility in the Brazilian cities considered in the program. Details of the method application in the workshops, as well as an analysis of the data, both comprehensively and in a regional perspective, can be found in (*10*). The outcome of the analyses of the aspects discussed in the eleven cities in which the workshops were organized was a list of fifty-five Alternatives. They reflected the main areas of concern regarding the issue of sustainable mobility. The Alternatives were divided in ninety-six FPVs, which were further subdivided in six hundred forty-five indicators. Given the large number of Alternatives, FPVs and Indicators identified, their aggregation was needed for reducing the number of elements and for establishing a hierarchy of common criteria to all cities considered.

2.2. Hierarchy of Criteria

The hierarchy of criteria of I_SUM started with the fifty-five Alternatives, which were defined after successive rounds of analyses, comparisons and combinations of concepts that expressed similar ideas. The final outcome of the process was the identification of nine groups, individually named to represent the main idea behind each group. Given the comprehensiveness of the concepts involved, the new groups derived from the Alternatives were then called Domains.

The reduction in the number of FPVs demanded analyses of the complete concepts obtained in the origin of the process, when several ideas were registered during the brainstorm phase of the workshops. In that process, each idea was registered along with a positive aspect connecting it to an action-oriented concept, and with a negative aspect representing its psychological opposite (more details can be found in *10*). The aggregation procedure in that case was driven by key ideas associated to each of the nine Domains. The ninety-six original FPVs were consequently reduced to thirty-seven Themes in the I_SUM hierarchy of criteria. They were also renamed to better express the broad concepts resulting from the aggregation process. Finally, the I_SUM hierarchy of criteria was completed with the relocation, in the Themes, of the Indicators originally associated to the FPVs.

2.3. Indicator Set

The selection of indicators to be used in I_SUM for monitoring each one of the Themes was based on the analysis of two sets of information: (i) a reference system with roughly 2,700 urban indicators organized by the authors after looking at experiences developed in Brazil and abroad; and (ii) the complete set of indicators obtained in the workshops conducted in the Brazilian cities, as described in section 2.1.

The first step in the process was to define a supporting framework to search for indicators in the reference system. The framework was formed by: the Domains, Themes and the respective definitions; and the topics raised in the workshops when looking at the Themes, as well as key words and expressions that could help in their identification. The search for key words and expressions resulted in 575 elements classified according to the themes and 623 elements classified according to the indicators. Subsequently, the two sets of elements were combined, resulting in a group with the most representative indicators of each theme, which were common to both sets. In order to select the final set of indicators, the technical and methodological information available in their original systems was retrieved. Those elements presenting clearer and more detailed information for further development and application were selected.

The process described above resulted in a final set of 87 indicators. A guide containing procedures for their development and application in Brazilian cities was thereafter developed by Costa (*17*). As one of the important components for their application is related to criteria weighing, normalization and aggregation, those steps are discussed in the sequence.

2.4. Criteria Weighing

The weights for Themes and Domains were obtained through a panel of experts, who work in the fields of urban planning, transportation planning, mobility and sustainability in Brazil as well as in other countries (e.g., Portugal, Germany, United States, Australia). The experts were also asked, in the case of the Themes, to assess their relative contribution directly to each one of the three Dimensions usually considered as the main parts of sustainability (i.e., Social, Economic, and Environmental). That information shall allow the assessment of the future impacts of a planned action in any particular Theme or group of Themes on each of these Dimensions. The evaluation was carried out through an Internet form using a scale of points with five levels, from one (insignificant) to five (extremely important). The weights of the Themes and of the sustainability Dimensions for each Theme were obtained directly from the average of the values given by the experts. In the case of the Domains, their weights were obtained from the average of the values coming from all Themes that are part of it. The weights of the Indicators were equal and they had to sum up one within each Theme. The complete list of Domains, Themes and Indicators used in I_SUM and their respective weights can be seen in Table 1.

TABLE 1 Indicators, themes, domains, sustainability dimensions, and weights of I_SUM

DOMAINS	DOMAINS WEIGHTS	SOC	ECO	ENV	THEMES	THEMES WEIGHTS	INDICATORS	INDICATORS WEIGHT
ACCESSIBILITY	0.108	0.38	0.36	0.26	Accessibility to transport systems	**0.29**	Accessibility to transit	**0.33**
							Public transportation for users with special needs	**0.33**
							Transport expenses	**0.33**
		0.40	0.32	0.27	Universal accessibility	**0.28**	Street crossings adapted to users with special needs	**0.20**
							Accessibility to open spaces	**0.20**
							Parking spaces to users with special needs	**0.20**
							Accessibility to public buildings	**0.20**
							Accessibility to essential services	**0.20**
		0.38	0.30	0.32	Physical barriers	**0.22**	Urban fragmentation	**1.00**
		0.46	0.28	0.27	Legislation for users with special needs	**0.21**	Actions towards universal accessibility	**1.00**
ENVIRON. ASPECTS	0.113	0.29	0.28	0.43	Control of environmental impacts	**0.52**	CO Emissions	**0.25**
							CO_2 Emissions	**0.25**
							Population exposed to traffic noise	**0.25**
							Studies of environmental impacts	**0.25**
		0.26	0.32	0.42	Natural resources	**0.48**	Fuel consumption	**0.50**
							Use of clean energy and alternative fuels	**0.50**
SOCIAL ASPECTS	0.108	0.40	0.31	0.29	Support to the citizens	**0.21**	Information available to the population	**1.00**
		0.45	0.30	0.25	Social inclusion	**0.20**	Vertical equity (income)	**1.00**
		0.39	0.30	0.31	Education and active citizenship	**0.19**	Education for sustainable development	**1.00**
		0.41	0.27	0.32	Public participation	**0.19**	Participation in decision-taking	**1.00**
		0.35	0.30	0.35	Quality of life	**0.21**	Quality of life	**1.00**
POLITICAL ASPECTS	0.113	0.33	0.34	0.32	Integration of political actions	**0.34**	Integration of different government levels	**0.50**
							Public-private partnerships	**0.50**
		0.33	0.40	0.27	Acquisition and management of resources	**0.33**	Acquisition of resources	**0.25**
							Investments in transport systems	**0.25**
							Distribution of resources (public x private)	**0.25**
							Distribution of resources (motorized x non-motorized)	**0.25**
		0.34	0.33	0.32	Urban mobility policy	**0.34**	Urban mobility policy	**1.00**
TRANSPORT INFRA.	0.120	0.28	0.41	0.31	Provision and maintenance of transport infrastructure	**0.46**	Density of the street network	**0.25**
							Paved streets	**0.25**
							Maintenance expenditures in transport infrastructure	**0.25**
							Streets signaling	**0.25**
		0.33	0.35	0.33	Distribution of transport infrastructure	**0.54**	Transit lanes	**1.00**
NON-MOTORIZED MODES	0.110	0.32	0.29	0.39	Bicycle transportation	**0.31**	Length and connectivity of cycleways	**0.33**
							Bicycle fleet	**0.33**
							Facilities for bicycle parking	**0.33**
		0.33	0.28	0.39	Non-motorized modes	**0.34**	Pathways for pedestrians	**0.50**
							Streets with sidewalks	**0.50**
		0.28	0.32	0.40	Trips reduction	**0.35**	Travel distance	**0.25**
							Travel time	**0.25**
							Number of trips	**0.25**
							Measures to reduce motorized traffic	**0.25**

I_SUM								
DOMAINS	DOMAINS WEIGHTS	DIMENSIONS WEIGHTS SOC	ECO	ENV	THEMES	THEMES WEGHTS	INDICATORS	INDICATORS WEIGHTS
INTEGRATED PLANNING	0.108	0.31	0.37	0.32	Managers training	0.12	Expertise of technicians and managers	0.50
							Training for technicians and managers	0.50
		0.35	0.30	0.35	Central areas and historical sites	0.11	Vitality of the central area	1.00
		0.31	0.34	0.35	Regional integration	0.12	Intercity partnerships	1.00
		0.38	0.32	0.31	Planning process transparency	0.12	Transparency and responsibility	1.00
		0.31	0.32	0.36	Planning and control of land use	0.14	Vacant land	020
							Urban growth	0.20
							Urban population density	0.20
							Mixed land use	0.20
							Illegal settlements	0.20
		0.32	0.35	0.33	Strategic and integrated planning	0.14	Integrated urban. environmental and transport planning	0.50
							Implementation and sequence of planed actions	0.50
		0.31	0.39	0.30	Infrastructure and urban facilities planning	0.13	Parks and green areas	0.33
							Urban facilities (schools)	0.33
							Urban facilities (hospitals)	0.33
		0.31	0.35	0.35	Master Plan and urban legislation	0.12	Master Plan	0.33
							Urban legislation	0.33
							Urban legislation actual application	0.33
URBAN CIRCULATION AND TRAFFIC	0.107	0.37	0.38	0.26	Traffic accidents	0.21	Traffic accidents	0.33
							Accidents with pedestrians and cyclists	0.33
							Accident prevention	0.33
		0.39	0.31	0.30	Traffic education program	0.19	Traffic education program	1.00
		0.29	0.35	0.36	Freedom of movements and circulation	0.19	Congestion	0.50
							Average traffic speed	0.50
		0.34	0.33	0.33	Traffic operation and enforcement	0.20	Violation of traffic rules	1.00
		0.32	0.31	0.36	Private transport	0.21	Motorization rate	0.50
							Vehicle occupation	0.50
URBAN TRANSPORT SYSTEMS	0.112	0.35	0.33	0.32	Transit availability and quality	0.23	Total extension of the transit network	0.13
							Transit service frequency	0.13
							On-time performance	0.13
							Transit average speed	0.13
							Transit fleet age	0.13
							Passengers per kilometer	0.13
							Annual number of passengers	0.13
							User satisfaction with the transit service	0.13
		0.31	0.34	0.34	Diversity of transportation modes	0.18	Diversity of transportation modes	0.33
							Public versus private transport	0.33
							Motorized versus non-motorized modes	0.33
		0.34	0.35	0.31	Transit regulations and enforcement	0.18	Contracts and licitations	0.50
							Informal transport	0.50
		0.37	0.33	0.30	Transit integration	0.22	Intermodal terminals	0.50
							Transit integration	0.50
		0.38	0.37	0.25	Fare policy	0.19	Discounts and free rides	0.33
							Transit fares	0.33
							Public subsidies	0.33

2.5. Criteria Normalization and Aggregation

Considering that each Indicator may be assessed in a particular way, the resulting values of different indicators usually cannot be directly combined. In order to overcome that problem, it was necessary to define a normalization process to each of the indicators applied in I_SUM.

In the case of I_SUM, the suggested normalization process is essentially based on a lookup table defined for each indicator. The reference values adopted in the lookup tables were proposed based either on Brazilian or international standards found in the literature or on the experience of the index developers, who adapted the existing reference values to the context of Brazilian cities. A good example of such a strategy comes from SUMMA (*18*). In the case of the indicator Affordability, for example, transportation costs are considered unaffordable if they exceed 20 % of the households' incomes (*18*). I_SUM has the some concept but with more than a single threshold: for reference values below 6 % the normalized value is one, between 6 and 10 % is 0.75, between 11 and 15 % is 0.50, between 16 and 20 % is 0.25, and above 20 % is zero. In some cases, the evaluation scale is composed only by qualitative levels. Even without having a value actually calculated, that allows a general assessment of the situation represented by the Indicator.

After all indicators were individually normalized to values between zero and one, they could be aggregated according to a decision rule. The aggregation method proposed to I_SUM was based on a weighted linear combination, in which all criteria were combined through a weighted average. That method allows for a total trade-off among criteria. It means that a very poor attribute, translated as a low score obtained for one criterion, can be compensated by a number of good attributes, translated as higher scores obtained for some other criteria.

Given the adopted structure of Domains, Themes and Indicators, and the insertion of the sustainability Dimensions, the criteria aggregation process resulted in a global index and in three sectorial indexes, one for each Dimension. That is shown in Equations 1 and 2, respectively.

$$\text{I\_SUM}g = \sum_{i=1}^{n} w_i^D \cdot w_i^T \cdot w_i^I \cdot x_i \qquad (1)$$

where: I_SUMg: Global Index for n indicators;
$w^D{}_i$: weight of the Domain that Indicator i belongs to;
$w^T{}_i$: weight of the Theme that Indicator i belongs to;
$w^I{}_i$: weight of Indicator i;
x_i: score (normalized value) obtained to Indicator i.

$$\text{I\_SUM}_{\text{SD}_j} = \sum_{i=1}^{n} w_i^{SD_j} \cdot w_i^D \cdot w_i^T \cdot w_i^I \cdot x_i \ , \qquad (2)$$

with SD$_j$ = Social, Economic or Environmental Dimensions, where:
I_SUM$_{\text{SD}j}$: sectorial Index to each sustainability Dimension SD$_j$;
w_i^{SDj}: weight of the Dimension SD$_j$ in the Theme that Indicator i belongs to;
$w^D{}_i$, $w^T{}_i$, $w^I{}_i$, x_i: as defined above.

2.6. Application Details

The structure suggested to I_SUM also allows evaluations based on a reduced number of indicators. That is the case when the data needed for the calculation of all eighty-seven indicators are not reliable or simply do not exist. However, if a reduced number of indicators is used, it is necessary to redistribute the weights of the indicators within each Theme. The same procedure may be needed for Themes and for Domains, in order to assure that the weights in each hierarchy level always sum up one.

Thus, I_SUM can be calculated for any city in two ways: as a global Index, through Equation 1, and for each of the sustainability Dimensions, through Equation 2. That allows a straightforward comparison of the values found for the three Dimensions and an analysis of the individual contribution of each Dimension to the global value of I_SUM. These are elements that can help in the identification of the city aspects that are not contributing to the sustainable urban mobility as they could. Consequently, any public policies formulated to tackle the mobility problems should necessarily address those critical aspects. Also, even if the data available allows only the calculation of a reduced number of indicators, the themes and domains of the I_SUM hierarchy of criteria provide a good understanding of several urban and transportation planning issues. This is particularly relevant for planning purposes, given that it applies not only for experts, but also for the community.

3. THE APPLICATION METHODOLOGY

The effectiveness of I_SUM was tested in São Carlos, which is a medium-sized city located in the state of São Paulo, Brazil. With 192,000 inhabitants at the beginning of the decade, the city gained almost 20,000 inhabitants in seven years, according to the Census Bureau. Other three aspects were important in the selection of the city as a case study: the characteristics of its mobility systems, the availability of data, and the local instruments of urban management. Unfortunately these elements are not common in all cities of the same size, as will be briefly discussed in the conclusions of this document.

A method developed by OECD (Organization for Economic Co-operation and Development) was adapted for evaluating the suitability of I_SUM to Brazilian cities. The original approach was created by the *Working Group on the State of the Environment* (WGSOE) for the analysis of a set of indicators aiming at the integration of environmental aspects into transport policies (*19*). The original methodology evaluated the indicators looking at the selection criteria and evaluation scales shown in Table 2. *Policy relevance* considers the utility of the indicators to the users. *Analytical soundness* refers to the technical and scientific theoretical foundation of the indicators. *Measurability* is related to the availability and quality of the data needed for the calculation of an indicator.

TABLE 2 Selection criteria and evaluation scales for the analysis of indicators of transport and environment

Selection Criteria	Evaluation		
	1	2	3
▪ Policy relevance, i.e. relevance to transport and environment policies	High	Medium	Low
▪ Analytical soundness	Good	Average	Poor
▪ Measurability, taking into account:			
• *Data availability*	Short term	Medium term	Long term
• *Data quality including international comparability*	Good	Average	Poor

Source: (*19*) OECD (1999).

In the present study only the aspects related to *Measurability* are examined, given that the other two criteria (*Policy Relevance* and *Analytical Soundness*) were already carefully considered in the selection of indicators for I_SUM. In other words, the indicators were selected for I_SUM only if they were either High or Medium regarding the criterion *Policy Relevance*, and either Good or Average regarding the criterion *Analytical Soundness* they were. The aspects of data availability and data quality, however, were analyzed later on, in the case study discussed next. The characteristics associated with higher scores regarding the measurability are not only the data availability, but also the costs and benefits of their acquisition, the existence of reliable metadata and the quality of the information provided by the data. The reliability of the data collection and storage procedures is also very important in that case.

The data needed for the calculation of each indicator were identified, as well as the data sources. The document containing the tables with all I_SUM indicators and the respective data sources for their calculations is shown in (*17*). Some important sources of data are governmental agencies, such as the Municipal government, the Census Bureau, and the State Department of Transportation. The Universities located in the city also played an important role, given the research documents they have produced about several aspects of the city and of the region. In the case studied, one of these research documents will be the report of an Origin-Destination survey that is now under development. The report, which is expected to be available still in 2009, shall be a rich source of data and information about the urban displacements. As such, this was considered as a source of good quality data that must be available in the medium term for the calculation of indicators. In general, the quality of the available data was evaluated considering the period they refer to, their geographical coverage, and their aggregation level. The data collection methodology and the metadata were also carefully considered.

4. I_SUM CRITERIA EVALUATION IN SÃO CARLOS, BRAZIL

The availability and quality of the data needed for the calculation of the eighty-seven indicators can be summarized in tables, as shown in the example of Table 3. The evaluation of each indicator presented is a result of a combined analysis of all data needed for its calculation. The codes used are similar to the classification proposed by OECD and already shown in Table 2 concerning data availability (ST - Short Term, MT - Medium Term, and LT - Long Term) and data quality (H - Good, A - Average, and P - Poor). In the case of Table 3, the indicators listed are only those forty-five that were not simultaneously classified as Short Term and Good,

In addition to the general analysis for the indicators partially summarized in Table 3, it is interesting to consider what happens in each Domain of I_SUM, in terms of data availability and quality. So, the nine Domains were evaluated according to the same two subcriteria, as shown in Table 4. That evaluation was performed by summing up the values received by the indicators in each Domain with the values of Table 2. Therefore, the final Domain values could vary from one to three. While the value 'one' meant that all indicators of a single Domain would be available in the short term or could rely on good quality data, the value 'three' meant that all indicators of a single Domain would only be available in the long term or could rely on poor quality data. In addition to the average and standard deviation values of each Domain, Table 4 also shows the overall average and standard deviation values of the nine Domains altogether.

TABLE 3 Forty-five indicators with Short Term data availability and Average or Poor data quality, and Medium or Long Term data availability in São Carlos, Brazil

INDICATORS	DATA	
	Availability	Quality
Accessibility to transit	ST	A
Acquisition of resources	ST	A
Distribution of resources (public x private)	ST	A
Paved streets	ST	A
Intercity partnerships	ST	A
Urban growth	ST	A
Accident prevention	ST	A
Traffic education program	ST	A
Public subsidies	ST	A
Distribution of resources (motorized x non-motorized)	ST	P
Transport expenses	MT	G
Actions towards universal accessibility	MT	G
Vertical equity (income)	MT	G
Quality of life	MT	G
Travel distance	MT	G
Travel time	MT	G
Number of trips	MT	G
Average traffic speed	MT	G
Vehicle occupation	MT	G
User satisfaction with the transit service	MT	G
Public versus private transport	MT	G
Motorized versus non-motorized modes	MT	G
Parking spaces to users with special needs	MT	A
Accessibility to public buildings	MT	A
Population exposed to traffic noise	MT	A
Information available to the population	MT	A
Public-private partnerships	MT	A
Investments in transport systems	MT	A
Maintenance expenditures in transport infrastructure	MT	A
Streets with sidewalks	MT	A
Training for technicians and managers	MT	A
Vitality of the central area	MT	A
Mixed land use	MT	A
Integrated urban, environmental and transport planning	MT	A
Implementation and sequence of planed actions	MT	A
Urban legislation	MT	A
Urban legislation actual application	MT	A
Transit average speed	MT	A
Traffic accidents	MT	P
Accidents with pedestrians and cyclists	MT	P
Studies of environmental impacts	LT	A
Street signs	LT	A
Bicycle fleet	LT	A
Transparency and responsibility	LT	A
Congestion	LT	A

TABLE 4 I_SUM indicators that can be developed in the Short Term and with Good Quality Data in the city of São Carlos, Brazil, per Domain

DOMAINS	DATA				Percentage of I_SUM indicators to be developed in	
	Availability (range: 1 - 3)		Quality (range: 1 - 3)			
	Average	Standard deviation	Average	Standard deviation	Short Term with Good Quality Data	All other combinations
Accessibility	1.40	0.516	1.30	0.483	50.0 %	50.0 %
Environmental aspects	1.50	0.837	1.33	0.516	66.7 %	33.3 %
Social aspects	1.60	0.548	1.20	0.447	40.0 %	60.0 %
Political aspects	**1.29**	0.488	1.86	0.690	28.6 %	71.4 %
Transport infrastructure	1.60	0.894	1.60	0.548	40.0 %	60.0 %
Non-motorized modes	1.67	0.707	1.22	0.441	44.4 %	55.6 %
Integrated planning	1.50	0.618	1.56	0.511	44.4 %	55.6 %
Urban circulation and traffic	1.67	0.707	1.78	0.833	22.2 %	77.8 %
Urban transport systems	**1.22**	0.428	**1.11**	0.323	72.2 %	27.8 %
Overall values	***1.49***	***0.161***	***1.44***	***0.267***	60.0 %	40.0 %

The results found in São Carlos indicate that a reasonable share of the indicators that form I_SUM (fifty-two indicators, or 60 % of the total) could be developed in the short term for the city. Moreover, eighty percent of them (i.e., forty-two indicators, or 48 % of the total) were based on good quality data. In summary, it means they were recent, they were obtained through a sound methodology, and they provided a good geographical coverage of the city. The data available for the calculation of the other indicators of the short term (ST) availability group were classified, according to their quality, as average (nine indicators) and poor (only one indicator). Therefore, even considering the possibility of development of those indicators in the short term, the data needed for their calculation have to be updated or collected with a different methodology, in order to increase their reliability and coverage. The other thirty-five indicators (40 %) of I_SUM can be developed in the medium and long terms for the city of São Carlos. A detailed analysis of Table 4 highlights the following aspects of the case studied:

i. The average value of the Availability data score for the nine Domains was 1.49, with a standard deviation value of 0.161. Two Domains have shown particularly good conditions regarding that criterion: urban transport systems (average of 1.22) and political aspects (average of 1.29).

ii. The average value of the Quality data score for the nine Domains was 1.44, with a standard deviation value of 0.267. While the Quality of the data was particularly good also for the Domain urban transport systems (1.11), it was just the opposite for political aspects (1.86)

iii. A comparison of the percentages of I_SUM indicators that could be obtained in the short term with good quality data showed that the following two Domains could be well represented by the indicators available: urban transport systems (72 %) and environmental aspects (67 %). More indicators were not available in the other Domains, particularly urban circulation and traffic (22 %) and political aspects (29 %).

The indicators that could be readily calculated with good quality data in the city of São Carlos are those highlighted in Table 5. As a consequence, the indicators and themes weights were redistributed, in order to adjust the calculation procedure to the group of indicators considered. Moreover, that alternative could be used to adjust I_SUM to the data available in other cities. An analysis of each of the I_SUM Domains in the case studied can be summarized as follows:

- Accessibility - in general, the accessibility indicators were measurable in the short term and they relied on high quality data, with the exception of the indicators describing universal design concepts.
- Environmental aspects - readily measurable with good quality data, except in the case of traffic noise, given the absence of continuous monitoring of the urban streets noise levels.
- Social aspects - several indicators were measurable in the medium term. However, their quality depend on the results of an origin-destination survey and other studies still under development.
- Political aspects - many indicators were quantifiable in the short term, although the quality of the available data varied significantly. It was not easy to obtain information regarding the distribution of resources to motorized and non-motorized transport modes and also about investments in the transport systems.
- Transport infrastructure - part of the data needed in this case could also be extracted from the O-D survey, and were therefore measurable in the short term. In addition, given the reliability of the methodology and of the procedures used in the survey, the available data comprise average and good quality information. The average quality of some data was a consequence of a geographical coverage limited to some regions of the city. Information about the application of resources in the maintenance of transport infrastructures were often too aggregated, what was not good for their use in the proposed indicators.
- Non-motorized modes - several indicators were measurable in the medium and long terms. That was a consequence of the current status of non-motorized modes, which are often not considered as good transport alternatives. As a result, data about them are rarely collected. The results of the upcoming O-D survey will hopefully change this picture, and they will allow the calculation of indicators in the medium term.
- Integrated planning - there is some equilibrium between the indicators that could be measured in the short and medium terms. Many of the indicators that could be measured in the short term relied on the good quality data obtained during the review process of the municipal Master Plan. The absence of reliable information about jobs in the commercial and service sectors limited the development of the indicators in this domain. It was also difficult to get data for monitoring the actions of the public administration.
- Urban circulation and traffic - several indicators could be measured in the medium and long terms. Difficulties for data acquisition and standardization problems were among the main problems observed in this domain, along with the inadequacy of some data regarding particular aspects (e.g., accident data were too aggregated). Also, no information was found describing traffic and circulation conditions through time.
- Urban transport systems - this domain was easily monitored, given the large number of indicators that could be measured in the short term with good quality data. The indicators of this group were often measured at the urban level, either by the municipal administration or by the transit operator. Other indicators, which could be extracted for the O-D survey results, were measurable in the medium term.

TABLE 5 Possible I_SUM structure in the city of São Carlos

I_SUM								
DOMAINS	DOMAINS WEIGHTS	DIMENSIONS WEIGHTS SOC	DIMENSIONS WEIGHTS ECO	DIMENSIONS WEIGHTS ENV	THEMES	THEMES WEIGHTS	INDICATORS	INDICATORS WEIGHTS
ACCESSIBILITY	0.108	0.38	0.36	0.26	Accessibility to transport systems	0.29	Accessibility to transit	0.00
							Public transportation for users with special needs	1.00
							Transport expenses	0.00
		0.40	0.32	0.27	Universal accessibility	0.28	Street crossings adapted to users with special needs	0.33
							Accessibility to open spaces	0.33
							Parking spaces to users with special needs	0.00
							Accessibility to public buildings	0.00
							Accessibility to essential services	0.33
		0.38	0.30	0.32	Physical barriers	0.22	Urban fragmentation	1.00
		0.46	0.28	0.27	Legislation for users with special needs	0.21	Actions towards universal accessibility	1.00
ENVIRON. ASPECTS	0.113	0.29	0.28	0.43	Control of environmental impacts	0.52	CO Emissions	0.50
							CO_2 Emissions	0.50
							Population exposed to traffic noise	0.00
							Studies of environmental impacts	0.00
		0.26	0.32	0.42	Natural resources	0.48	Fuel consumption	0.50
							Use of clean energy and alternative fuels	0.50
SOCIAL ASPECTS	0.108	0.40	0.31	0.29	Support to the citizens	0.00	Information available to the population	0.00
		0.45	0.30	0.25	Social inclusion	0.00	Vertical equity (income)	0.00
		0.39	0.30	0.31	Education and active citizenship	0.49	Education for sustainable development	1.00
		0.41	0.27	0.32	Public participation	0.51	Participation in decision-taking	1.00
		0.35	0.30	0.35	Quality of life	0.00	Quality of life	0.00
POLITICAL ASPECTS	0.113	0.33	0.34	0.32	Integration of political actions	0.50	Integration of different government levels	1.00
							Public-private partnerships	0.00
		0.33	0.40	0.27	Acquisition and management of resources	0.00	Acquisition of resources	0.00
							Investments in transport systems	0.00
							Distribution of resources (public x private)	0.00
							Distribution of resources (motorized x non-motorized)	0.00
		0.34	0.33	0.32	Urban mobility policy	0.50	Urban mobility policy	1.00
TRANSPORT INFRA.	0.120	0.28	0.41	0.31	Provision and maintenance of transport infrastructure	0.46	Density of the street network	1.00
							Paved streets	0.00
							Maintenance expenditures in transport infrastructure	0.00
							Streets signaling	0.00
		0.33	0.35	0.33	Distribution of transport infrastructure	0.54	Transit lanes	1.00
NON-MOTORIZED MODES	0.110	0.32	0.29	0.39	Bicycle transportation	0.31	Length and connectivity of cycleways	0.50
							Bicycle fleet	0.50
							Facilities for bicycle parking	0.00
		0.33	0.28	0.39	Non-motorized modes	0.34	Pathways for pedestrians	1.00
							Streets with sidewalks	0.00
		0.28	0.32	0.40	Trips reduction	0.35	Travel distance	0.00
							Travel time	0.00
							Number of trips	0.00
							Measures to reduce motorized traffic	1.00

I_SUM								
DOMAINS	DOMAINS WEIGHTS	DIMENSIONS WEIGHTS SOC	ECO	ENV	THEMES	THEMES WEIGHTS	INDICATORS	INDICATORS WEIGHTS
INTEGRATED PLANNING	0.108	0.31	0.37	0.32	Managers training	0.24	Expertise of technicians and managers	1.00
							Training for technicians and managers	0.00
		0.35	0.30	0.35	Central areas and historical sites	0.00	Vitality of the central area	0.00
		0.31	0.34	0.35	Regional integration	0.00	Intercity partnerships	0.00
		0.38	0.32	0.31	Planning process transparency	0.00	Transparency and responsibility	0.00
		0.31	0.32	0.36	Planning and control of land use	0.27	Vacant land	0.33
							Urban growth	0.00
							Urban population density	0.33
							Mixed land use	0.00
							Illegal settlements	0.33
		0.32	0.35	0.33	Strategic and integrated planning	0.00	Integrated urban. environmental and transport planning	0.00
							Implementation and sequence of planed actions	0.00
		0.31	0.39	0.30	Infrastructure and urban facilities planning	0.26t	Parks and green areas	0.33
							Urban facilities (schools)	0.33
							Urban facilities (hospitals)	0.33
		0.31	0.35	0.35	Master Plan and urban legislation	0.24	Master Plan	1.00
							Urban legislation	0.00
							Urban legislation actual application	0.00
URBAN CIRCULATION AND TRAFFIC	0.107	0.37	0.38	0.26	Traffic accidents	0.00	Traffic accidents	0.00
							Accidents with pedestrians and cyclists	0.00
							Accident prevention	0.00
		0.39	0.31	0.30	Traffic education program	0.00	Traffic education program	0.00
		0.29	0.35	0.36	Freedom of movements and circulation	0.00	Congestion	0.00
							Average traffic speed	0.00
		0.34	0.33	0.33	Traffic operation and enforcement	0.49	Violation of traffic rules	1.00
		0.32	0.31	0.36	Private transport	0.51	Motorization rate	1.00
							Vehicle occupation	0.00
URBAN TRANSPORT SYSTEMS	0.112	0.35	0.33	0.32	Transit availability and quality	0.23	Total extension of the transit network	0.17
							Transit service frequency	0.17
							On-time performance	0.17
							Transit average speed	0.00
							Transit fleet age	0.17
							Passengers per kilometer	0.17
							Annual number of passengers	0.17
							User satisfaction with the transit service	0.00
		0.31	0.34	0.34	Diversity of transportation modes	0.18	Diversity of transportation modes	1.00
							Public versus private transport	0.00
							Motorized versus non-motorized modes	0.00
		0.34	0.35	0.31	Transit regulations and enforcement	0.18	Contracts and licitations	0.50
							Informal transport	0.50
		0.37	0.33	0.30	Transit integration	0.22	Intermodal terminals	0.50
							Transit integration	0.50
		0.38	0.37	0.25	Fare policy	0.19	Discounts and free rides	0.50
							Transit fares	0.50
							Public Subsidies	0.00

5. CONCLUSIONS

I_SUM has several characteristics that were identified by Litman (*12*) as important in the development of indicators for comprehensive and sustainable transport planning. First of all, the I_SUM indicator set can be used to evaluate progress toward goals and objectives. In addition, its indicators can have many specific uses: they can help identify trends, predict problems, assess options, set performance targets, and evaluate the mobility conditions in a particular jurisdiction or organization. As the choice of the indicators can significantly affect planning decisions, Litman (*12*) emphasizes the importance of carefully selecting indicators that reflect overall goals. It is also important to take into account data availability, understandability and usefulness in decision-making. I_SUM development was guided by those principles. Therefore, it answers positively to those issues, as discussed in the sequence.

An important feature of I_SUM is the fact that its structure is based on concepts gathered from technicians and experts directly involved with urban and transportation planning in important Brazilian cities. Therefore, it reflects the most relevant issues for mobility planning from a practical standpoint. That is distinctive from other international experiences aiming at the development of hierarchical structures with goals and objectives focusing on sustainability, as well as sustainable transportation indicators systems, which were essentially based on reviews of the established literature (as, for instance, in *13*). Moreover, the method adopted for building the index allowed the incorporation of many concepts from different spatial and temporal contexts, what made it adaptable to specific contexts.

The framework and the weighing system proposed for I_SUM form a tool for a comprehensive assessment of urban mobility. In such a way, it can be used for monitoring and for supporting integrated mobility policies. In addition, it can be concurrently used in the formulation of policies aiming at specific Dimensions or Domains, what is particularly interesting in face of financial shortcomings. The approach used in I_SUM for assessing the contribution of the index elements to the social, economic, and environmental three dimensions is innovative, given it assumes that all elements of the urban structure and of the transportation systems concurrently affect all dimensions of sustainability. It is different from other approaches often found in the literature (as in *14*, and *5*), in which the indicators independently affect either the social, the economic, or the environmental dimensions. Furthermore, I_SUM can be applied either in an entire urban area or in urban subdivisions or neighborhoods. That allows for comparisons, what can result in the development of actions or plans tailored to meet particular conditions of specific urban segments.

Additional differences of I_SUM in comparison to other tools traditionally applied for the assessment of sustainable mobility are noticeable. According to Gudmundsson (*5*), the authors of many studies worldwide have developed essentially descriptive indicators. That provides an entirely open interpretation of the sustainability trends. In I_SUM, minimum and maximum values are defined not only for the global index evaluation but also for the dimensions. Also, as we define control parameters for normalization (as discussed in section 2.5), the index gives a closed interpretation in terms of sustainability. In other words, it clearly indicates goals and objectives to be pursued. It also reveals the current system status in relation to the pre-established parameters. In addition, those parameters can be defined for specific contexts, in order to meet the objectives and goals established in policies and strategies aiming at a sustainable development. They are, however, flexible enough to be reviewed and changed to reflect different conditions along time. Finally, as the indicators values are normalized, as well as the final values of the global and sectorial indices, I_SUM can be used to compare different spatial units.

The analyses carried out in this study were meant to test the viability of using I_SUM particularly in Brazilian medium-sized cities. The case study confirmed that a large proportion (60 %) of the indicators that are part of I_SUM could be applied in the city of São Carlos in the short term while relying on essentially good quality data. Conversely, the other 40 % could be applied in the medium and long terms. In that case, however, there is a strong need of improvement in the data collection procedures. Other recommendations include the development of permanent strategies for data update ant control, and the definition of geographical analyses areas compatible with the census tracts and with the boundaries adopted by other official agencies in charge of data collection and dissemination.

However, the results obtained in the application of I_SUM in the city of São Carlos must be carefully taken. The city has particular characteristics that differentiate it even from most medium-sized cities in the State of São Paulo. The existence of two important public universities in the city is an important factor in the development of several studies concerning mobility and other urban issues. The outcomes of most of these studies are often good quality data, which are obtained following reliable well-established methodologies. In addition to that, the recent review process of the municipal Master Plan also demanded data. That data was in many cases strongly related to mobility and therefore useful in the calculation of I_SUM. Those particular conditions must be taken into account when one looks to the application of I_SUM in the short term, because they are usually not present in most Brazilian cities.

Finally, we have to emphasize the importance of the index development for the progress of sustainable transportation indicators standardization, as suggested by Litman (*11*). I_SUM supports the need for indicators of sustainable transportation as a significant element in comprehensive transportation planning. In addition, the following aspects are noticeable in the case of the index development: it established a research program concerning the collection, analysis and application of high quality, standardized data; it worked with several Brazilian urban and metropolitan organizations, and it also worked with experts from different countries to establish an indicator set suitable for planning and policy benchmarking. However, the limitations of data availability in most cities still demand further improvements and adjustments in I_SUM. The challenge now is to make it simpler while still an effective tool for the development of public policies directed to sustainable urban mobility. The problems are not only related to data limitations, but also to human and technological deficiencies. That is one of the reasons why new applications of I_SUM are now under way in Brazil and in Portugal, in order to consolidate and to improve the index. One of the applications is in the city of Curitiba, Brazil, which is considered a successful example of good transportation planning. The outcomes of that particular application shall bring important insights to the field.

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