Advanced OR and AI Methods in Transportation
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SUSTAINABLE MOBILITY EVALUATION IN URBAN AREAS

Vânia Barcellos Gouveia CAMPOS
Rui António Rodrigues RAMOS

Abstract. This work applies the sustainable evaluation to the case of transport and land use planning in urban areas. A set of indicators according the three dimensions of sustainability, environment, economics, and social aspects, are defined to evaluate the mobility in urban areas. The aim of this work is to present a procedure to define a Sustainable Mobility Index in Urban Areas. A set of transports and land use indicators was proposed and used in a Multi-criteria Analysis to define the Index. Based on the Multi-criteria Analysis the indicators' priority was defined by a group of specialists in urban and transport planning.

1. Introduction

The search for the sustainability in the cities includes the knowledge of the interaction between the several activities developed in the cities and its impacts in the environment, in the society and in the urban economy. At first, the concern is related to reduce the environmental impacts, even so it is important to observe that the implementation of some measures that minimize the environmental problems can produce negative impacts in the urban economy, and consequently in the population life conditions. Therefore, the main difficulty in urban areas is the implementation of measures that can reduce the environmental problems and should maintain a reasonable urban economy. In this aspect, the transports system is very important for the maintenance of the urban economy, but produce some negative environmental impacts. For that it is important to associate the characteristics of the urban development with an adequate sustainable mobility.

The sustainable development is usually seen inside three main dimensions: Environment, Society and Economy, and each dimension cannot be analyzed independently. For each one of these dimensions some basic impacts can be identified and related to transports systems:

- in the environment context: the air, noise and water pollution and natural resources consumption;
- in the social context: health, equality and justness of opportunities;
- in the economic context: regional and urban economy, transports cost, competitiveness and subsidies.

The sustainable mobility is one of the components for a sustainable development of a city and can be achieved by measures that facilitate the population displacement in order to improve the quality of life and promoting efficient consumption of natural resources. In order to evaluate the sustainable mobility, it is necessary to design an evaluation methodology based on transport and land use indicators related to the sustainable urban development. Hence, it has developed a research to identify some relevant indicators to use in a Sustainable Mobility Index. Then an index was defined using a Multi criteria Analysis, and the importance of the different indicators was defined by a group of specialists in urban and transport planning.

2. The Sustainable Mobility

An integrated urban planning and transports system can develop the implementation of structures in which ecological, social and economic sustainability can be reached. The integration of measures in land use planning and transports system can contribute to a better urban sustainability by the implementation of a sustainable mobility.

Erìl &Feber [1] consider that the sustainable mobility can be achieved considering the following chain of goals/actions:

- Improve accessibility and the use of the space;
- Increase the environment-friendly modes' share (public transport, cycling, walking);
- Reduce congestion;
- Improve safety;
- Reduce air pollution, noise, and visual nuisance.

while:
- Developing and maintaining a healthy urban society;
- Ensuring social equity and transport opportunities for all community sectors.

In the development of the referred work it was considered that the sustainable mobility is a mobility way that promotes an equality of possibilities in transport, with access to all the activities in the urban area and contributes to reduce the energy consumption by the transportation system. Consequently, the sustainable mobility promotes a reduction of the environmental pollution and improves the efficiency of the natural resources expended in the implantation of transportation facilities. This means, in a general way, a promotion to reduce the private vehicle use adopting measures that facilitate and increase the access of the population to the activities by public transportation, walking and biking.

3. Methodology

In the development of case studies in some European cities (Laas et al. [2], TRANSPLUS [4] and PROSPECT [3]), it was observed some successful good practices
connecting measures in land use and urban transport. The measures implemented vary in conformity with each city's political and characteristics. In several cities some indicators were used for monitoring and analyzing how the adopted measures seek the urban sustainability.

A methodology to build a Sustainable Mobility Index has developed with the goal of evaluating the sustainable mobility level in an urban area, and to compare with others. The following stages have to be applied: to obtain the referred Index:

First stage - Proposal of a set of indicators integrating transport system and land use;

Second stage - Build a Sustainable Mobility Index using a Multi-Criteria Analysis (MCA) method for valuing and weighting the indicators;

Third stage - Quantify the Indicator, normalize and apply them to the model resulted from the second stage, obtaining the Index.

Multi-criteria Analysis methods reflect the subjective insights of decision maker. A wide variety of MCA methods have been developed, many of which originated in the analysis of consumer choice. These include goals achievement matrix, regime analysis and analytical hierarchy process. These methods all aim to help decision makers to determine which strategy they should implement based on the known impacts and are particularly applicable for impacts that cannot be readily monetized and therefore not included into a traditional Cost Benefit Analysis (SPECTRUM [7]).

According to the proposed methodology, it has developed a set of sustainable mobility indicators which were distributed in different Themes related with sustainable mobility objectives. Based on the hierarchical Multi-criteria process, the Themes defines the first level of analysis, and represents a synthesis of the associated indicators on the second level. The main sustainable mobility objectives identified were: increase the use of public transport and more walking and cycling trips; integrate the transport policies and the land use planning; improve the environmental quality; reduce the use of private vehicle trips; and, to promote the urban economy.

Five Themes were proposed:
- Promotion public transport, that seeks land use planning and transport policies to encourage the use of the public transport;
- Promotion non-motorized modes, that seeks land use planning strategies to encourage walking and cycling, and hence, reduce the use of cars;
- Environmental comfort and safety, that seeks land use planning and transport policies increase pedestrians and cyclists safety and enhanced environmental quality;
- Jointing transport systems and urban economy, that seeks to promote the urban economy by adopting better transport policies;
- Intensity of private vehicle use, that seeks to identify the type and intensity of private vehicle use in the region.

The Themes and Indicators proposed are presented in Table 1. The third column of the table presents the influence of the indicator in the Sustainable Urban Mobility, (+) if the increase of the indicator promotes a higher urban sustainability or (-) otherwise, the decrease of the indicator promotes a higher urban sustainability. So, the Indicators with (+) must be reinforced and the others must be reduced.

In the second stage, for building the Sustainable Mobility Index it uses a Multi-criteria analysis method, to obtain a weight for each indicator and theme. The weights can be generated by a pair-wise comparison matrix for the themes and for each group of indicators. The weights are produced by means of the principal eigenvector of the pair-wise comparison matrix Saaty [5].

A group of specialists, in urban and transport planning, have been invited to make the compare pair-wise of Themes and Indicators present in Table 1. The weights obtained to those Indicators and Themes are also present in Table 1, between parentheses.

The Sustainable Mobility Index (MSI) can be obtained from the following equation:

\[
MSI = \frac{1}{n} \sum_{i=1}^{n} \left( \sum_{j=1}^{n} \sum_{k=1}^{n} \frac{a_{ij} \cdot w_{ij} \cdot n_{jk}}{\sum_{k=1}^{n} a_{ik}} \right)
\]

\( a_{ij} \): 1 or -1, that depends on Indicator's influence in Sustainable Mobility;
\( w_i \): Indicators' weight;
\( w_j \): Normalized value obtained by the Indicator i in the Study Area;
\( w_t \): Theme's weight;
\( n_{ik} \): Number of Indicators of the Theme k;
\( m_t \): Number of Themes.

The procedure to determine the Index has for objective to obtain in a unique value (MSI) the aggregation of the Indicators evaluation. The Indicators aggregation is made using the Weighted Linear Combination (Vosog [6]).

4. Conclusion

From the methodology presented stands out that the final value of the Index will depend on the quantification of the Indicators involved in the analysis of an urban area, or areas, However, in some cases not whole the Indicators proposed can be quantified, in that case, it should be used the more relevant Indicator as resulted from the specialist analysis (value between parentheses) showed on the table 1.

Also, using Geographical Information Systems, it will be possible to represent the spatial distribution of the MSI Indices in different urban areas, or only some Indicators. The cartographic representation of the Indices, or the Indicators, will permit to identify spatial differences and to enhance areas that need specific measures to mitigate the identified weaknesses, and promote a better Sustainable Mobility.
## Table 1. Sustainable Urban Mobility Themes and Indicators

<table>
<thead>
<tr>
<th>Themes (weight)</th>
<th>Indicators (weight)</th>
<th>Influence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Promotion of Public Transportation</td>
<td>Urban Public Transportation supply (0.28)</td>
<td>+</td>
</tr>
<tr>
<td>(0.26)</td>
<td>Propensity of Urban Public Transportation supply (0.22)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Urban Public Transportation (UPT) supply for mobility impaired (0.19)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Average UPT travel time to central city (0.13)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Resident population distance less than 500m from UPT stations (0.18)</td>
<td>+</td>
</tr>
<tr>
<td>Promotion of non-motorized modes</td>
<td>Residen population distance less than 500m from public green areas (0.29)</td>
<td>+</td>
</tr>
<tr>
<td>(0.25)</td>
<td>Proportion of total area of commercial land uses (mixed use) (0.10)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Diversity of commercial and service uses used within a 500m area (0.13)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Length of the network for biking (0.13)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Mean distance to schools (0.26)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Number of retail stores per total land consumption (0.11)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Resident population living on distance less than 500m from roads with predominance of commercial and service land uses (0.18)</td>
<td>+</td>
</tr>
<tr>
<td>Environmental Comfort</td>
<td>Total length of roads with traffic calming measures (0.11)</td>
<td>+</td>
</tr>
<tr>
<td>and Safety (0.29)</td>
<td>Proportion of the UPT moved by clean energy (0.08)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Proportion of roads with sidewalks (0.22)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Numbers of accidents per 1000 residents involving pedestrians/cyclists (0.31)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Proportion of intersection street with pedestrian crossings (0.21)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Proportion of trucks moved by clean energy (0.07)</td>
<td>+</td>
</tr>
<tr>
<td>Joining transport systems and urban</td>
<td>Mean travel cost by using public transportation to city centre (0.29)</td>
<td>-</td>
</tr>
<tr>
<td>economy (0.11)</td>
<td>Average population income / monthly expenditure using public transportation (0.38)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Adequate loading / unloading places on the street (0.07)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Mean UPT travel time / Mean car travel time (0.26)</td>
<td>-</td>
</tr>
<tr>
<td>Intensity of use of private vehicles</td>
<td>Number of private vehicle-trip / total length of main transportation road (0.14)</td>
<td>-</td>
</tr>
<tr>
<td>(0.09)</td>
<td>Number of private vehicles-trip / person (0.19)</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Car travel demand (0.26)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Daily congestion hours expended on the main roads that cross the region or are near it (0.41)</td>
<td>+</td>
</tr>
</tbody>
</table>

## References


