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Sustainability assessment of a transportation system under uncertainty: an integrated multicriteria approach

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Abstract: Urban development is a critical issue that many cities are facing, due to the demography growth which results from the economic attractiveness of the urban centers. Based on common standards such as the Urban Development Plans, some projects for transportation systems renewal are progressively launched. In order to allow social cohesion, especially by providing travelers with services which may allow to better organize the transport, it is necessary to structure the transportation system according to sustainability requirements. This paper examines an integrated approach for assessing the sustainability of the current transportation system design, based on a policy making problem, aiming at providing decision makers with a framework allowing them to choose the most eco-responsible policy amongst many alternatives. Since the sustainability indicators may conflict each other, in order to better take into account the requirements of the whole transportation system in its design phase, a system-based approach has been adopted to characterize the complex structure of these indicators. A general methodology for their elicitation is proposed, using a process-object methodology and based on surveys from recent research on sustainable transportation, along with eco-design principles, in order to take into account urban transport priorities, sustainability challenges and the analysis of the whole lifecycle of the transport infrastructure and equipment. To validate this proposal, a multi-criteria decision method, allowing subjectivity, uncertainty, incomplete judgments and group consensus is then performed, based on a case study which shows the flexibility of fuzzy analytical hierarchy process for such assessment.

Keywords: transportation system, sustainability, complexity, system engineering, multi-criteria decision-making, uncertainty, fuzzy analytical hierarchy process.

1. INTRODUCTION

Since a United Nations commission report has formalized the concept of sustainable development, many definitions have been adapted in the context of sustainable transportation, amongst which the one proposed in (Richardson, 2005): *"the ability to meet today's transportation needs without compromising the ability of future generations to meet their transportation needs"*. The main aim is to integrate economic, social and environmental requirements of sustainable development at all phases of a transportation system design. In the context of city development, nowadays, it is necessary to take into account these requirements in order for the cities to comply with rules and standards regarding sustainability. Notwithstanding the existence of various methods dealing with sustainability, organizing authorities in cities fail in providing transportation solutions which may fit citizens' needs, along with urban development challenges, mainly due to two major reasons: *(1)* lack of broad characterization of sustainability which can mitigate conflicted travelers' needs, *(2)* low availability of flexible decision aid tools allowing to assess transport policy based on human expertise. The present work aims at filling these gaps.

Sustainable transportation has been object of many research, amongst which those dealing with the *impact of land use*, including social aspects and quality of life (Scheiner, 2006; De la Barra, 1989), *optimization of city logistics and mobility* (Ahmadi-Javid & Hooshangi-Tabrizi, 2015; Anand, Yang, Van Duin, & Tavasszy, 2012; Banister, 2008; Scheiner, 2006), *optimization of infrastructure* (Khadaroo & Seetanah, 2007; Sahely, Kennedy, & Adams, 2005), *economic efficiency* (Litman, 2016), *behavioral factors* influencing voluntary reduction of car use (Bamberg, Fujii, Friman, & Gärling, 2011), etc. These studies tend to focus on specific aspect of transport sustainability, and consequently, according to Goldman & Gorham (2006), they can fail to provide a meaningful and efficient way of facing the sustainability issue that is useful for policy makers, since neither provides a readable idea to which a transportation system might look like. Following Goldman and Gorham, the authors of this paper believe that, in order to keep the whole system in compliance with sustainable requirements over time, a larger picture of the broad system in which a transportation system is embedded should be taken into account, especially when analyzing a transport policy.

Multi-criteria decision making (MCDM) methods provide various frameworks, allowing decision makers (DM) from different domains to fulfill their judgments, including those dealing with uncertainty and incomplete information,

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particularly when a DM is not able the assess a criterion. In nowadays' numerical society, few of these frameworks have been successfully integrated in the architecture of the existing tools: sometimes due to the difficulty of interpreting the theory behind the results, sometimes due to the lack of convenient interaction between experts and the proposed systems. To fill these gaps, the objective of this work is to provide the organizing transportation authorities in a city with a methodology for a new transport system design, and then to assess several transport policies in order to choose the one which can satisfy sustainability requirements, including citizens and other stakeholders needs. To this end, the major part of the work is devoted to the definition of an integrated multi-criteria framework for transport system analysis in order to facilitate its integration in an existing decision support system.

The rest of the paper is structured as follows: section 2 presents the background of this study. In section 3, the methodology for knowledge elicitation regarding the sustainability indicators of a transportation system is described, followed in section 4 by the presentation of a case study. The last section concludes the work and suggests directions for future work.

2. RELATED WORK

Within the current global economy expansion, under the well-known concept of "sustainable development", has emerged the necessity to preserve the ability of the future generations to meet their needs in whatever the society provides. In the context of urban development, the improvement of transportation systems has then become an important part of urban projects renewal. For that purpose, a sustainability indicator system is required in order to guide policies for improving sustainable development. For instance, in (Shiau et al., 2015), the authors have proposed a review of sustainability measurement frameworks for guiding in generation and selection of sustainability indicators, based on principles amongst which: relevance, controllability, availability (including ease of availability, speed of availability), measurability, interpretability, etc. Three categories of frameworks have been outlined: *(1)* linkage-based framework which emphasizes causality, *(2)* impact-based framework which focuses on listing impacts for sustainability evaluation (such as "economy, society, environment") and *(3)* influence-oriented framework which examines the categories of indicators by their level of influence. These studies and others have succeeded in providing qualitative and quantitative frameworks. In a policy making (the context of this work), the authors of the paper believe that a hierarchical-based framework, allowing to characterize complex sustainability indicators structure is necessary.

In a broad sense, a transportation system can be defined as a set of elements and their relationships that produce both the demand for travel within a given period, and the provision of transportation services (Cascetta, 2009); it could be seen as a complex system composed of network of interactions between its components and subsystems (infrastructures, information systems, stakeholders, etc.). Due to the complexity of the structure of sustainability indicators, these latter may conflict each other (for instance, to wish limiting the use of private cars in favor of public transport, and at the same time, to wish enhancing accessibility in order to promote the city attractiveness). In order to build a robust sustainability indicators' system, we have then adopted a system-based approach, focusing on the analysis of the current design of a transportation system, which combines various points of view (including properties, states, structures and dynamic of the system). Indeed, we think that such approach of characterizing sustainability indicators may help to mitigate their mutual influences if they are defined at the system level, during it design phase. Thus, the sustainability assessment can better comply with the whole transportation system requirements (including sustainable development priorities and challenges) along with the stakeholders needs.

To validate the proposed indicators' system, relatively to urban development, a policy making problem has been considered. To achieve this goal, MCDM-based methods provide an ideal framework of assessment. A dozen methods have been outlined in recent survey (Mardani et al., 2016) amongst which the following: Multi-Attribute Utility Theory, ELECTRE, PROMETHEE, TOPSIS, AHP (Analytic Hierarchy Process). AHP is *"a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales"* (Saaty, 1980). Due to its ease of use (pair-wise comparisons are indeed familiar process to human reasoning in real-world problem) its development has increased. Due to the pair-wise comparisons, a critical issue is that inconsistent judgments may occur. For that purpose, consistency check methods have been introduced, in order to control such issue and avoid wrong decision. Since it has been successfully used in various real-world applications close to the context of our work (e.g., performance-type problem, resource management, corporate strategy, public policy, political strategy, transport development, etc.) and due to its ease of use, AHP has been finally adopted to validate the proposed sustainability indicators system. Its ability to define hierarchical structure has re-enforced this choice. However, knowledge related to a policy making problem is not given. For that purpose, a methodology for elicitation is described in the following, based on a system engineering approach.

3. ELICITATION OF KNOWLEDGE FOR THE SUSTAINABILITY ASSESSMENT

Since knowledge on sustainability assessment is generally based on various principles, depending on the point of view used, in order to provide a robust evaluation framework which may be useful in a long-term period, we have adopted a system engineering approach, based on a holistic view of a transportation system. The associated theoretical framework is described in the following, based on the process-object methodology.

3.1 System-based approach for transportation system design

Object-Process Methodology (OPM) is *"a holistic approach to the study and development of systems, which integrates the object-oriented and process-oriented paradigms into a single frame of reference"* (Dori, 2002). Hence, this methodology allows to design a system, allowing to define both its structure and its behavior. And besides, another interesting feature is the