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Investigating ideal-solution based multicriteria decision making techniques for sustainability evaluation of urban mobility projects

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ABSTRACT

Confronted with negative environmental impacts, rising fuel costs and increasing congestion, many cities are implementing sustainable mobility measures to improve the flow of passenger and goods. Examples of these measures are use of public transport, cycling, walking, energy efficient vehicles, biofuels. The challenge before transport decision makers is which one(s) to choose for implementation as often there is no or limited quantitative data available on the subject. Moreover, the context of each city, its geographic and transport conditions restrict the generalization of results obtained in experienced cities. In this paper, we are investigating application of ideal solution based multicriteria decision making (MCDM) techniques namely fuzzy TOPSIS, fuzzy VIKOR, and fuzzy GRA for sustainability evaluation of urban mobility projects. A real application for city of Luxembourg is provided. Three projects are evaluated namely implementation of a new tramway in the city center of Luxembourg, re-organization of existing bus lines in the city to perform optimized service, and implementation of electric vehicle car-sharing stations in the city. Sensitivity analysis is performed to determine the influence of input parameters on modeling results.

The proposed work is one of the first few works to investigate application of ideal-solution based multicriteria decision making techniques for sustainability evaluation of urban mobility projects under uncertainty. Besides, the best alternative is selected using veto thereby overcoming the limitations of single MCDM methods.

1. Introduction

Sustainable mobility is vital for modern cities to ensure seamless movement of goods and people while ensuring a healthier society and environment. It can be defined as “the ability to meet the needs of society to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values today or in the future.” (Mobility, 2001 report). According to Black (2005), the current transport system is non-sustainable due to diminishing petroleum reserves, global atmospheric impacts, local air quality impacts, fatalities and injuries, congestion, noise, low mobility, biological impacts, and lack of equity. The goal of sustainable transport is to ensure that environment, social and economic considerations are factored into decisions affecting transportation activity (Transport Canada, 1999). More and more cities are becoming active in this direction and implementing measures that encourage sustainable mobility such as travel reduction, distance reduction, modal shift, technological innovation, use of public transport and soft modes of transport such as walking and biking, land use and transport integration, regulation instruments, use of electric and other alternative-fueled vehicles, carsharing, park-and-ride etc. (Banister, 2008, Hickman

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et al., 2013).

The commonly used approaches for sustainability evaluation of urban mobility projects can be classified into:

- Life cycle analysis/assessment: Life cycle analysis (LCA) systematically looks at a product's complete life cycle, from raw materials to final disposal of the product. It offers a "cradle to grave" look at a product or process, considering environmental aspects and potential impacts. The use of LCA to evaluate the environmental impact of transport system is growing (Goedkoop, 2000; Guinée, 2002). However, its main limitation is that it does not take into consideration social aspects.
- Cost benefit analysis (CBA) and Cost effectiveness analysis (CEA): CBA is a microeconomic approach that computes the benefits and costs of projects in dollar values by taking into account positive and negative impacts. On the other hand, CEA is often used where it may be inappropriate to monetize the effects. In the context of transportation, it compares costs and emissions impacts of potential transit strategies to reduce emissions. Use of CBA has been reported for sustainable transportation analysis by Browne and Ryan (2011), Eliasson (2009), Damart and Roy (2009), and Tudela et al. (2006). Tsamboulas and Mikroudis (2000) propose CEA for evaluation of environmental impacts and costs of transport initiatives. Kunreuther et al. (2003) use CEA for evaluation of mitigation measures. With CBA and CEA approaches (Kunreuther et al., 2003), it is extremely difficult to estimate directly external and social costs (e.g. air pollution, noise pollution, accidents, congestions and fuel costs).
- Assessment indicator models: The assessment indicator models use indicators to assess sustainability of transportation systems. According to Tao and Hung (2003), three categories of assessment indicator models are composite index models, multi-level index models and multidimension matrix models. The output of a composite index model is a single index representing degree of satisfying economical, social and environmental objectives (Maoh and Kanaroglou, 2009). For example, ecological footprint (Browne et al., 2008), green gross national product, etc. In multilevel index model, a series of indicators representing different goals and hierarchies are used. In multi-dimensional matrix model, interaction among different indicators is defined using logic architectures. Examples of these models are the Pressure-State-Response, Driving-Force-State response, Driving-Force-Pressure-State-Impact-Response, and Driving Force-Pressure-State-Exposure-Effect-Action. Assessment indicator models have been used for sustainable transport planning by Lima et al. (2014), Black et al. (2002), Haghshenas and Vaziri (2012), Jeon and Amekudzi (2005), Gudmundsson (2003), Litman (2009), Browne et al. (2008). Identification of right number and type of indicators that accurately represent the social, economic and environmental dimensions being measured is critical to effective functioning of these models.
- Multicriteria decision making (MCDM): MCDM constitutes both the framework for structuring decision problems, as well as a set of methods for generating preferences among alternatives. Examples of MCDM techniques are AHP, TOPSIS, PROMETHEE, ELECTRE etc. Their main advantage is the ability to take into account conflicting, multidimensional, incommensurable and uncertain effects of decisions explicitly (Beinat, 2001). The limitation is that the solutions generated are tradeoff among the multiple objectives and not optimal ones due to nature of the problem. MCDM technqiues have been widely used for sustainability evaluation of transportation projects (Hickman et al., 2012; Curiel-Esparza et al., 2016; Yedla and Shrestha, 2003; Awasthi and Chauhan, 2011). Recently, importance of integrating multiple stakeholders perspectives into multicriteria techniques has been emphasized by various researchers (Macharis and Bernardini, 2015). A detailed review of MCDM techniques has been provided in Section 2.

The study conducted in this paper is inspired by Ministry of Luxembourg who is contemplating implementation of several sustainability initiatives to improve mobility and modal split towards public transport. Modal split represents the distribution (in percentage) of travellers with respect to usage of different modes of transport (e.g. bus, tram, private car, cycling). Modal split in favour of public transport will improve city sustainability. The Luxembourg authority (Ministry of Sustainable Development and Infrastructure) is aiming to achieve a modal split of 75/25 in 2020 (75% of trips by private vehicles and 25% by public transportation). In 2007, the modal split was 85.5/14.5 (MODU strategy). To achieve this target, the Luxembourg Government is planning several transport projects. Among them three projects are considered in our study. These projects are implementation of a new tramway in the city center of Luxembourg, re-organization of existing bus lines in the city to perform optimized service, and implementation of electric vehicle car-sharing stations in the city (Section 4). These transport projects will affect the mobility of people inside city centers and the trans-border commuters in particular (Schmitz et al., 2012). Therefore, it is important to perform careful evaluation of these projects to achieve sustainable mobility. The research questions we are trying to address in this paper are :

- Determine the criteria to choose for sustainability evaluation (ex-ante) of urban mobility projects.
- Perform sustainability evaluation of urban mobility projects using ideal-solution based multicriteria decision making techniques.
- Determine the stability of model results with respect to variation in input parameters using sensitivity analysis.
- Model decision makers preferences under uncertainty using linguistic assessments and fuzzy set theory.

The rest of the paper is organized as follows. In Section 2, we present the related literature. The solution approach is provided in Section 3. Section 4 presents the numerical application of the proposed approach. Finally, in Section 5 we provide the conclusions and steps for future work.

2. Related literature

This section is dedicated to detailed literature review of multicriteria decision making methods for sustainability evaluation of