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Application of fuzzy TOPSIS in evaluating sustainable transportation systems

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ABSTRACT

Sustainable transportation systems are the need of modern times. There has been an unexpected growth in the number of transportation activities over years and the trend is expected to continue in the coming years. This has obviously associated environmental costs like air pollution, noise, etc. which is degrading the quality of life in modern cities. To cope us this crisis, municipal administrations are investing in sustainable transportation systems that are not only efficient, robust and economical but also friendly towards environment. The challenge before the transportation decision makers is how to evaluate and select such sustainable transportation systems. In this paper, we present a multicriteria decision making approach for selecting sustainability transportation systems under partial or incomplete information (uncertainty). The proposed approach comprises of three steps. In step 1, we identify the criteria for sustainability assessment of transportation. In step 2, experts provide linguistic ratings to the potential alternatives against the selected criteria. Fuzzy TOPSIS is used to generate aggregate scores for sustainability assessment and selection of best alternative. In step 3, sensitivity analysis is performed to determine the influence of criteria weights on the decision making process. A numerical illustration is provided to demonstrate the applicability of the approach.

The strength of the proposed work is its practical applicability and the ability to generate good quality solutions under uncertainty.

1. Introduction

Sustainability is an important subject for modern transportation decision makers. There have been numerous discussions on how sustainability can be accurately defined and measured. The Brundtland Commission (United Nations World Commission on Environment & Development, 1987) defines sustainability as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. World Bank (1996), Loo (2002) and Schipper (2003) use the "triple bottom line" of economic, environmental, and social equity to define sustainability. Using these definitions, sustainable transportation can be considered as one that is able to meet today's transportation needs without compromising the ability of future generations to meet their transportation needs (Black, 1996; Richardson, 2005). Examples of sustainable transportation are energy efficient vehicles, vehicle with clean fuels like biodiesel, electricity, etc., carsharing, park-and-ride, etc. The center for sustainable transportation (1997) defines sustainable transportation system as one that:

- Allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations.
- Is affordable, operates efficiently, offers choice of transport mode and supports a vibrant economy.
- Limits emissions and waste within the planet's ability to absorb them, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise.

In order to identify, compare and select sustainable transportation system, efficient decision making approaches are required. The commonly used approaches for sustainability evaluation can be classified into the following categories:

1. Life cycle analysis (LCA): Originally developed for industrial processes, the use of LCA (Goedkoop, 2000; Guine, 2002) to evaluate the environmental impact of transport system is growing. Its central concept is to combine, in a small number of

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criteria, the polluting emissions and resources used during the life course of a product. This method has been the subject of considerable efforts to standardize the impacts assessment and the results interpretation. However, it does not take into consideration for example social aspects, so this method does not relate to our application.

2. Cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA): The cost-benefit analysis is based on taking into account the monetary equivalent of all the positive and negative impacts of the company project. When the advantages of a project are not quantifiable in a monetary way or when the realization degree of the result to reach is given, cost effectiveness analysis is used. This type of study aims to minimize the costs necessary to the achievement of a given objective and not for maximizing the advantages. With CBA and CEA approaches (Kunreuther, Grossi, Seeber, & Smyth, 2003), it is extremely difficult to estimate directly external and social costs (e.g. air pollution, noise pollution, accidents, congestions and fuel costs). For example, air pollution costs, related to transportation, are difficult to estimate because several other economy sectors also generate pollution. In this case the environmental costs should be apportioned according to each sector emission. Applications of cost-benefit analyses for sustainable transportation can be found in El-Diraby, Abdulhai, and Pramod (2005) and Jonsson (2008).
3. Environmental impact assessment (EIA): The aim of this method is to assess the environmental impacts of a new localized pollution source, such as an industry or highway, and its surroundings (Bond, Curran, Kirkpatrick, & Lee, 2001; Fischer, Wood, & Jones, 2002; Jay & Handley, 2001; Wood, 2002). Applied to transport, EIA has been used to study the environmental impact of some practices. This method is standardized and consists of several stages from the recording of the emissions to decision-making by the authorities. The three aspects of sustainability namely environmental, economic and social are taken into account, as one tries to evaluate the impact of a new activity on the environment, the population and the attractiveness of the neighborhood of the site.
4. Optimization models: A mathematical optimization model consists of an objective function and a set of constraints in the form of a system of equations or inequalities. In the context of sustainable transportation, an optimization model attempts to find an optimal solution under the constraints of the social, economic and environmental objectives. Linear programming is commonly used. An application of dynamic optimization approach for sustainable urban transport development can be found in Zuidgeest (2005).
5. System dynamics models: System dynamics is used to model complex systems. In system dynamic models, relationships between the system elements are demonstrated through stocks, flows and a feedback mechanism over time. These models can design and evaluate a cause and effect relationship within an integrated sustainable transportation system (Tao & Hung, 2003). Richardson (2005) presents frameworks for sustainability analysis of passenger and freight transport using influence diagrams and root cause analysis.
6. Assessment indicator models: The assessment indicator models use indicators to assess sustainability of transportation systems. Tao and Hung (2003) classify them in three categories namely composite index models, multi-level index models and multi-dimension matrix models. The output of a composite index model is a single index representing degree of satisfying economical, social and environmental objectives (Maoh & Kanaroglou, 2009). For example, ecological footprint (Browne, O'Regan, & Moles, 2008), green gross national product, etc. However, a universal and single composite index of sustainable transportation is difficult to obtain (Phillis & Andriantiantsaholiniaina, 2001). 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. The Pressure-State-Response types of models were the first of this type of models to be introduced in 1990s. Later, Driving-Force-State-response (DSR) and Driving-Force, Pressure-State-Impact-Response (DPSIR), Driving Force-Pressure-State-Exposure-Effect-Action (DPSEEA) (Waheed, Khan, & Veitch, 2009) frameworks were developed.
7. Data analysis: This category of models involves use of statistical data and application of data analysis techniques like surveys, hypothesis testing, structural equation modeling etc. to investigate sustainable transportation systems. Ülengin, Kabak, Önsel, Ülengin, and Aktaş (2010) present a problem-structuring model for analyzing transportation–environment relationships. Mohan (1999) use statistical data to illustrate the need of non-motorized modes of traffic and associated infrastructure design for designing sustainable transport system for urban areas.
8. Multi-Criteria Decision Analysis (MCDA) methods: A wide set of MCDA methods exist: *Multi-Attribute Value Function Theory* (*MAVT*), *Multi Attribute Utility Function Theory* (*MAUT*), *Analytic Hierarchy Process* (*AHP*) and *ELECTRE methods*, etc. Decision analysis provides both tools and a framework for the integration of tools from other disciplines to create an overall strategy for decision support. Several applications have been developed especially for management environment (Beinat, 2001; Chang & Chen, 1991; Chen, Tzeng, & Liu, 2003; Dempster, 1968; Spiekermann & Wegener, 2004; Wellar, 2000) by selecting one alternative among several. Generally, in a multi-criteria problem there is no solution optimizing all the criteria at the same time therefore compromise solutions must be found. However, we should note that when different conflicting evaluation criteria are taken into consideration, a multi-criteria problem is mathematically ill defined (Simos, 1990). Decision analysis looks at the paradigm in which an individual decision maker (or decision group) contemplates a choice of action in an uncertain environment. In MCDA methods, the selection is facilitated by evaluating each choice on the criteria set. The criteria must be measurable; even if the measurement is performed only at the nominal scale (yes/no; present/absent) and their outcomes must be measured for every decision alternative. Criterion outcomes provide the basis for choices comparison and consequently facilitate the selection of one satisfactory choice. Criterion outcomes of decision alternatives are collected in a table (called decision matrix or decision table) comprising of a set of columns and rows. MCDA methods (Delgado, Verdegay, & Vila, 1992; Herrera, 1993), especially AHP and ELECTRE, are generally used for ranking several alternatives under criteria set, by using one expert or several experts and by using a numeric same scale or linguistic terms. Yedla and Shrestha (2003) use AHP to evaluate six sustainable transportation modes. Tsamboulas and Mikroudis (2000) present a multi-criteria evaluation framework of environmental impacts and costs of transport initiatives. Awasthi and Omrani (2009) present an AHP and belief theory based approach for evaluating sustainable transportation solutions.

Recently, other methods combining MCDA and Artificial Intelligence have been explored to develop enhanced methodologies for knowledge based decision support system. By combining MCDA with fuzzy logic theory (Zadeh, 1965; Zadeh, 1986), new methods have been developed like, the most useful method, fuzzy AHP