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Using AHP and Dempster–Shafer theory for evaluating sustainable transport solutions

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ABSTRACT

In this paper, we present a hybrid approach based on the Analytical Hierarchy Process (AHP) and Dempster–Shafer theory for evaluating the impact of environment-friendly transport measures like mode sharing, multi-modal transport solutions, intelligent transport solutions, etc. on city sustainability. The proposed approach is a mix of curiosity driven and client-driven research in the sense that the problem is guided by the client for practical applicability and the solution is motivated by technical or scientific contribution to research.

The solution approach comprises multiple steps. In the first step, we identify the criteria for sustainability evaluation. AHP is used to structure and rate the criteria. In the second step, we test the transportation measure for sustainability and collect data from multiple information sources like human experts, questionnaire, sensors, models, etc on the selected criteria for evaluation purposes. The information from multiple data sources is combined using Dempster–Shafer theory. In the third step, we estimate the state of sustainability of the city using a Transport Sustainability Index (TSI). The Transport Sustainability Index is computed at two stages: pre- and post-test stages of the transportation measure. In the fourth step, we assess the impacts of the transportation measure on the city sustainability by observing the difference between the values at the pre- and the post-test stages. If an increase in the value of TSI is observed, then the impact of the transportation measure on city sustainability is judged as positive and it is recommended for adoption. We illustrate our approach by application on the transportation measure "Carsharing".

1. Introduction

According to the World Business Council for Sustainable Development (2001), sustainable mobility can be defined as "The ability to meet society's need to move freely, gain access, communicate, trade and establish relationships without sacrificing other essential human or ecological values, today or in the future". Recent years have brought the subject of sustainable mobility on the forefront in all domains. The reasons are numerous problems faced by the modern society like air pollution, noise, congestion, safety, security, rising costs, travel delays and many more. To curb these growing problems, transportation experts have come up with several solutions involving one or more of the following measures.

- Clean fuels like electricity, biodiesel, etc.
- Energy efficient vehicles options like Stop-and-Start engines, etc.
- Trip reduction in private vehicle movements in the city, for example, carsharing, park-and-ride, access control zones.
- Restrictions on the entry time and size of vehicles entering the city.
- Pricing measures like carbon tax.
- Regulatory policies on passenger and freight transportation.
- Technology adoption like intelligent transportation systems.

These measures contribute to sustainable mobility by causing improvements in city transport conditions either in terms of environment, societal benefits or economy. Research is under way to develop sustainable mobility solutions and transport measures that achieve these goals.

Kennedy (2005) proposes four pillars for sustainable transportation namely: effective governance of land use and transportation; fair, efficient, stable funding; strategic infrastructure

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investments; and attention to neighborhood design. Black (1997) investigates sustainable transportation in North America. Gudmundsson and Höjer (1996) investigate sustainable development principles and their implications for transport. Anderson et al. (2005) present means and measures through which freight transport can be made more sustainable. This includes development of low emission zones, congestion charging, weight restrictions and time restrictions. Button and Nijkamp (1997) study key linkages between social change and sustainable transport. Hull and Tricker (2005) investigate barriers to sustainable transport. The dilemma before cities implementing new mobility solutions is always to assess if these measures would bring real benefits to the society.

There are a number of methods and techniques that could be used for evaluating the impact of environment-friendly measures like mode sharing, multi-modal transport solutions, etc. Richardson (2005) presents cause-and-effect based analysis frameworks for freight and passenger transport. Browne et al. (2008) use ecological footprinting to explore alternative transport policy scenarios in an Irish city-region. Jeon and Amekudzi (2005) present indicators and metrics for addressing sustainability in transportation systems. Litman and Burwell (2006) address issues and indicators for sustainable transportation. The Transport Canada project report by Wellar (2009) presents 42 techniques that could be used for evaluating sustainability of urban transportation, and provides commentaries on 20 of them, including life cycle analysis, cost–benefit analysis, impact assessment, multi-criteria decision analysis, delphi techniques, surveys, and indexing.

Originally developed for industrial processes, the use of LCA (Goedkoop and Spriemsma, 2000) to evaluate the environmental impact of transport system is growing. Its central concept is to combine, in a small number of criteria, the polluting emissions and resources used during the life course of a product. Cleary (2009) proposes the use of life cycle assessment for municipal solid waste management systems. Tan (2005) presents a rule-based life cycle impact assessment approach using rough set induction methodology.

The cost–benefit analysis is based on taking into account the monetary equivalent of all the positive and negative impacts of a 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 for achievement of a given objective while maximizing the benefits (Kunreuther et al., 2003). Thill et al. (2004) apply cost–benefit analysis for evaluating intelligent transportation systems. Eliasson (2009) perform a cost–benefit analysis of the Stockholm congestion charging system.

The Environmental impact assessment (EIA) method is used to assess the environmental impacts of a new localised pollution source, such as an industry or highway, and its surroundings (Bond et al., 2001; Jay and 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. Salhofer et al. (2007) perform strategic environmental assessment of waste management systems. Neto et al. (2008) model the environmental impact of an aluminium pressure die casting plant and options for control.

A wide set of multi-criteria decision methods (MCDM) have been reported in literature. These methods involve assessing given alternatives using a selected set of criteria by a group of decision makers. Most commonly used MCDM methods are Analytic Hierarchy Process (AHP), Multi-Attribute Value Function Theory (MAVT), Multi-Attribute Utility Function Theory (MAUT), and Outranking methods, etc. Use of MCDM for environmental management has been reported by Beinat (2001) and Chen et al. (2003). Sólnes (2003) performs environmental quality indexing of large industrial development alternatives using AHP. Yedla and Shrestha (2003) present an AHP based approach for the selection of alternative options for environmentally sustainable transport system in Delhi. Krajnc and Glavič (2005) compare sustainability of companies using multi-criteria decision analysis. Arnette et al. (2010) perform stakeholder ranking of watershed goals with the vector analytic hierarchy process. Yi et al. (2011) use AHP for selecting sustainable renewable energy source for energy assistance to North Korea. A review on multi-criteria decision analysis aid in sustainable energy decision-making can be found in Wang et al. (2009).

Recently, others methods combining MCDA and AI (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 Fuzzy AHP (Simos, 1990), Fuzzy comprehensive assessment (Lu et al., 1999) (Yang and Yang, 1998), etc. In addition, some approaches using the framework of evidence theory with MCDA methods have been proposed by Beynon (2002). Beynon et al. (2000) propose an AHP and Dempster–Shafer (D–S) Theory (Dempster, 1968) based approach. Xu et al. (2005) propose an evidential reasoning (ER) approach for dealing with complex decision problems in management.

Our approach for evaluating sustainable transport measures is based on Analytic Hierarchy Process (AHP) (Saaty, 1990) and Dempster–Shafer theory (Dempster 1968, Shafer 1976). These two techniques were chosen because of their ability to deal with multiple decision makers and heterogeneous data types. AHP was used for rating the evaluation criteria for transportation measures. The D–S Theory was used because of its ability to deal with ignorance and missing information which is very likely the case in realistic transport situations.

The proposed research is a mix of curiosity driven and client-driven research. According to Wellar (2010), curiosity driven research puts a high degree of emphasis on invention or creativity and contribution to subject matter knowledge by adding to the ways and means of the scientific method. The client-driven research on the other hand is driven by the research question, problem, issue or other basis of engagement as specified by a third party. In our case, the client requirements were coming from the city transportation group and the curiosity from the technical team for development of a generic scientific approach that can be easily applied for the sustainability evaluation of urban transportation systems.

The proposed work was carried out as part of the project SUCCESS (Smaller Urban Communities in CIVITAS for Environmentally Sustainable Solutions). The aim of the project SUCCESS is to implement sustainable transportation measures in medium-sized cities to improve the mobility conditions of goods and people. During this project, innovative methods and techniques were developed to estimate the environmental impacts of transport activities and associated measures. Our approach was also developed during this work. Please note that the focus of our research in this paper is on the mobility of private motor vehicles moving people and freight. The mobility of pedestrians, cyclists, or transit users for example is not part of the study.

2. Problem definition

The major problem treated in the paper is to find a common framework in order to aggregate information/data coming from multiple information sources for evaluating the sustainability of transportation measure under consideration. Let us consider four information sources namely human experts, sensors, surveys, models in Fig. 1.