Ecological Indicators 71 (2016) 503–513

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Sustainable transportation systems performance evaluation using fuzzy logic

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ARTICLE INFO

Article history:
Received 29 March 2016
Received in revised form 18 July 2016
Accepted 20 July 2016

Keywords:
Sustainability
Transport sustainability
Performance evaluation
Decision making
Fuzzy logic
Linguistic variables

ABSTRACT

Sustainability has become an overarching concern for transportation policy and planning around the world. This article presents an approach for urban transport sustainability performance evaluation using fuzzy logic. This article presents a model for transport sustainability performance evaluation. Appropriate transport sustainability indicators were identified based on literature. The model addresses all major dimensions of transport sustainability such as Economic Sustainability, Social Sustainability, Environmental Sustainability and Transportation System Effectiveness. Transport sustainability index has been computed as (5.05, 6.62, 8.12) and weaker transport sustainability attributes were found. Transport sustainability index highlights the question how far toward becoming transport sustainable is an enterprise or region? While, weaker transport sustainability attributes reveals that how can an enterprise or region improve its transport sustainability effectively? Appropriate actions were initiated to improve urban transport sustainability performance. The results indicate that the model is capable of effectively assessing transport sustainability and has practical relevance. An example is also used to illustrate the approach developed. The results obtained using fuzzy approach has been validated with conventional crisp approach. 20 transport sustainability attributes out of 60 are found to be weaker and appropriate actions were derived to improve the weaker attributes.

1. Introduction

Sustainable development is that meets the needs of the present without compromising the ability of future generations; it balances economic, social and environmental objectives (Bartlett, 2012). Black (1996) define sustainable transportation as "satisfying current transport and mobility needs without compromising the ability of future generations to meet these needs". Sustainable transport planning refers to transport policy analysis and planning practices that support sustainable development. Some externalities of transportation systems significantly impact on vast aspects, including energy, land use, traffic safety, accessibility and economic development. It is widely accepted that sustainable transportation systems imply balancing current and future economic development, transport qualities and environmental preservation (Shiftan et al., 2003; Steg and Gifford, 2005). The aim of sustainable transportation is to control pollution, energy consumption, accidents and improving livability and economic well-being of the city.

The growing economy nurtured the industrial, business, and other activities in the cities; offered more job opportunities; higher income, and generated wealth & general welfare (Malayath and Verma, 2013). A critical component of sustainable transport planning is the development of a comprehensive evaluation program that evaluates transport system performance based on an appropriate set of environmental, social and economic indicators (Bongardt et al., 2011). Due to vague and ambiguous indicators which exist within transport sustainability assessment, measures are describe in terms of linguistic variable which are characterized by ambiguity and multi-possibility, and the conventional assessment approaches cannot suitably nor effectively handle such measurement (Lin et al., 2006). However, fuzzy logic provides a useful tool which eliminates the drawbacks like vagueness, uncertainties, ambiguity, and impreciseness (Vinodh and Devadasan, 2011). This article presents a comprehensive model for evaluation of transport sustainable performance. The architecture has four enablers, 20 criteria and 60 attributes. Appropriate performance indicators are being developed based on exhaustive literature review as well as in discussion with practitioners and experts. After gathering appropriate inputs

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http://dx.doi.org/10.1016/j.ecolind.2016.07.031
1470-160X/

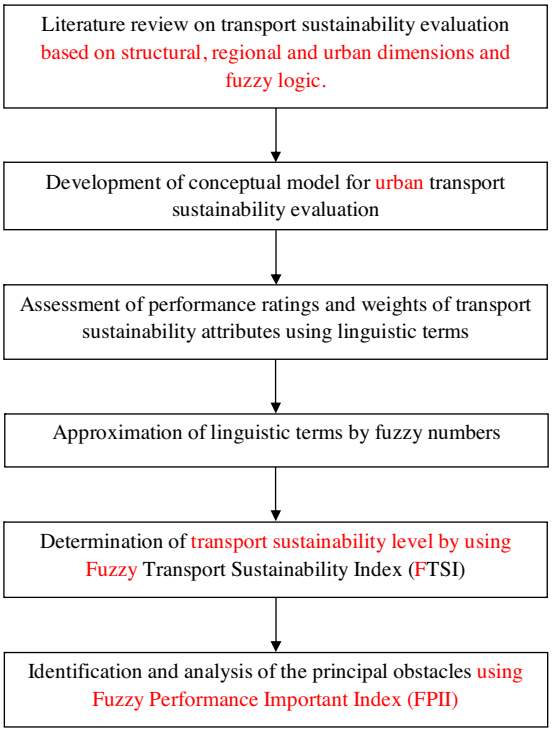

Fig. 1. Research Methods used in this study.

from experts and decision makers in terms of linguistic variables, inputs are fuzzified and Fuzzy Transport Sustainability Index (FTSI) has been computed. The computed FTSI is matched with standard transport sustainability labels to validate transport sustainability level. Then, Fuzzy Performance Importance Index (FPII) of various transport sustainability attributes was computed to identify weaker areas so as to identify proposals for improvement of transport sustainability performance.

2. Literature review

The issue related to sustainable development principles; definition, evaluation and implementation of sustainable transportation have been studied by several authors. (Gudmundsson and Höjer, 1996; Jeon and Amekudzi, 2005; Litman and Burwell, 2006). Assessment of the Barriers to achieve sustainable transportation has been investigated by many authors (Banister, 1996; Tricker and Hull, 2005; May, 2008; Browne et al., 2011). A framework for transport sustainability, the interaction of factors that influence indicators; tradeoffs among the indicators has been presented by Richardson (2005). Kennedy (2005) presented four pillars for sustainable transportation namely: effective governance of land use and transportation; fair, efficient, stable funding; strategic infrastructure investments; and attention to neighborhood design. Black and Sato (2007) summarized climate change and its impact on transport over the past sixteen years from 1989 to 2006. They purely concerned for global warming into a general concern for sustainable transportation and the other factors that make transport non-sustainable: air quality problems, injuries and fatalities from vehicle incidents, petroleum resource depletion and congestion. Twenty-Two Quality-of-Life aspects have been given by Poortinga et al. (2004); Steg and Gifford (2005). Bongardt et al. (2011) reviewed the existing set of sustainable transportation indicators and Key challenges in the transport sector to determine which are most appropriate for sustainable transport planning and policy purposes on an international level. Sustainable transportation: a US perspective has been analysed by Black (1996). Malayath and Verma (2013) reviewed the ability of travel demand models applied in India in analyzing the sustainable transport policies. A framework which includes set of sustainability indicators, principles, measures, and along with data sources to measure sustainable regional development for the twin cities region over the long term have been proposed by Kirk et al. (2010). Boschmann and Kwan (2008) reviewed research on Socially Sustainable Urban Transportation (SSUT) and argued that how urban transportation influences the achievement of social sustainability in urban regions including social equity, social exclusion, and quality of life. Singal (2010) described about the steps being taken by the Indian government to promote sustainable urban transport, while the author suggests the need to make cities pedestrian-friendly for quick and ongoing relief, and proposed four essential ingredients for sustainable urban transport in the long term. Tanguay et al. (2010) developed the urban Sustainable Development Indicators (SDI) to measure the sustainability of cities and Haghshenas and Vaziri (2012) ranked the various world cities in terms of urban sustainable transport composite index. A framework for identifying and selecting a small subset of sustainable transport indicators has been developed by Castillo and Pitfield (2010). Salling and Pryn (2015) developed a sustainable planning and decision support framework for transport infrastructure assessment. Transportation related tools and strategy in four sectors namely Technology & Infrastructure; Business & Finance; Policies and Institutions; Social and Community Groups, discussed by Shay and Khattak (2010). Nijkamp et al. (2007) proposed a methodological/operational contribution to sustainable mobility policy in the Naples metropolitan area. Scenario analysis has been used to design combined land-use/transportation plans accompanied sustainability perspective. Song et al. (2013) developed a Simulation-Based Optimization (SBO) approach for sustainable transportation systems evaluation and optimization. They attempted to find the optimal combination of transportation planning and operations strategies which should minimize costs of multimodal traveling.

A literature review on application of fuzzy logic in performance management has been conducted by Gurrea et al. (2014). Fuzzy logic has been used by many authors for example Lin et al. (2006) and Vinodh and Devadasan (2011) evaluated agility index of an enterprise using fuzzy logic; Vinodh and Vimal (2012) used fuzzy logic for leanness assessment. Yang and Li (2002) presented multi-grade fuzzy approach to evaluate agility. Convertino and Valverde (2013) presented a Portfolio Decision Analytic (PDA) framework to promote the efficient allocation of scarce resources in coastal ecosystems and claim that PDA framework allows decision makers to achieve higher environmental benefits, with equal or lower costs, than those achievable by Multi Criteria Decision Analysis (MCDA) model. Jeon et al. (2010) demonstrated an application of Multiple Criteria Decision Making (MCDM) approach for evaluating the selection of transportation and land use plans in the Atlanta region using multiple sustainability parameters. They used four indicators namely; Transportation Effectiveness, Environmental Sustainability, Economic Sustainability and Social Sustainability Indicators. They introduced composite sustainability index as decision support tool for transportation planning along with identifying the most sustainable plan for predetermined objectives. Wellar (2009) presented 42 techniques that could be used in making decisions to identify, adopt, or implement sustainable transport practices and focused on 20 of them including, Benefit-Cost Analysis, Cross-Impact Analysis, Delphi Techniques, Impact Assessment, Life-cycle Analysis, MCDM, Open House, surveys, and indexing. A hybrid approach based on the Analytical Hierarchy Process (AHP) and Dempster –Shafer theory is proposed by Awasthi and Chauhan (2011) for evaluating the impact of environment-friendly transport measures like multi-modal transport solutions, mode sharing,