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Selection of sustainable urban transportation alternatives using an integrated intuitionistic fuzzy Choquet integral approach

Gülçin Büyüközkan*, Orhan Feyzioğlu, Fethullah Göçer

Industrial Engineering Department, Galatasaray University, 34349 Ortaköy, Istanbul, Turkey

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ABSTRACT

Unrestrained urban development and rapid expansion of motorized vehicles inevitably lead to unsustainable transportation systems from economic, social and environmental points of view, not only endangering public health but also pressuring ecosystems. Trying to address these issues, transportation policy makers face major challenges in their attempts to identify sustainable transportation alternatives. To provide a systematic approach for such endeavors, this paper evaluates different public bus technologies as urban transportation alternatives. In order to incorporate expert opinion into the model environment, a set of sustainability related criteria is established and expert opinion regarding the sustainability of vehicle options are obtained based on each criterion. Since the fulfillment of a single criterion is not sufficient to deduct meaningful conclusions, the evaluation considered the dependencies among the decision criteria in search of compromising solutions. To address this, an aggregation method based on Intuitionistic Fuzzy Choquet Integral (IFCI) and Group Decision Making (GDM) techniques is proposed. A fuzzy pairwise-comparison measure identification method is used in IFCI in order to define its parameters. TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), another multi-criteria method that ignores interactions, and 2-additive Choquet integral are also employed. The outcomes of IFCI, 2-additive Choquet integral and TOPSIS are compared with one another. The findings indicate that dependencies among decision criteria significantly affect the selection process of the most sustainable urban transportation system and can alter the rankings.

1. Introduction

The field of sustainable development is attracting great interest in the last few decades, which can be attributed to technological advance, changes in societal necessities and transforming living habits, coupled with high urban population growth. The term sustainable development is characterized as “the concept of meeting the needs of the present without compromising the ability of future generations to meet their needs” (United Nations General Assembly, 1987). Local governments today perceive metropolitan urban transportation as one of the major concerns and its solution as a priority. Sustainable development in these high-density cities is being affected by the rapid urbanization and motorization. Since the Brundtland Commission report (WC, 1987) brought the concept of sustainable development to the global agenda, researchers and policy-makers are putting great effort to explore how to sustainably transform urban metropolitan areas.

Various economic, environmental, and social indicators should be taken into consideration to meet essential goals of sustainability by simultaneously pursuing economic, environmental, and social goals (Ji et al., 2016). In the field of transportation, there

* Corresponding author.
E-mail addresses: gulcin.buyukozkan@gmail.com (G. Büyüközkan), orhanfeyzioglu@gmail.com (O. Feyzioğlu), gocer.fethullah@gmail.com.tr (F. Göçer).

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exist many positive and negative factors, as also stated in the related literature (Esters and Marinov, 2014; Song et al., 2014). The role of urban transportation systems is growing, particularly in the sense of related externalities, such as traffic, energy consumption, and air quality. Sustainable transport is defined in the literature by many scholars (Jeon and Amekudzi, 2005). The development of policies for sustainable transportation often involves inter-departmental cooperation, as well as local and central governmental collaboration (Chang and Chen, 2009). Shortly, sustainable transportation is defined as "the transportation that meets mobility needs while also preserving and enhancing human and ecosystem health, economic progress and social justice now and in the future" (Deakin et al., 2002). The Council of the European Union (CEU, 2001) proposed the following requirements for a sustainable transport system:

(1) Ensuring basic access and development needs of individuals, businesses and the society safely and consistently by respecting public health, ecosystems and generational equity;
(2) Being affordable, efficient and fair that provides alternatives to transport modes and promotes competitive local development;
(3) Controlling waste and harming emissions so that they remain under the earth's absorption capacity, consume renewable resources below their replenishment rate, reduce noise and impact on land and use less depleting resources until suitable renewable substitutes are developed.

Sustainable transportation is a challenging field of study with a number of issues to consider, which can be analyzed in the following four categories (Litman and Burwel, 2006). *Economic issues* cover commercial activities, employment, and productivity. *Technical issues* involve vehicle and road capacity and flow conformance. *Social issues* include equity, public health, and inclusiveness. *Environmental issues* address the prevention of pollution, climate change and habitat deterioration. Given that urban transport systems aims at ensuring sustainable development as opposed to considering sustainability as its primary objective, the focus of this article is to provide a deeper understanding of urban transportation systems and to explain how such systems contribute to sustainable development in terms of environmental, economic, and social perspectives (Walker et al., 2006).

This article evaluates the sustainability of alternative urban bus systems. The characteristic features of urban transportation significantly depend on regional needs and specific local circumstances. To better determine the scope and boundaries of the evaluation, Istanbul, the largest city in the northwest of Turkey with the highest population density, is selected for the analysis. This selection is not only based on Istanbul's rapid and uncontrolled urbanization, but also on its historical settlement patterns, accelerated population rise, difficult topography, complex administration in city management and a highway-reliant urban transportation network since all the factors contributed to the increase in the number of vehicles and the growing need for major expansion of transportation infrastructure.

Even though the life expectancy of a bus is approximately 20 years (Welsh, 2007), utilization restrictions might reduce this expected age significantly. For instance, in Santiago, Chile, as of 2001, the maximum age of buses was limited to 10 years, while the average age was 6 years (Estache and Gómez-Lobo, 2005). The initial purchase cost of a bus ranges from $600,000 to $2,000,000 (Patil and Herder, 2010), depending on the fuel technology used. Alternative fuel types have different impacts on the environment and human health. For example, Brandon and Hommann (1995) estimated that one person dies in Delhi every 70 mins as a result of air pollution. Transportation systems should, therefore, be enhanced by prioritizing public transportation and pedestrian traffic for more convenient and energy efficient transportation (Song et al., 2015). Thus, the decision with regards to the purchase of buses for urban transportation, especially the one with appropriate fuel type, is a strategic priority for policy-makers.

Selection of a bus system depends on a number of criteria, such as energy efficiency, emissions, technology, cost, and facilities. To accommodate this, this article utilizes a Multi-Criteria Decision-Making (MCDM) approach. It should be noted that a solution that works well on a limited number of criteria, while failing at others is not acceptable. Since compromising solutions are preferred in these instances, dependencies among the utilized criteria become significant. These dependencies are often neglected in many MCDM approaches, including analytical hierarchy process (AHP) (Saaty, 1977), technique for order preference by similarity to ideal solution (TOPSIS) (Jen Chen and Lai Hwang, 1992), decision-making trial and evaluation laboratory (DEMATEL) (Gabus and Fontela, 1976), and Vlsekriterijumska Optimizacija I KOmpromisno Resenje (VIKOR) (Opricovic, 1998). All these and mostly other traditional methods ignore the mutual relationships among the selection criteria. In evaluation processes however, the nature and ambiguity of the human subjective judgment makes the information uncertain or fuzzy. Furthermore, there are some methods that allow one to implicitly take the dependence between criteria into account without formally representing it with a formulation or a function. Combined permutation tests are described in (Bonnini et al., 2014, Bonnini et al. (2012)). As a decision problem becomes more complicated, the task of identifying the best alternative also becomes more difficult for an expert. Many studies in the literature use the classical fuzzy set theory due to its similarity to human reasoning, to decide on an alternative among many. However, when compared to the classical fuzzy set, Intuitionistic Fuzzy (IF) sets have more advantages in the sense that they are more adequate and capable of identification of decision makers' (DMs) judgments (Büyüközkan and Güleryüz, 2016; Büyüközkan et al., 2017). Therefore, this study proposes a Choquet integral method (Grabisch, 1996) supported with a Group Decision Making (GDM) approach, which is applied in an IF environment in order to prevent bias, overcome uncertainties and reduce the subjectivity of decision-making processes. This ensures that the interactions and dependencies among decision criteria are sufficiently considered, and DMs' judgments are precisely captured. IF sets are suitable to investigate the fuzziness in DM's judgments where classical fuzzy sets prove inadequate. Fuzzy measure and Choquet integral models are particularly beneficial evaluation methods when the fuzzy measure is identified with a pairwise comparison technique (Takahagi, 2008).

The proposed method, IF Choquet Integral (IFCI), consists of an MCDM methodology under IF environment with a GDM approach using the Choquet integral technique. A case study is conducted to evaluate the performance of the integrated method. The main