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A fuzzy assessment framework to select among transportation investment projects in Turkey

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ABSTRACT

Selecting the best transportation investment project (TIP) is often a difficult task, since many social, environmental and economic criteria have to be considered simultaneously. Evaluating a set of different projects, especially the best set of alternatives, portfolios, is even more complex. Pursuing the goal of selecting the best TIP portfolio, we propose a fuzzy assessment method to aid the selection process of a multi-criterion project by utilizing the concept of entropy and interval normalization procedure in a fuzzy analytic hierarchy process (F-AHP). Then, regarding this informative phase, we propose a fuzzy linear programming model to select the best TIP portfolio under uncertain cost pressure. A real case study is conducted to illustrate the efficiency of the proposed method.

1. Introduction

Fuzzy logic presents a fundamental basis to mathematically express human beings' daily proficiency of inference and interpretation. People decide with linguistic terms, which are not strictly defined in the routine of daily life. Therefore, decisions vary from person to person according to their living conditions, culture, and viewpoint. Researchers have been interested in expressing these linguistic terms in mathematical forms to mimic the human behavior, which has given birth to expert systems. The incapability of conventional Boolean logic to express linguistic terms calls forth the development of fuzzy logic which handles the concept of partial truth. Partial truth mainly designates the values between "completely true" and "completely false". The prevailing side of fuzzy logic is its capability of expressing partial truth in mathematical form without the need for complex mathematical modeling.

In recent decades, fuzzy logic has increasingly taken an essential part of multi-criterion decision making (MCDM) literature. The nature of the selection problem stimulates utilization of fuzzy logic for multi-criterion evaluations, linguistic expressions, and uncertain decision environments. The fuzzy extensions of many MCDM methods are studied by many researchers. Analytic hierarchy process (AHP) has been extended to fuzzy environments many times (Cheng, 1996; Ruoning & Xiaoyan, 1992; Triantaphyllou & Mann, 1990); a fuzzy extension of the TOPSIS method was proposed by Chen (2000); and fuzzy extensions of ELECTRE (and its derivatives) have recently been studied by Hatami-Marbini and Tavana (2011). Since MCDM methods are flexible and available to improve, many researchers have proposed many improvements to these methods to deal with several multi-criterion selection problems.

The development of transportation systems in a city has an important role in the development of social welfare in terms of economic, environmental, and social means. Municipalities are currently responsible for providing efficient and effective transportation services to their residents. Every municipality throughout the world is funded by government to provide better transportation facilities. Therefore, it is required for managers of municipalities to use formal TIP evaluation procedures. These procedures have to consider key issues such as the project's risks, financing costs, demand, market imperfections, labor force availability, and various incompatibilities between trip rates, travel times and activity locations (Berechman, 2009). Projects, which are selected using such a well-structured evaluation procedure, may result in significantly well-founded demand, environmentally conscious transportation systems and efficient use of public transportation.

In practice, decision makers consider specific objectives, i.e. reducing traffic density by encouraging the public transportation. However, these objectives are mainly logical; they are often insufficient to select the best project portfolio. Teng and Tzeng (1998) propose a fuzzy multi-objective 0–1 programming model for TIP selection problem and explain the fuzzy spatial algorithm for non-independent TIPs. Iniestra and Gutierrez (2009) model the multi-objective TIP selection problem as a constrained multi-objective optimization problem with quadratic objective functions and utilize evolutionary-based framework in order to identify pareto solutions, filter non-attractive properties using a knee identification procedure, and final rankings are obtained by using ELECTRE III. Ferrari (2003) proposes an extension of AHP that diverges from

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traditional AHP procedures with regard to estimation of the weights in order to solve the transportation project selection problem.

This paper introduces a decision support model to select the best set of TIPs with a number of decision makers in an uncertain environment. The remainder of this paper is organized as follows: Section 2 presents the TIP selection criteria. Section 3 gives a brief explanation about transformation of linguistic terms and understanding fuzzy evaluations. Section 4 explains the proposed analytical decision aiding model by describing the concept of entropy and the normalization procedure. The fuzzy linear programming model is discussed in Section 5. Section 6 presents a transportation project portfolio selection case in a municipality in Turkey. Finally, Section 7 presents concluding remarks of our findings.

2. TIP evaluation and selection criteria

The evaluation and selection of TIPs is one of the major public investment decisions made by the government. Under an ever-complex social infra-structure and international environment, one criterion for one single objective is no longer valid (Teng & Tzeng, 1998). In the real world, selecting the best TIP often includes qualitative and quantitative criteria. Since TIPs intend to enhance social welfare and sustainable development, the decision criteria should include both economic and noneconomic attributes. The goal of selecting the best TIP is to find the TIP candidate which yields the highest social return, which is defined as a combination of transportation, economic, environmental, and social benefits (Berechman, 2009).

In this study, four main criteria and eighteen sub-criteria of these main criteria are used for the selection of the best TIP. The definitions of the main- and sub-criteria are summarized as follows.

2.1. Product feature risks

Under this main criterion, three sub-criteria are defined: *technical risks*, *environmental risks* and *external risks.* Product feature risks, which mainly result from the TIP's characteristics, are related to improper technical specifications, unfitting and abnormal product functionality, underestimated external elasticity, etc. The external elasticity level reveals how the TIP is affected by the change in the external environment. The external risks can be funding changes, political factors and the environmental risks can be changes in environmental regulations, historic site regulations and environmental permit delays.

2.2. Project management risks

Under this main criterion, we summarize three sub-criteria as *organizational risks*, *schedule* and *cost effectiveness*. These risks are mainly caused by the project plan, i.e. inexperienced staff; inconsistent time, cost, scope and quality objectives; priority changes; lack of communication and coordination; schedule errors; poor schedule, deliverable and scope definitions.

2.3. Public benefits

Under the public benefits criterion, we list eight sub-criteria as *travel time savings, predicted density of passengers, environmental effect, reducing barrier effect, reducing noise, reducing air pollution, improving land use*, and *safety*. The public benefits criterion mainly reveals the essential consideration of upgrading the social welfare and economic development by presenting alternative public transportation channels to the residents, rather than by encouraging individual use of cars.

2.4. Reputation

Under the reputation criterion, we list four sub-criteria as following: *quality of work, technical excellence and contribution to innovation, improvement in votes of confidence*, and *durability*. The excellence of an investment project is very critical for municipalities since these investments arouse the interest of scientists, intellectuals, and other local and foreign municipalities.

3. Understanding fuzzy evaluations and relevant literature

Most of decision making in the physical world takes place in a situation in which the pertinent data and the sequences of possible actions are not precisely known criteria (Triantaphyllou, 2000). Generally, decision-makers avoid assigning crisp numbers as a judgment value when asked to evaluate decision elements to form a judgment matrix. The difficulties in getting exact data forced researchers to develop new approaches to handle imprecise data.

Fuzzy logic serves as a useful tool to deal with these imprecise evaluations, such as inexact measurements or available expert knowledge in the form of verbal descriptions. Triangular fuzzy numbers (TFNs) are often utilized to express imprecise information owing to their ease-of-use in fuzzy arithmetic operations. However, ranking these fuzzy numbers is very hard when these numbers are highly close and telescoping.

In the literature, ranking TFNs is studied by many authors (Cheng, 1998; Wu, Lee, & Lin, 2004). Cheng (1998) proposed a ranking method by defining an index of coefficient of variation (CV) and utilized a distance method to improve the ranking method of Maeda and Murakami (1993). This method ranks TFNs by a distance index $R(\widetilde{M}_i)$ between the centroid point and original point (Cheng, 1998). Chu and Tsao (2002) observed that Cheng's CV index and distance method do not consistently rank fuzzy numbers and proposed a ranking approach for fuzzy numbers with the area between the centroid and original points. Chen and Lu (2001) present an approximate approach for ranking fuzzy triangular numbers based on the left and right dominance. The proposed approach requires a few left and right spreads at some a-levels of fuzzy numbers to determine the respective dominance of one fuzzy number over the other (Chen & Lu, 2001). By combining the left and right dominances, the total dominance is performed according to the decision maker's optimistic perspectives. Wu et al. (2004) adopted the fuzzy mean and spread method to defuzzify and rank the TFNs.

In this paper, we obtained the rankings by processing a ranking procedure of fuzzy triangular numbers, applying a normalization procedure for fuzzy interval weights, and calculating entropy values for final weighted evaluations. The following section presents detailed information about these methods and procedures.

4. Entropy embedded fuzzy AHP

The analytical hierarchy process (AHP) is a well-known decision support tool used for complex decision making problems by providing a multi-level hierarchical structure for discrete decision making problems. In the literature, several fuzzy extensions of the AHP method are presented in order to evaluate alternative candidates regarding individual subjective decision criteria under an uncertain decision environment (Cheng, 1996; Efendigil, Onut, & Kongar, 2008; Şen & Çınar, 2010). Since the utilization of TFNs facilitates fuzzy calculations and interpretations, researchers generally utilize TFNs to develop fuzzy decision making methods in order to handle uncertainty. Kwong and Bai (2002) introduced