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An improved approach to evaluate car sharing options

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ABSTRACT

We develop an improved approach to evaluate car sharing options under uncertain environments with the combination of Fuzzy Analytic Hierarchy Process (F-AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS), which consists of three steps. In the first step, we propose a SCUMN (Specific, Comprehensive, Understandable, Measurable, and Neutral) methodology to identify appropriate indicators and obtain a final list of 24 indicators according to their relevance to car sharing options. In the second step, we determine the weight of each indicator with F-AHP and conduct consistency check of the comparison matrix of selected indicators. In the third step, comparison of different options is performed with selected indicators and F-TOPSIS. A case study is provided to validate the proposed approach. Twenty-four indicators are identified to evaluate five different car sharing options and rank them according to their closeness coefficients in decreasing order. And thirty-one sensitivity analysis experiments are conducted to figure out the influence of indicators on decision making. The experimental results show that the proposed approach is capable of evaluating car sharing options with uncertainty and vagueness. F-AHP is able to determine the weight for each selected indicator and F-TOPSIS demonstrates its advantage in comparing potential options.

1. Introduction

Nowadays, more and more people choose to work in city center and live in suburban areas. For example, Beijing, as capital of China, has a population of nearly 30 million and more than half of them live in outer suburbs, resulting in busy commuting on workdays. Influx of tourists and business travelers makes the traffic condition in urban areas even worse. Basically, there are two modes of transportation for them: public transport systems including subways and buses; and point-to-point traffic means such as cars and taxies (Kriston et al., 2010). There is no denying the fact that most urban areas are now suffering from terrible air pollution, atmospheric haze, congestion, and parking problems. Transportation administrators try every means to solve the above-mentioned issues, for instance, odd-and-even license plate rule, restriction against automobile purchasing, charging for congestion, increased parking fee and so on. However, none of these measures is proved to be effective enough and transporting capacity cannot satisfy mobility demands very well. Ever-increasing world-wide urbanization calls for innovative solutions to meet the mobility demands of urban dwellers (Glotz-Richter, 2012).

As to the field of urban transportation, there are many different kinds of transport modes, and some of them have negative impacts and hinder the achievement of sustainability goals (Alonso et al., 2015). Among all these transport modes, private cars are still the first choice of many people due to its convenience and mobility. However, after a great amount of money spent on buying a car, it is parked 92% of its life time, 1% caught in traffic jam, 1.6% looking for parking and the other 5% driving with only one driver in most cases, resulting in great waste of money, time, and energy (McKinsey Center for Business and Environment, 2015). Automobile usage is a major source of air and noise pollution and improper use of private car is responsible for many of the serious environmental and social problems (Katzev, 2003). Therefore, we should pay special attention to efficient usage of cars within the sustainable development framework (Joumard and Nicolas, 2010).

What is the efficient way of car usage? Sharing them with others may be a good idea. Car2go is such a system that allows users to take and return vehicles at any point within the city limits (Firnkorn and Müller, 2011). The idea of "sharing" proposes new prospects for sustainable development. The concept of "sharing economy" (Hamari et al., 2015) refers to an innovative type of business based on shared use of resources, which provides users

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with access to products without actual purchasing. Product service system (PSS) is such a good way to advocate the idea of sharing. The core idea of PSS is to provide solutions to customers by integration of "products" and "services", satisfying user needs while reducing energy and resource consumption at the same time (Qu et al., 2016). Tukker (2004) proposed eight types of PSS and divided them into three categories: product-oriented, use-oriented, and result-oriented. Product-oriented PSS aims at product sales with some extra services provided. Use-oriented PSS does not care so much about product selling as in the product-oriented PSS. Instead, service providers hold the ownership of products and provide users with different forms of services. In a result-oriented PSS, customers and providers agree on a pre-determined result. Customers no longer buy an automobile and they only need to pay for a particular trip.

Car sharing is a typical PSS in the mobility sector and it is a rather innovative mode of transportation in reducing personal vehicle ownership in urban areas, which is critical to reduce the burdens of vehicle ownership and helps individuals to maintain a high level of mobility meanwhile (Costain et al., 2012). We discuss "car sharing" in a broad sense of meaning in this study, which means "access to cars without actual ownership". We are going to compare five potential options: rental, leasing, piggy-backing, driving-for-you, and drive-sharing. The first four options come from a pioneer car sharing company in China and the last one is a new way of sharing and more complex to deal with than the other four. Detailed information about these five options can be found in Section 5.1.

It is obvious that most car sharing services are mainly use-oriented PSS since users do not need to buy a car for themselves. But they still need to drive by themselves in cases of rental, leasing, and piggy-backing. Different from other transportation modes, driving-for-you and drive-sharing are result-oriented PSS, in which customers and drivers agree on the departure and arrival time in advance and customers are relieved from driving. It is of great significance to evaluate these options and choose the best one from a comprehensive point of view. The evaluation of car sharing options is a typical multiple criteria evaluation and group decision making process, in which there is no ideal solution as to each indicator at the same time. A comprehensive evaluation framework aims to provide a compromised solution, taking conflicting evaluation indicators into account.

We'd like to assist car sharing administrators and urban planners by developing an improved approach to rank different potential options under uncertain circumstances in combination with F-AHP and F-TOPSIS. The paper is organized as follows. Section 2 is literature review from the following three perspectives: evaluation of car sharing systems, selection of sustainable mobility indicators and application of F-AHP and F-TOPSIS in decision making; Section 3 introduces fundamental knowledge including triangular fuzzy number, linguistic variable, and detailed steps of using F-AHP and F-TOPSIS. Thereafter, an integrated approach to evaluate car sharing options is proposed and discussed in Section 4. A case study is conducted in Section 5 to show the procedure of the proposed approach at length. We conclude the paper and discuss the significances and limitations of the improved approach in the last section.

2. Literature review

2.1. Evaluation of car sharing systems

More and more researchers are focusing their attention on the evaluation of car sharing systems from different perspectives. Mihyeon Jeon and Amekudzi (2005) focused on the definitions, indicators and metrics of sustainability in transportation systems. They classified all the indicators into four categories: transportation-related (including safety), economic, environmental, and social/cultural-related. Besides, they listed frameworks identified in previous studies into three categories: linkages-based, impacts-based, and influence-oriented frameworks. Rabbitt and Ghosh (2013) developed a method to estimate the potential market and influence of car sharing by examining the geographic, financial and environmental factors. There are three phases in the proposed approach. First of all, a geographic analysis is conducted to estimate the car sharing market; potential economic and environmental benefits to users of car sharing systems are analyzed in the second phase; and the results of the first two phases are combined in the last one to evaluate the potential scale and overall impact of different car sharing modes. Firnkorn and Müller (2011) studied the environmental effects of car2go, a free-floating car-sharing system in Ulm, Germany. They classified car-sharing effects into three categories, i.e., environmental, social, and economic categories, and then split the environmental category into three processes, i.e., construction, operation, and decomposition of mobility systems. However, the authors only focused on the total CO_2-emissions from the operation of mobility systems and static land consumption. They did not conduct quantitative evaluation of car2go's impact related to dynamic land consumption due to lack of data. Limitations of their study lie in the following three aspects: they did not analyze annual mobility cycles; CO_2-assessment excluded infrastructure construction and maintenance; and they did not consider rebound effect and time use analysis. Smith et al. (2013) applied the Process Analysis Method of sustainability evaluation to find out appropriate indicators across the environmental, economic and social dimensions. The environmental indicators care more on the consequences of resource use. The economic indicators focus on the costs and contributions to the economy. And the social indicators are concerned with the quantity and quality of the mobility and impacts of car fleet operation on the community, especially in terms of health and safety. Fellows and Pitfield (2000) applied cost benefit analysis (COBA) techniques to assess the economic and operational performances of urban car-sharing systems. They arrived at positive conclusions as to the benefits of car-sharing including individual benefits with lower travel costs, reductions in vehicle kilometers, fuel, accidents and emissions, and increased average speeds. To analyze the impact of green car technologies on energy and environment, Lee et al. (2013) developed an innovative approach with the combination of market allocation models and a forecasting model to deal with the problems of technology diffusion and some special attributes that cannot be measured in terms of monetary value.

From the above-mentioned analysis, we can conclude that previous studies on the evaluation of car sharing systems were mainly conducted from a comprehensive point of view and most of the identified literature focused on three aspects of car sharing systems: economic, environmental, and social. This study differs itself in the proposed 24 indicators from four dimensions: economic, environmental, social, and car sharing system performance. And five potential options are compared with the proposed approach to demonstrate the detailed procedure of comparison.

2.2. Sustainable mobility indicators

Indicators refer to those things that we apply to evaluate progress toward some intended goals or objectives and the way of things being measured has a direct influence on their perceived value (Litman, 2007). Despite that a growing number of measures and tools have been developed to deal with sustainable mobility, there is no universal indicator for the evaluation of car sharing options.