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Article *in* Ecological Indicators · January 2017

DOI: 10.1016/j.ecolind.2016.07.018

Ecological Indicators 72 (2017) 686–702

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

An improved approach to evaluate car sharing options

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ARTICLE INFO

Article history:
Received 22 January 2016
Received in revised form 5 June 2016
Accepted 14 July 2016
Available online 12 September 2016

Keywords:
Fuzzy analytic hierarchy process
Fuzzy technique for order preference by similarity to ideal solution
Car sharing
Indicator
Sensitivity analysis

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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http://dx.doi.org/10.1016/j.ecolind.2016.07.018
1470-160X/

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.

Dodgson et al. (2009) proposed three kinds of approaches to identify indicators. The most widely used is an informal or semi-structured manner such as expert interviews or "brain storming" with decision makers and stakeholders. Another approach is to study policy documents and secondary sources to obtain relevant indicators. The third method is to conduct role-playing exercises by decision makers to role play key stakeholders. It is worth noting that these approaches are universal and not targeted at sustainable car sharing. Gilbert et al. (2003) proposed a definition of sustainable transportation and emphasized the following aspects of a potential variable: environmental and health consequences of transport; transport activity; land use, urban form and accessibility; supply of transport infrastructure and services; transportation expenditures and pricing; technology adoption; implementation and monitoring. A set of 14 indicators for evaluating sustainable transportation performance was identified. According to Miller et al. (2013), indicators should have the following properties: comprehensible, measurable, complete, operational, decomposable, nonredundant, and minimal. They proposed a framework for the establishment of quantitative livability and sustainability indicators and suggested future research on dynamic indicators.

Haghshenas and Vaziri (2012) summarized indicators from previous studies and proposed 7 criteria for the selection of indicators. They are:

- Target relevance—each indicator must show one aspect of sustainability;
- Data availability and measurability- indicators must be measurable in the database.
- Validity—indicators must actually measure the issue it is supposed to measure;
- Sensitivity—able to reveal cities sustainable transport changes;
- Transparency—easy to understand and possible to reproduce for intended users;
- Independent—indicators should be independent of each others;
- Standardized—indicators should be standardized by city size for comparison.

According to identified frequency of indicators and the above criteria, they arrived at a list of 9 indicators that are measurable by "Millennium cities database for sustainable mobility". Alonso et al. (2015) proposed the concept of "composite indicators" on the basis of a benchmarking approach and identified 9 most influential factors in the sustainability evaluation of transport system. Mihyeon Jeon and Amekudzi (2005) provided a detailed list of 177 indicators for sustainable transportation systems from the following dimensions: economic (11 indicators), transportation-related (64 indicators), environmental (67 indicators), safety-oriented (6 indicators), and social-cultural/Equity-related (29 indicators). The authors listed indicators identified in literature review with an emphasis on the transportation-related and environmental dimensions of the system. However, too many indicators will make comparison rather complicated and bring unpredictable problems in the evaluation process.

Traditionally speaking, the evaluation of a sustainable mobility attaches importance to three dimensions: economic, environment, and society. These three dimensions are known as the Triple-Bottom-Line (TBL) of sustainability. Nowadays, more and more researchers would like to develop more comprehensive frameworks to evaluate sustainability. Gillis et al. (2015) applied SMART (Specific, Measurable, Achievable, Relevant, and Timely) methodology in the selection of sustainable mobility indicators. They identified a list of 22 indicators for sustainable mobility evaluation from four dimensions: global environment, economic success, quality of life, and performance of the mobility system. Nine indicators belong to the fourth dimension, demonstrating their interest in the overall performance of the mobility system. To name a few, system performance indicators include accessibility, affordability, functional diversity, and so forth.

No matter how they are derived, indicators for the evaluation of car sharing options should have the following properties (Gillis et al., 2015; Litman, 2007; Miller et al., 2013):

1. Specific: A particular indicator stands for a relevant aspect of car sharing option exactly and can be assessed independently.
2. Comprehensive: Indicators should cover all relevant aspects of a potential car sharing option and reflect its economic, environmental, social and system operational performances comprehensively. With a focus on personal transport of car sharing systems, we do not take into account those indicators related to freight transport and light-duty passenger vehicles.
3. Understandable: Indicators should be understandable by decision makers and the general public to ensure that they represent the actual degree of achievement as to the particular objective. The more information included, the less understandable they are.
4. Measurable: Indicators should be measurable with enough accurateness. Data collection should be easy to conduct and standardized to ensure comparison between different options.
5. Neutral: Indicators themselves do not favor or disfavor a particular type of potential options.

According to the SCUMN (Specific, Comprehensive, Understandable, Measurable, and Neutral) principles and with an aim to choose appropriate indicators to evaluate car sharing options, we conduct an extensive and systematic literature review and identify 78 indicators, with 21, 22, 13, and 22 to economic, environmental, mobility system performance, and social dimension respectively (Alonso et al., 2015; Awasthi et al., 2011; Gilbert et al., 2003; Gillis et al., 2015; Haghshenas and Vaziri, 2012), as shown in Table 1. The following adjustments are made in this process. Firstly, some authors (Awasthi et al., 2011; Gilbert et al., 2003) did not classify indicators into different dimensions. Instead, we classify the proposed indicators to fit for the purpose of this study. Secondly, different authors may propose different indicators with similar meanings. For example, land usage and land consumption have similar meanings and can be combined together. Thirdly, authors may attribute some indicators to different dimensions. For example, Gillis et al. (2015) attributed "noise hindrance" and "air polluting emissions" to a dimension named "quality of life". We transfer them to the dimension of "environmental" to make comparison easier to conduct. Fourthly, we delete those repeated items and items that are not closely related to car sharing systems such as "share of passenger travel not held by land-based public transport" and "coverage ratio of public transport". Finally, we add some important items that have not been identified by these authors but indispensable to car sharing systems. For instance, we add "employment" to the dimension of economic, which means "opportunities of being employed by the system"; and we add "congestion" to environmental dimension because we hope to reduce congestion through car sharing. Besides, we replace the dimension of "mobility system performance" with "car sharing system performance" and add three indicators to it, i.e., accidents, car utilization ratio, and reservation acceptance ratio.

2.3. Application of F-AHP and F-TOPSIS

Analytic Hierarchy Process (AHP) was proposed by Satty (1980). It is a comprehensive method for multi-criteria decision process, with the basic idea of constructing a pair-wise comparison matrix to determine the weight of each criterion. However, under actual circumstances with uncertainty and complexity, it is usually hard to tell the relative importance of one element compared to the

Table 1
Identified indicators for sustainable mobility in previous studies.

Dimension	Indicator	Author
Economic	Share of passenger travel not held by land-based public transport	(Gilbert et al., 2003)
	Index of relative household transport costs	
	Index of the relative cost of urban transit	
	Net public finance	(Gillis et al., 2015)
	Congestion and delays	
	Economic opportunity	
	Commuting travel time	
	Coverage ratio of public transport	(Alonso et al., 2015)
	Time spent	
	Costs of transport for users	
	Household expenditure allocated to transport	(Haghshenas and Vaziri, 2012)
	Expenditures on transportation for local government	
	Total time spent in traffic	
	Operating costs	(Awasthi et al., 2011)
	Travel costs	
	Benefits to economy	
	Competency	
	Possibility of expansion	
	Productivity	
	Occupancy rate	
	Share in public transit	
Environmental	Use of fossil fuel energy for all transport	(Gilbert et al., 2003)
	Greenhouse gas emissions from all transport	
	Index of emissions of air pollutants from road transport	
	Rate of use of urban land	
	Length of paved roads	
	Index of energy intensity of the road vehicle-fleet	
	Index of emissions intensity of the road-vehicle fleet	
	Emissions of greenhouse gases	(Gillis et al., 2015)
	GHG Global environment	
	Energy efficiency	
	Land consumption of transport infrastructures	(Alonso et al., 2015)
	Energy consumption	
	Emissions	
	Emissions of local air pollutants per capita	(Haghshenas and Vaziri, 2012)
	Transport energy use per capita	
	Land consumption for transport infrastructure (roads, parking)	
	Air pollutants	(Awasthi et al., 2011)
	Noise	
	GHG emissions	
	Usage of fossil fuels	
	Waste from road transport	
	Energy consumption	
	Land usage	
Mobility system performance	Accessibility for mobility impaired groups	(Gillis et al., 2015)
	Affordability of public transport for poorest group	
	Security	
	Functional diversity	
	Intermodal connectivity	
	Intermodal integration	
	Resilience for disaster and ecologic/social disruptions	
	Occupancy rate	
	Opportunity for active mobility	
	Mobility	(Awasthi et al., 2011)
	Convenience to use	
	Quality of service	
	Reliability	
Social	Index of incidence of injuries and fatalities from road transport	(Gilbert et al., 2003)
	Total motorized movement of people	
	Total motorized movement of freight	
	Movement of light-duty passenger vehicles	
	Mobility space usage	(Gillis et al., 2015)
	Quality of public area	
	Access to mobility services	
	Traffic safety	
	Noise hindrance	
	Air polluting emissions	
	Comfort and pleasure	
	Transport fatalities per inhabitant	(Alonso et al., 2015)
	Density of public transport network	
	Affordability of public transport by lower income residents	
	Fatality and injured of traffic accidents per capita	(Haghshenas and Vaziri, 2012)
	Access to public transport	
	Satisfaction of citizens and variety and quality of transport options	
	Accessibility	(Awasthi et al., 2011)
	Equity	
	Tangibles	
	Safety	
	Security	

other. To deal with uncertainty and vagueness in decision making process, we can express the comparison ratios as triangular fuzzy numbers (Mikhailov and Tsvetinov, 2004). Actually, F-AHP and F-TOPSIS have been widely used in multiple criteria evaluation and group decision making process.

Kahraman et al. (2003) applied F-AHP to measure service quality and choose the best supplier firm with the greatest satisfaction. They divided selection criteria into the following four types: supplier criteria, product performance criteria, service performance criteria, and cost criteria. This study was conducted in 2003, when the application of F-AHP was at an initial stage of development. F-AHP itself was not efficient enough to rank different alternatives. The authors advocated that future research may focus on the application of other multi-criteria evaluation methods including ELECTRE, DEA, and TOPSIS in an uncertain environment. Chen and Tsao (2008) extended the TOPSIS method on the basis of interval-valued fuzzy sets in the process of decision analysis. And they carried out comprehensive experimental and comparative analysis to figure out the effect of different distance measures on the interval-valued fuzzy TOPSIS results. What's more, they provided a second-order regression model to emphasize the influences of the number of options, attributes, and distance measures on average Spearmen correlation coefficients. Song et al. (2013) proposed a new decision approach for selecting new product design concepts based on rough AHP and rough TOPSIS. According to characteristics of criteria, they classified them into two categories: cost and benefit. For benefit criterion, the positive ideal solution (PIS) is the largest possible value and the negative ideal solution (NIS) is the lowest one. For cost criterion, the largest upper limit of all the rough numbers is selected as the NIS value and the lowest lower limit as the PIS value. Roszkowska and Wachowicz (2015) applied TOPSIS to establish a scoring system for negotiation offers in ill-structured negotiations. They divided criteria into benefit and cost categories and they normalized fuzzy decision matrix with application of linear normalization, depending on the type of criterion. For benefit criteria, the greater value, the better; for cost criteria, the lower value, the better.

Sun (2010) proposed a performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods to help decision makers to deal with imprecision and comprehend the complete evaluation process. The proposed method provides a more accurate and effective support tool for decision-making process with combination of F-AHP and F-TOPSIS. But the author did not check the consistency index of the fuzzy decision matrix, which may result in invalid comparison; and they did not consider cost criteria while using fuzzy TOPSIS. Hu et al. (2012) developed a sustainability evaluation framework for PSS with application of fuzzy Delphi and fuzzy analytic hierarchy method to settle the consistency of criteria and determine the relative weights of the selected criteria. With an aim to establish a model to implement PSS at an initial stage, the proposed approach did not consider specific characteristics of a product or service. The authors did not conduct case studies to validate the evaluation model either.

Awasthi et al. (2011) proposed a multi-criteria decision-making methodology to choose proper sustainable transportation systems under partial information, consisting of three steps: identification of criteria; linguistic ratings of potential options against each of the criteria with application of Fuzzy TOPSIS; and sensitivity experiments to identify the effect of criteria weights on the decision-making process. They classified criteria into cost and benefit categories in order to bring various criteria scales into a comparable one. A limitation of their study lies in the application of F-TOPSIS to determine the criteria weights and rank potential options, which is not very efficient in determining the weights for selected criteria. Alfian et al. (2014) proposed a simulation tool on the basis of fuzzy classification to assess the service model in a car-sharing system. They applied fuzzy classification to obtain a service model with the highest profit for service providers and the best service for customers as well. Thirty-six car sharing service models were proposed with relocation techniques and trip types taken into consideration. The authors evaluated the performance of service models by three indicators: average profit per day, car utilization ratio, and reservation acceptance ratio. However, they applied a limited number of relocation techniques and the service models focused only on customers in Seoul. They did not consider predictive relocation techniques, dynamic pricing, and different time periods such as weekend and weekday in the simulation.

Therefore, we combine F-AHP and F-TOPSIS in the evaluation of car sharing options. F-AHP is applied to identify the weight for each selected indicator and F-TOPSIS to rank potential options according to their closeness coefficients in decreasing order. Moreover, we improved the method proposed by (Sun, 2010) by conducting consistency index check of the comparison matrix of selected indicators and taking into account cost indicators to normalize fuzzy decision matrix.

3. Fundamental knowledge

The concept of 'fuzzy sets' was proposed by Professor Zadeh in 1965. A fuzzy set is a class of objects with a continuum of grades of membership (Zadeh, 1965). The fuzzy set theory uses linguistic terms to represent decision makers' preferences (Mihyeon Jeon and Amekudzi, 2005). For instance, the possibility that he will come to our party can be represented in linguistic variables as very high, high, medium, low, and very low. A fuzzy set $\tilde{M}$ in X is characterized by a membership (characteristic) function $\mu_{\tilde{M}}(x)$ which maps each element x in X to a real number in the interval [0, 1], with the value of $\mu_{\tilde{M}}(x)$ at x standing for the 'grade of membership' of x in $\tilde{M}$. Therefore, the nearer the value of $\mu_{\tilde{M}}(x)$ to unity, the higher the grade of membership of x in $\tilde{M}$(Awasthi et al., 2011) is. A fuzzy number refers to a connected set of possible values instead of one single value. Each of the possible values has its weight from 0 to 1. Fuzzy numbers are an extension of real numbers and the computation with fuzzy numbers incorporates uncertainty and subjectivity. Triangular fuzzy number (TriFN) and trapezoidal fuzzy number (TraFN) are two kinds of fuzzy numbers that are often used. This study mainly makes use of triangular fuzzy number to show the vagueness of decision makers.

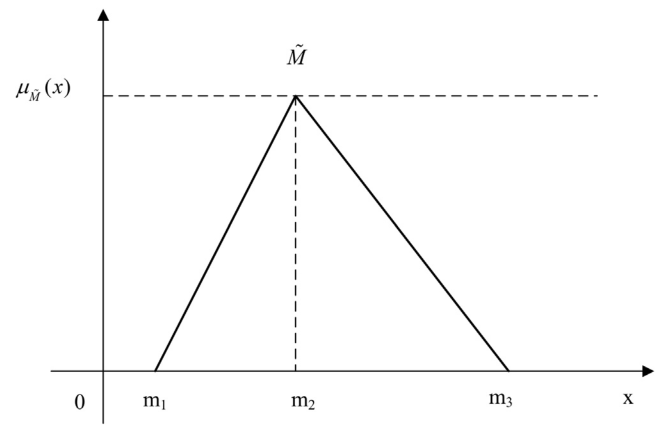

Fig. 1. Triangular fuzzy number $\tilde{M}$.

3.1. Triangular fuzzy number

A triangular fuzzy number (TriFN) is represented as a triplet $\tilde{M} = (m_1, m_2, m_3)$, as is shown in Fig. 1. The membership function $\mu_{\tilde{M}}(x)$ of TriFN $\tilde{M}$ is given by:

$$\mu_{\tilde{M}}(x) = \begin{cases} 0, x < m_1 \\ (x - m_1)/(m_2 - m_1), m_1 \le x \le m_2 \\ (m_3 - x)/(m_3 - m_2), m_2 \le x \le m_3 \\ 0, x > m_3 \end{cases} \quad (1)$$

where m_1, m_2, m_3 are real numbers and $m_1 \le m_2 \le m_3$, and m_1, m_3 are the lower and upper limits of the available area for the evaluation data while $|m_3 - m_1|$ reflects its fuzziness.

Given two TriFNs $\tilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$, then the addition, subtraction, multiplication, division, and inverse are operated as follows:

(1) Addition of two TriFNs

$$\tilde{m} \oplus \tilde{n} = (m_1 + n_1, m_2 + n_2, m_3 + n_3), m_1 \ge 0, n_1 \ge 0$$

(2) Subtraction of two TriFNs

$$\tilde{m}(-)\tilde{n} = (m_1 - n_1, m_2 - n_2, m_3 - n_3), m_1 \ge 0, n_1 \ge 0$$

(3) Multiplication of two TriFNs

$$\tilde{m} \otimes \tilde{n} = (m_1 \times n_1, m_2 \times n_2, m_3 \times n_3), m_1 \ge 0, n_1 \ge 0$$

(4) Division of two TriFNs

$$\tilde{m}(/)\tilde{n} = (m_1/n_1, m_2/n_2, m_3/n_3), m_1 \ge 0, n_1 \ge 0$$

(5) Inverse of a TriFN

$$\tilde{m}^{-1} = (1/m_3, 1/m_2, 1/m_1)$$

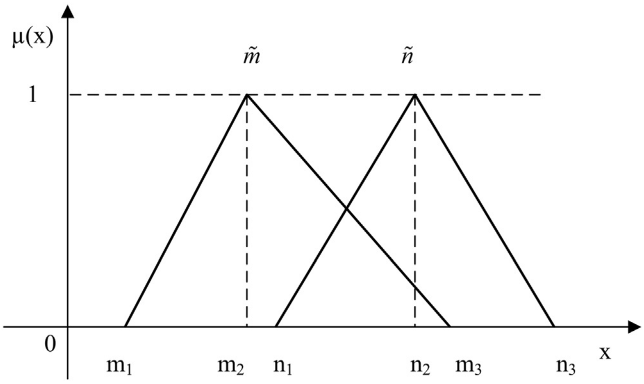

Fig. 2. Two triangular fuzzy numbers.

Table 2
Membership functions of linguistic variables. Adapted from (Hsieh et al., 2004).

Fuzzy number	Linguistic variable	Triangular fuzzy number
$\tilde{9}$	Absolutely important	(7,9,9)
$\tilde{7}$	Rather important	(5,7,9)
$\tilde{5}$	Essentially important	(3,5,7)
$\tilde{3}$	Weakly important	(1,3,5)
$\tilde{1}$	Equally important	(1,1,3)
$\tilde{1}^{-1}$	Equally Less important	(1/3,1,1)
$\tilde{3}^{-1}$	Weakly Less important	(1/5,1/3,1)
$\tilde{5}^{-1}$	Essentially Less important	(1/7,1/5,1/3)
$\tilde{7}^{-1}$	Rather Less important	(1/9,1/7,1/5)
$\tilde{9}^{-1}$	Absolutely Less important	(1/9,1/9,1/7)
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}, \tilde{2}^{-1}, \tilde{4}^{-1}, \tilde{6}^{-1}, \tilde{8}^{-1}$	Medium value of two adjacent triangular fuzzy numbers.	

Suppose $\tilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$ are two TriFNs (Fig. 2). The Vertex distance between them can be calculated by (Roszkowska and Wachowicz, 2015):

$$d_V(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]} \quad (2)$$

3.2. Linguistic variable

Linguistic variable is a variable whose values are expressed by words or sentences in a natural or artificial language instead of crisp numbers (Zadeh, 1975). For example, wealth can be a linguistic variable if its values are described as fuzzy variables labeled *very rich, rich, not rich, poor, very poor,* etc., rather than accurate numbers such as a million or 10 billion dollars. The concept of a linguistic variable offers us a means to describe complicated phenomena which are rather difficult in conventional quantitative terms. In this study, the linguistic variables are defined based on (Hsieh et al., 2004), as shown in Tables 2 and 3.

Table 2 displays membership functions of linguistic variables to compare two indicators. For example, if a decision maker is asked to compare indicator *i* with *j* and he thinks that indicator *i* is absolutely more important than indicator *j*. Then he can assign a fuzzy number $\tilde{9}$ as to this comparison and the corresponding triangular fuzzy number is (7, 9, 9). And if he thinks that indicator *i* is absolutely less important than indicator *j*, then he can assign a fuzzy number $\tilde{9}^{-1}$ as to this comparison and the corresponding triangular fuzzy number is (1/9, 1/9, 1/7).

When it comes to the rating of a specific option against a particular indicator, we apply linguistic variable listed in Table 3. For instance, if a decision maker is asked to assess option *p* with respect to indicator *i* and he thinks that option *p* is very good (VG), then the membership function should be (7, 9, 9). And if he thinks that option *p* performs very poor (VP) as to the specific indicator, then the membership function should be (1, 1, 3). Each membership function is defined by three numbers of a triangular fuzzy number.

Table 3
Linguistic variables for option ratings.

Linguistic variable	Membership function
Very poor (VP)	(1,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very good (VG)	(7,9,9)

Table 4
Random index $RI(n)$.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3.3. F-AHP

The steps of applying F-AHP in determining the weights of indicators are listed as follows:

Step 1: Establishing the hierarchy system of evaluation indicators.

Step 2: Constructing pair-wise comparison matrix $\tilde{A}$ among all evaluation indicators in each dimension of the hierarchy structure. Invite decision makers to assign linguistic variables to pair-wise comparisons by determining the one with more importance between the two indicators.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \quad (3)$$

where

$$\tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} \text{when } i \text{ is more important than} j \\ 1, \text{when} i = j \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1}, \text{when} i \text{ is less important than} j \end{cases}$$

Step 3: Computing consistency index (CI) and consistency ratio (CR).

To ensure the consistency of the constructed matrix, we should first convert a fuzzy number $\tilde{M}(l, m, n)$ to a crisp one by:

$$M_{-crisp} = (l + 4m + n)/6 \quad (4)$$

Then, consistency should be checked by consistency index (CI) and consistency ratio (CR) by:

$$CI = (\lambda_{\max} - n)/(n - 1) \quad (5)$$

$$CR = CI/RI \quad (6)$$

where *RI* stands for random index and can be obtained from Table 4 (Golden et al., 1989).

When $CR \leq 0.1$, the matrix is ok with acceptable consistency. Otherwise, when $CR > 0.1$, it should be revised.

Step 4: Applying geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each indicator by (Hsieh et al., 2004) as follows:

$$\tilde{r}_i = \sqrt[n]{(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{ij})}, \\ \tilde{\omega}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1} \quad (7)$$

Here $\tilde{a}_{ij}$ refers to fuzzy comparison value of indicator i to j, $\tilde{r}_i$ stands for the geometric mean of fuzzy comparison value of indicator i to each indicator j, $(j = 1, 2, \cdots, n)$; $\tilde{\omega}_i$ is the fuzzy weight of the ith indicator, being indicated by a TFN, $\tilde{\omega}_i = (\omega_{i1}, \omega_{i2}, \omega_{i3})$, with $\omega_{i1}, \omega_{i2}, \omega_{i3}$ representing its lower, medium, and upper values.

The final fuzzy weight (FFW_i) of indicator I_i is computed by:

$$FFW_i = \tilde{\omega}_i \times \omega_{D_i} \quad (8)$$

where FFW_i, ω_{D_i} represent the final fuzzy weight of indicator I_i and weight of dimension D_i to which the indicator belongs.

3.4. F-TOPSIS

The basic idea of TOPSIS is: suppose there is a positive ideal solution (PIS) and a negative ideal solution (NIS) and we can determine the distance of each potential option to both of them. The one which is nearest to the PIS and furthest to the NIS is the final ideal solution. However, due to the vagueness existing in decision making process, it is usually difficult or impossible to obtain the crisp values. We are going to discuss the steps of F-TOPSIS in this section.

Step 1: Construct the fuzzy decision matrix and work out appropriate linguistic variables of all possible options with respect to each indicator. Suppose there are m indicators $I_u(u = 1, 2, \cdots, m)$, n potential options $O_v(v = 1, 2, \cdots, n)$ and K decision makers. The fuzzy decision matrix for the options and the indicators can be established as follows:

$$\tilde{D} = \begin{array}{c} \\ I_1 \\ I_2 \\ \vdots \\ I_u \end{array} \begin{array}{c} \begin{array}{cccc} O_1 & O_2 & \cdots & O_v \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \tilde{x}_{uv} & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array}, u = 1, 2, \cdots, m; v = 1, 2, \cdots, n \quad (9)$$

$$\tilde{x}_{uv} = \frac{1}{K}\sum_{k=1}^{K}\tilde{x}_{uv}^{k} \quad (10)$$

where $\tilde{x}_{uv}^{k}$ refers to the performance rating of option O_v with respect to indicator I_u given by decision maker k, and $\tilde{x}_{uv}^{k} = (a_{uv}^{k}, b_{uv}^{k}, c_{uv}^{k})$.

Step 2: Normalize the fuzzy decision matrix.

The normalized fuzzy decision matrix is given by:

$$\tilde{R} = [\tilde{r}_{uv}]_{m\times n}, u = 1, 2, \cdots, m; v = 1, 2, \cdots, n \quad (11)$$

where

$$\tilde{r}_{uv} = \left(\frac{a_{uv}}{c_v^*}, \frac{b_{uv}}{c_v^*}, \frac{c_{uv}}{c_v^*}\right), c_v^* = \max_u c_{uv} \quad \text{(For benefit indicators)}$$

$$\tilde{r}_{uv} = \left(\frac{a_v^-}{c_{uv}}, \frac{a_v^-}{b_{uv}}, \frac{a_v^-}{a_{uv}}\right), a_v^- = \min_u a_{uv} \quad \text{(For cost indicators)}$$

Step 3: Calculate the weighted normalized matrix.

$$\tilde{Q} = [\tilde{q}_{uv}]_{m\times n}, u = 1, 2, \cdots, m; v = 1, 2, \cdots, n and \tilde{q}_{uv} = \tilde{r}_{uv} \otimes \tilde{\omega}_u \quad (12)$$

Step 4: Calculate the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).

$$S^* = (\tilde{q}_1^*, \tilde{q}_2^*, \cdots, \tilde{q}_v^*) where \tilde{q}_v^* = \max_u \{q_{uv}\}, u = 1, 2, \cdots, m; v = 1, 2, \cdots, n \quad (13)$$

$$S^- = (\tilde{q}_1^-, \tilde{q}_2^-, \cdots, \tilde{q}_v^-) where \tilde{q}_v^- = \min_u \{q_{uv}\}, u = 1, 2, \cdots, m; v = 1, 2, \cdots, n \quad (14)$$

Step 5: Calculate the distance of each option to FPIS (d_v^*) and FNIS (d_v^-).

$$d_v^* = \sum_{u=1}^{m} d_q(\tilde{q}_{uv}, \tilde{q}_v^*), v = 1, 2, \cdots, n \quad (15)$$

$$d_v^- = \sum_{u=1}^{m} d_q(\tilde{q}_{uv}, \tilde{q}_v^-), v = 1, 2, \cdots, n \quad (16)$$

$$d_q(a, b) = \sqrt{\frac{1}{3}\sum_{u=1}^{m}(a_u - b_u)^2} \quad (17)$$

Step 6: Compute the closeness coefficient (CC_v) for each option.

$$CC_v = \frac{d_v^-}{d_v^- + d_v^*}, v = 1, 2, \cdots, n \quad (18)$$

Step 7: Rank the options.

Different options are ranked according to CC_v in decreasing order.

4. Improved approach to evaluate car sharing options

There are three steps in the improved approach to evaluate different car sharing options (as shown in Fig. 3).

Step 1: Indicator selection.

To evaluate car sharing options, the first and foremost thing is to select proper indicators. Based on previous studies, we propose five principles to identify appropriate indicators to evaluate car sharing options. These principles are: specific, comprehensive, understandable, measurable, and neutral (SCUMN). After an extensive literature review, we first identify the most frequently used indicators in sustainable transportation systems. Those repeated items and items that are not closely related to car sharing options are deleted and a final list of 24 indicators is obtained according to their relevance to car sharing options, as shown in Table 5.

It is noteworthy that we divide these indicators according to two types of criteria and they are independent of each other. The first division falls into two categories- cost and benefit while the second division falls into four dimensions- economic, environmental, car sharing system performance, and social dimension.

To normalize the fuzzy decision matrix in the application of F-TOPSIS, we divide the 24 indicators into two categories: cost and benefit. Cost indicators include public expenditure, operating cost, travel cost, and so on. For cost indicators, the lower the value, the better the option is. Benefit indicators include productivity, employment, tax revenues, and so on. For benefit indicators, the higher the value, the better the option is. It can be easily found that indicators I_4 to I_{13} are cost category indicators. That is to say, the lower the value, the better the option is with respect to these indicators. And indicators I_1 to I_3 and I_{14} to I_{24} belong to the benefit category, viz., the higher the value, the better the option is.

The reason of dividing them into four dimensions is to make pair-wise comparison of indicators easy to conduct. It is meaningless to compare two indicators from two different dimensions, for example, productivity from economic dimension and congestion from environmental dimension. As is known, AHP method is used in case of the maximum 15 criteria (Satty, 1980). More than 15 criteria will confuse the decision makers during comparison of the criteria. Therefore, we divide the 24 indicators into four dimensions, i.e., economic, environmental, car sharing system performance, and social dimension, based on (Gillis et al., 2015; Mihyeon Jeon and Amekudzi, 2005). There are 6 indicators for each of the dimensions. Then decision makers only need to compare six indicators within the same dimension at a time. And we assume the same weight

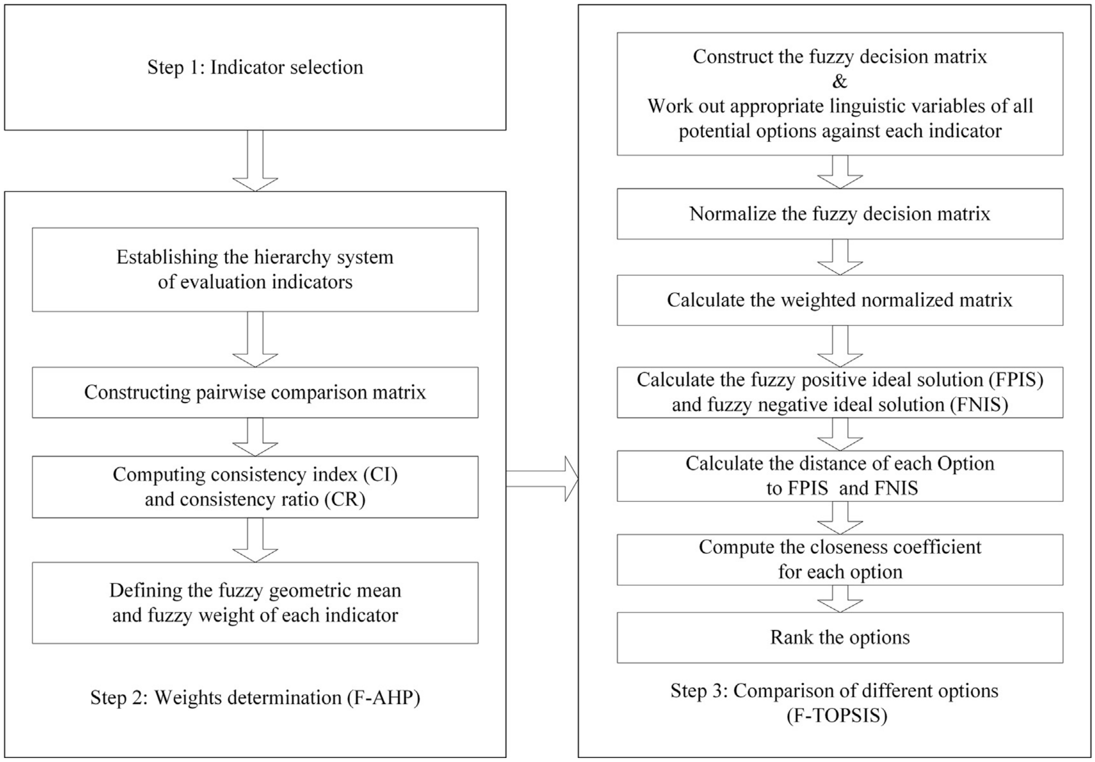

Fig. 3. The improved approach to evaluate car sharing options.

Table 5
Selected indicators for evaluation of car sharing options.

Dimension	Indicators	Definition	Category
Economic (D_1)	I_1: Productivity	Ability to accomplish performance targets	B
	I_2: Employment	Opportunities of being employed by the system	B
	I_3: Tax revenues	Tax revenues brought by the car sharing system	B
	I_4: Public expenditure	Public expenditure needed by the service system	C
	I_5: Operating cost	Costs for service provider to run the business, including maintenance, staff salary etc.	C
	I_6: Travel cost	Costs for customers to enjoy the service	C
Environmental (D_2)	I_7: Emissions of air pollutants	Emissions of air pollutants from cars and automobile manufacturing, including waste gases and toxic substances	C
	I_8: Energy consumption	Energy and fossil fuels consumed	C
	I_9: Noise level	Noise released from the car sharing system	C
	I_{10}: Land usage	Space used for stations and parking	C
	I_{11}: Congestion	Traffic jam	C
	I_{12}: Waste	End-of-life vehicles, tires and so forth.	C
Car sharing system performance (D_3)	I_{13}: Accidents	Accidents caused by different car sharing options	C
	I_{14}: Mobility	Mobility provided by the car sharing system	B
	I_{15}: System Reliability	Capability to perform the promised service dependably	B
	I_{16}: Service quality	Service quality supplied by the system	B
	I_{17}: Car utilization ratio	Percentage of actual driving hours of cars	B
	I_{18}: Reservation acceptance ratio	Reservations accepted over total number of reservations	B
Social (D_4)	I_{19}: Affordability	Affordability by lower income classes	B
	I_{20}: Public health	Reduce public exposure to emissions and noise	B
	I_{21}: Equity	Equity of the aged and handicapped citizens	B
	I_{22}: Access	Access to home, workplace, CBD and so on	B
	I_{23}: Customer satisfaction	Customers' satisfaction of service provided	B
	I_{24}: Safety	Safety offered by the car sharing option	B

B (benefit)—The higher, the better; C (cost)—The lower, the better.

for each dimension since it would be too complex to obtain a fair comparison of these four dimensions and it is beyond the scope of this study.

Step 2: Weights determination.

Apply F-AHP introduced in Section 3.3 to determine the weight of each selected indicator. Hierarchy system of evaluation indicators is established; then pair-wise comparison matrix is constructed and the matrix must pass consistency check by calculating consistency index and consistency ratio. Fuzzy weight of each indicator can be obtained as a result.

Step 3: Comparison of different options using selected indicators and F-TOPSIS.

Firstly, decision makers are invited to evaluate different options against each indicator. The option ratings are provided in Table 3.

Secondly, linguistic variables are transformed to TriFNs accordingly. Thirdly, F-TOPSIS is applied to calculate the closeness coefficient (CC_v) of each option. The one with the highest CC_v is chosen as the best car sharing option.

5. A case study

The goal of this case study is to identify key indicators to evaluate potential car sharing options of a pioneer car sharing company in China and determine the effect of indicators by conducting sensitivity analysis experiments. Twenty-four indicators are identified for the evaluation of car sharing options from four dimensions: economic, environmental, car sharing system performance, and social. It goes without saying that managers of car sharing companies care more about economic aspects of the system than sustainability. But in most cases, sustainability is not contradictory with the economic goal of a company. A more sustainable way of development aims at saving of resources and energy, and it usually results in reduction of operational costs of a company.

Decision makers play a decisive role in the process of weight determination of indicators and comparison of potential options. It is therefore of great significance to choose appropriate decision makers. We invite an experienced operational manager from a car sharing company, a professor with much experience in car sharing research and a senior system designer to participate in this study. To make it easier to conduct, we assume the same weight for each of the decision makers. That is to say, there is no apparent difference in their weights.

5.1. Background information

Company C was founded in September 2007, with its headquarters located in Beijing. It advocates the idea of "4-Anys" (Anyone, Any Time, Any Car, Anywhere). "Anyone" means that users can be anyone with a driver's license; "Any Time" refers to the simplified procedure and 24 h service provided; "Any Car" implies that customers can choose from more than 100 types of vehicles; "Anywhere" means a network of more than 1000 parking lots in nearly 200 cities of China. It has about 130,000 vehicles and a registration of nearly a million individual customers and thousands of corporate customers. As a pioneer in Chinese car sharing market, it provides different kinds of car sharing services, including rental, leasing, driving-for-you, piggy-backing, corporate-renting, and overseas renting, offering us an access to a car without purchasing, and providing a reliable, reasonable, flexible and eco-efficient alternative of car-owning. Besides, they also aid their customers with supporting services such as global position system (GPS) navigation and emergency rescue. With a focus on Chinese individual customers, this study mainly takes into account the former four kinds of services. And we suggest a more sustainable and economic way of sharing named "drive-sharing" for the company. Drive-sharing is also called "dynamic ride-sharing" in some cases and it is defined as "a system where an automated process employed by a ride-share provider matches up drivers and riders on very short notice, which can range from a few minutes to a few hours before departure time" (Agatz et al., 2011).

Rental is usually based on short-term agreements and targets for carless driver license owners. The advantages of rental include: customers can not only rent different types of cars, but also make the best use of their money. They only need to pay for the particular time period when a car is needed. Instead, a lease has a rather long period of time, for example, six months or a year, during which service providers and users should adhere to the agreement. Neither party can change any terms of car sharing agreement before the lease expires. Leasing is designed for companies, governmental institutions, and those who cannot afford to buy enough cars to meet the great demands and those who do not have a chance to purchase new cars due to governmental restrictions against car-purchasing in some big cities of China, such as Beijing. For a renting term longer than 6 months, the car-sharing company usually provides totally new cars and helps them to deal with taxes and insurances. Driving-for-you service aims at middle and high income customers, and it is totally different from taxies. Customers can make an order by calls, internet, or mobile application and experienced drivers will come to pick you up quite soon. Piggy-backing is the least expensive way of sharing a car and it is somewhat like drive-sharing. For one-way trips, cars will be returned in another city, calling for necessary reallocation to maintain a vehicle balance. If you happen to travel to their targeted reallocation destinations during a fixed time period, the company usually offers a great discount to achieve a win–win deal. For example, normally it takes 360 Chinese Yuan to rent an economy car from Shanghai to Hangzhou. In case of a piggy-backing deal, you only need to pay 100 Yuan, no more than a-third of the original price. However, customers usually cannot choose time and the car according to their own will in piggy-backing. Besides these options, the company may offer a more sustainable and way of car sharing, namely, drive-sharing in the future, in which users with the same destination share a car and the travel cost. It is more complex than other transportation modes in practice.

5.2. Weights determination by means of F-AHP

Step 1: Establish the hierarchy system of evaluation indicators. Fig. 4 displays the hierarchy system of the selected indicators to evaluate car sharing options.

Step 2: Construct pair-wise comparison matrix $\tilde{A}$ among all evaluation indicators in each dimension of the hierarchy structure. Invite 3 decision makers to assign linguistic variables to pair-wise comparisons by determining the one with more importance between the two indicators.

For example, as to the six indicators $I_1 - I_6$ in economic dimension, the following AHP matrixes of the 3 decision makers are constructed as follows:

$$A_{11} = \begin{array}{c} \\ I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{array} \begin{array}{c} \begin{array}{cccccc} I_1 & I_2 & I_3 & I_4 & I_5 & I_6 \end{array} \\ \begin{bmatrix} 1 & \tilde{7} & \tilde{3} & \tilde{9} & \tilde{5} & \tilde{6} \\ \tilde{7}^{-1} & 1 & \tilde{3}^{-1} & \tilde{2} & \tilde{4}^{-1} & \tilde{2}^{-1} \\ \tilde{3}^{-1} & \tilde{3} & 1 & \tilde{7} & \tilde{2} & \tilde{3} \\ \tilde{9}^{-1} & \tilde{2}^{-1} & \tilde{7}^{-1} & 1 & \tilde{5}^{-1} & \tilde{4}^{-1} \\ \tilde{5}^{-1} & \tilde{4} & \tilde{2}^{-1} & \tilde{5} & 1 & \tilde{2} \\ \tilde{6}^{-1} & \tilde{2} & \tilde{3}^{-1} & \tilde{4} & \tilde{2}^{-1} & 1 \end{bmatrix} \end{array} \quad A_{12} = \begin{array}{c} \\ I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{array} \begin{array}{c} \begin{array}{cccccc} I_1 & I_2 & I_3 & I_4 & I_5 & I_6 \end{array} \\ \begin{bmatrix} 1 & \tilde{7} & \tilde{2} & \tilde{8} & \tilde{3} & \tilde{4} \\ \tilde{7}^{-1} & 1 & \tilde{4}^{-1} & \tilde{3} & \tilde{3}^{-1} & \tilde{2}^{-1} \\ \tilde{2}^{-1} & \tilde{4} & 1 & \tilde{8} & \tilde{2} & \tilde{3} \\ \tilde{8}^{-1} & \tilde{3}^{-1} & \tilde{8}^{-1} & 1 & \tilde{6}^{-1} & \tilde{5}^{-1} \\ \tilde{3}^{-1} & \tilde{3} & \tilde{2}^{-1} & \tilde{6} & 1 & \tilde{3} \\ \tilde{4}^{-1} & \tilde{2} & \tilde{3}^{-1} & \tilde{5} & \tilde{3}^{-1} & 1 \end{bmatrix} \end{array} \quad A_{13} = \begin{array}{c} \\ I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{array} \begin{array}{c} \begin{array}{cccccc} I_1 & I_2 & I_3 & I_4 & I_5 & I_6 \end{array} \\ \begin{bmatrix} 1 & \tilde{6} & \tilde{2} & \tilde{9} & \tilde{4} & \tilde{5} \\ \tilde{6}^{-1} & 1 & \tilde{7}^{-1} & \tilde{2} & \tilde{6}^{-1} & \tilde{3}^{-1} \\ \tilde{2}^{-1} & \tilde{7} & 1 & \tilde{8} & \tilde{3} & \tilde{5} \\ \tilde{9}^{-1} & \tilde{2}^{-1} & \tilde{8}^{-1} & 1 & \tilde{6}^{-1} & \tilde{3}^{-1} \\ \tilde{4}^{-1} & \tilde{6} & \tilde{3}^{-1} & \tilde{6} & 1 & \tilde{4} \\ \tilde{5}^{-1} & \tilde{3} & \tilde{5}^{-1} & \tilde{3} & \tilde{4}^{-1} & 1 \end{bmatrix} \end{array}$$

Step 3: Compute consistency index (CI) and consistency ratio (CR).

To ensure the consistency of the constructed matrix, we should first convert a fuzzy number $\tilde{M}(l, m, n)$ to a crisp one by Eq. (4). Crisp values of pair-wise comparison matrixes as to indicators I_1–I_6 can be found in Appendix A.

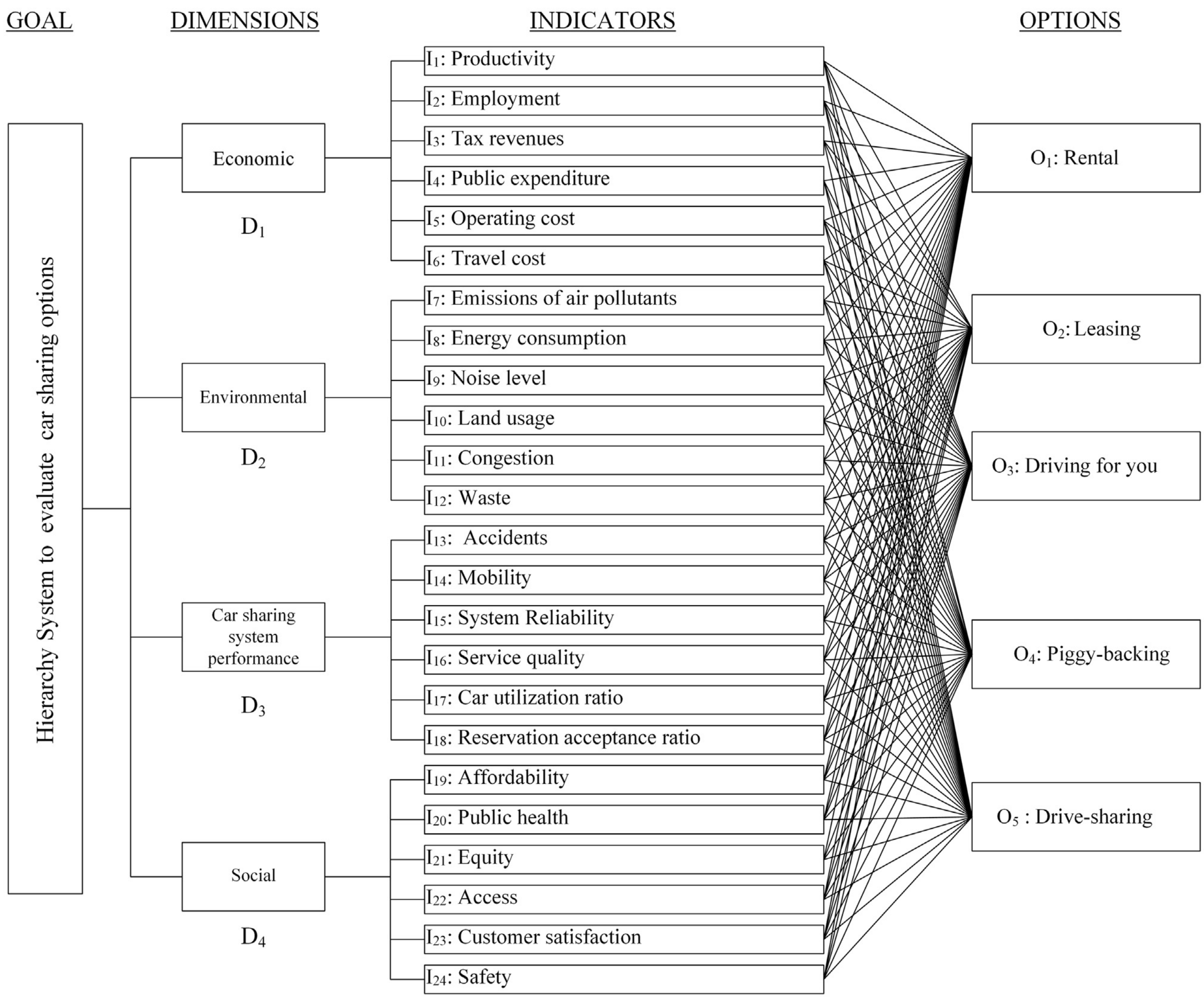

Fig. 4. Hierarchy system to evaluate car sharing options.

Then, consistency should be checked by consistency index (CI) and consistency ratio (CR) by Eq. (5)–(6). With the aid of MATLAB, it is easy to compute the maximum eigenvalue of A_{11}.

$$\lambda_{\max} = 6.3221$$

$$CI = (\lambda_{\max} - n)/(n-1) = (6.3221 - 6)/(6-1) = 0.0644$$

$$CR_{11} = CI/RI = 0.0644/1.24 = 0.052 < 0.1$$

Thus, we can conclude that the matrix is ok with acceptable consistency. Similarly, $CR_{12} = 0.082 < 0.1$, $CR_{13} = 0.095 < 0.1$.

Step 4: Apply geometric mean technique to define the fuzzy geometric mean and fuzzy weight of each indicator by: $\tilde{a}_{ij} = \sqrt[3]{\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \otimes \tilde{a}_{ij}^3}$, for instance:

$$\tilde{a}_{12} = (\tilde{a}_{12}^1 \otimes \tilde{a}_{12}^2 \otimes \tilde{a}_{12}^3)^{1/3} = [(5,7,9) \otimes (5,7,9) \otimes (4,6,8)]^{1/3}$$
$$= (5\times5\times4)^{1/3}, (7\times7\times6)^{1/3}, (9\times9\times8)^{1/3} = (4.642, 6.649, 8.653)$$

Other matrix elements can be obtained in the same way. Hence, the synthetic pair-wise comparison matrixes of the three decision makers for indicators I_1–I_6 can be constructed, as shown in Appendix B.

Using Eq. (7) to get the fuzzy weights of each indicator for the three decision makers, that is:

$$\tilde{r}_1 = \sqrt[6]{\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \tilde{a}_{13} \otimes \tilde{a}_{14} \otimes \tilde{a}_{15} \otimes \tilde{a}_{16}}$$
$$= \sqrt[6]{1 \times 4.642 \times 1.587 \times \cdots \times 2.884},$$
$$\sqrt[6]{1 \times 6.649 \times 2.289 \times \cdots 4.932},$$
$$\sqrt[6]{1 \times 8.653 \times 4.309 \times \cdots 6.952}$$
$$= (2.521, 3.695, 4.870)$$

Similarly, the remaining $\tilde{r}_i$ can be got as follows:

$$\tilde{r}_2 = (0.319, 0.450, 0.717); \tilde{r}_3 = (1.365, 2.218, 3.057)$$
$$\tilde{r}_4 = (0.203, 0.259, 0.369); \tilde{r}_5 = (0.753, 1.205, 1.868)$$
$$\tilde{r}_6 = (0.497, 0.749, 1.253)$$

The weight of each indicator can be obtained according to the following equation:

$$\tilde{\omega}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1}$$

Therefore,

$$\tilde{\omega}_1 = \tilde{r}_1 \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_6)^{-1-1} = [(2.521/(4.870 + 0.717 + \cdots + 1.253),$$
$$3.695/(3.695 + 0.450 + \cdots + 0.749), 4.870/(2.521 + 0.319 + \cdots + 0.497)]$$
$$= (0.208, 0.431, 0.860)$$

Likewise,

$$\tilde{\omega}_2 = (0.026, 0.052, 0.127); \tilde{\omega}_3 = (0.112, 0.259, 0.540)$$
$$\tilde{\omega}_4 = (0.017, 0.030, 0.065); \tilde{\omega}_5 = (0.062, 0.141, 0.330)$$
$$\tilde{\omega}_6 = (0.041, 0.087, 0.221)$$

Table 6
Fuzzy weights of indicators I_1–I_{24}.

Dimensions(weight)	Indicator	Fuzzy Weight $\tilde{\omega}_i$	Final Fuzzy Weight (FFW)
Economic (0.25)	I_1	(0.208,0.431,0.860)	(0.052,0.108,0.215)
	I_2	(0.026,0.052,0.127)	(0.007,0.013,0.032)
	I_3	(0.112,0.259,0.540)	(0.028,0.065,0.135)
	I_4	(0.017,0.030,0.065)	(0.004,0.008,0.016)
	I_5	(0.062,0.141,0.330)	(0.016,0.035,0.083)
	I_6	(0.041,0.087,0.221)	(0.010,0.022,0.055)
Environmental (0.25)	I_7	(0.210,0.413,0.826)	(0.053,0.103,0.207)
	I_8	(0.116,0.248,0.509)	(0.029,0.062,0.127)
	I_9	(0.039,0.086,0.202)	(0.010,0.022,0.051)
	I_{10}	(0.019,0.038,0.078)	(0.005,0.010,0.020)
	I_{11}	(0.066,0.160,0.340)	(0.017,0.040,0.085)
	I_{12}	(0.028,0.055,0.136)	(0.007,0.014,0.034)
Car sharing system Performance (0.25)	I_{13}	(0.204,0.394,0.819)	(0.051,0.099,0.205)
	I_{14}	(0.042,0.096,0.222)	(0.011,0.024,0.056)
	I_{15}	(0.027,0.055,0.139)	(0.007,0.014,0.035)
	I_{16}	(0.112,0.271,0.543)	(0.028,0.068,0.136)
	I_{17}	(0.018,0.036,0.084)	(0.005,0.009,0.021)
	I_{18}	(0.062,0.148,0.342)	(0.016,0.037,0.086)
Social (0.25)	I_{19}	(0.070,0.151,0.351)	(0.018,0.038,0.088)
	I_{20}	(0.017,0.031,0.070)	(0.004,0.008,0.018)
	I_{21}	(0.045,0.101,0.228)	(0.011,0.025,0.057)
	I_{22}	(0.026,0.056,0.125)	(0.007,0.014,0.031)
	I_{23}	(0.109,0.250,0.532)	(0.027,0.063,0.133)
	I_{24}	(0.202,0.412,0.826)	(0.051,0.103,0.207)

Table 7
Distances (d_v^*) and (d_v^-) for each option.

Indicator	(d_v^-)					(d_v^*)				
	O_1	O_2	O_3	O_4	O_5	O_1	O_2	O_3	O_4	O_5
I_1	0.095	0.117	0.070	0.116	0.130	0.148	0.132	0.164	0.136	0.123
I_2	0.017	0.015	0.018	0.018	0.018	0.021	0.023	0.019	0.022	0.022
I_3	0.075	0.069	0.075	0.074	0.074	0.082	0.085	0.082	0.086	0.088
I_4	0.003	0.009	0.003	0.005	0.006	0.013	0.011	0.013	0.012	0.011
I_5	0.015	0.047	0.013	0.017	0.013	0.071	0.060	0.072	0.069	0.072
I_6	0.005	0.007	0.004	0.019	0.032	0.051	0.049	0.051	0.044	0.039
I_7	0.025	0.030	0.018	0.025	0.118	0.184	0.181	0.189	0.184	0.147
I_8	0.013	0.013	0.011	0.016	0.073	0.115	0.115	0.116	0.113	0.090
I_9	0.011	0.013	0.008	0.011	0.029	0.043	0.041	0.044	0.043	0.035
I_{10}	0.003	0.005	0.003	0.005	0.011	0.017	0.016	0.017	0.016	0.014
I_{11}	0.013	0.018	0.015	0.015	0.049	0.073	0.071	0.072	0.072	0.058
I_{12}	0.009	0.012	0.008	0.019	0.012	0.026	0.025	0.027	0.023	0.025
I_{13}	0.041	0.041	0.114	0.049	0.061	0.169	0.169	0.143	0.164	0.158
I_{14}	0.029	0.032	0.032	0.027	0.031	0.036	0.034	0.036	0.040	0.038
I_{15}	0.018	0.019	0.020	0.019	0.019	0.023	0.023	0.022	0.024	0.024
I_{16}	0.068	0.069	0.076	0.074	0.074	0.087	0.085	0.079	0.085	0.086
I_{17}	0.010	0.011	0.011	0.009	0.012	0.014	0.013	0.014	0.015	0.013
I_{18}	0.050	0.049	0.045	0.038	0.049	0.054	0.056	0.057	0.062	0.058
I_{19}	0.031	0.043	0.027	0.052	0.053	0.067	0.060	0.069	0.055	0.053
I_{20}	0.009	0.008	0.006	0.008	0.011	0.012	0.013	0.014	0.013	0.011
I_{21}	0.026	0.029	0.032	0.026	0.032	0.039	0.038	0.035	0.039	0.035
I_{22}	0.016	0.017	0.018	0.012	0.018	0.020	0.020	0.018	0.023	0.020
I_{23}	0.061	0.068	0.075	0.074	0.075	0.089	0.084	0.081	0.084	0.082
I_{24}	0.107	0.106	0.119	0.115	0.113	0.127	0.131	0.118	0.130	0.138
$\sum I_u$	0.751	0.847	0.824	0.840	1.111	1.581	1.532	1.552	1.555	1.440

Table 6 shows the fuzzy weights of indicators I_{1-24} for the evaluation of car sharing options, which are obtained by F-AHP approach. It can be seen from Table 6 that among the 6 indicators in economic dimension, productivity ranks first, with tax revenues, operating cost, travel cost, employment, and public expenditure following one by one. It is noteworthy that we assume the same weight (0.25) to the four dimensions due to their relatively equal importance and the difficulty of deciding which one is more important than the others.

The final fuzzy weight (FFW) of indicator I_1 is computed by Eq. (8):

$$FFW_1 = \tilde{\omega}_1 \times 0.25 = (0.208, 0.431, 0.860) \times 0.25 = (0.052, 0.108, 0.215) .$$

In the similar manner, we can get final fuzzy weights of all other indicators. For the other three dimensions (D_2–D_4), the above steps are repeated and the final fuzzy weights for all selected indicators are listed in Table 6. Decision matrixes for D_2-D_4 can be found in Appendix C.

5.3. Comparison of different options using F-TOPSIS

Five different car-sharing options are compared with the aim to find out the best one. They are O_1: rental, O_2: leasing, O_3: driving-for-you, O_4: piggy-backing and O_5: drive-sharing respectively.

Step 1: Establish the fuzzy decision matrix and work out appropriate linguistic variables of all possible options with respect to each indicator. Linguistic assessments of three decision makers as to the five options can be found in Appendix D, according to linguistic variables listed in Table 3. This study makes use of average value to comprehend the fuzzy judgments values of the decision makers and the aggregate fuzzy decision matrix for the options can be constructed as Appendix E.

Step 2: Normalize the fuzzy decision matrix.

The normalized fuzzy decision matrix is given by Eq. (11). For example, the normalized rating for option O_1 as to indicator I_1 (productivity) which is a benefit one can be computed as:

$$c_1^* = \max_u(7.000, 8.333, 5.000, 8.333, 9.000) = 9.000$$

$$\tilde{r}_{11} = \left(\frac{a_{11}}{c_1^*}, \frac{b_{11}}{c_1^*}, \frac{c_{11}}{c_1^*}\right) = \left(\frac{3.000}{9.000}, \frac{5.000}{9.000}, \frac{7.000}{9.000}\right) = (0.333, 0.556, 0.778)$$

The normalized rating for option O_1 as to indicator I_4 (public expenditure) which is a cost one can be given by:

$$a_1^- = \min_u(4.333, 1.667, 4.333, 3.000, 2.333) = 1.667$$

$$\tilde{r}_{41} = \left(\frac{a_1^-}{c_{41}}, \frac{a_1^-}{b_{41}}, \frac{a_1^-}{a_{41}}\right) = \left(\frac{1.667}{8.333}, \frac{1.667}{6.333}, \frac{1.667}{4.333}\right) = (0.200, 0.263, 0.385)$$

Similarly, we can obtain the normalized values of the five options against the remaining indicators as presented in Appendix F.

Step 3: Compute the weighted normalized matrix by Eq. (12). We make use of the $\tilde{r}_{uv}$ values from Appendix F and FFW values from Table 6 to calculate the weighted normalized matrix for each option, as shown in Appendix G.

For example, the fuzzy weight of option O_1 against indicator I_1 (productivity) is given by:

$$\tilde{q}_{11} = \tilde{r}_{11} \otimes FFW_1 = (0.333, 0.556, 0.778) \otimes (0.052, 0.108, 0.215) = (0.017, 0.060, 0.167)$$

Likewise, we get the final fuzzy weights of all the options against the remaining indicators.

Step 4: Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) by Eq. (13)-(14) as shown in the last two columns of Appendix G.

Step 5: Calculate the distance of each option to FPIS (d_v^*) and FNIS(d_v^-)by Eq. (15)-(17).

For instance, for option O_1 and indicator I_1, the distances can be calculated as:

$$d_q(O_1, O^*) = \sqrt{\frac{1}{3}[(0.017-0.215)^2 + (0.060-0.215)^2 + (0.167-0.215)^2]} = 0.148$$

$$d_q(O_1, O^-) = \sqrt{\frac{1}{3}[(0.017-0.010)^2 + (0.060-0.010)^2 + (0.167-0.010)^2]} = 0.095$$

Table 8
Closeness coefficient (CC_v) of the five options.

	O_1	O_2	O_3	O_4	O_5
(d_v^-)	0.751	0.847	0.824	0.840	1.111
(d_v^*)	1.581	1.532	1.552	1.555	1.440
(CC_v)	0.322	0.356	0.347	0.351	0.435

Similarly, we can get the distances of each option from FPIS (d_v^*) and FNIS (d_v^-) as to the remaining indicators (Table 7).

For example, for option O_1 and indicators $I_{1–24}$, the distances (d_1^*) and (d_1^-) can be got as follows:

$$d_1^* = \sqrt{\frac{1}{3}[((0.017-0.215)^2 + (0.060-0.215)^2 + (0.167-0.215)^2} + \sqrt{\frac{1}{3}[(0.004-0.032)^2 + (0.010-0.032)^2 + (0.030-0.032)^2} + \cdots + \sqrt{\frac{1}{3}(0.028-0.207)^2 + (0.080-0.207)^2 + (0.192-0.207)^2} = 1.581$$

$$d_1^- = \sqrt{\frac{1}{3}[(0.017-0.010)^2 + (0.060-0.010)^2 + (0.167-0.010)^2} + \sqrt{\frac{1}{3}[(0.004-0.002)^2 + (0.010-0.002)^2 + (0.030-0.002)^2} + \cdots + \sqrt{\frac{1}{3}(0.028-0.017)^2 + (0.080-0.017)^2 + (0.192-0.017)^2} = 0.751$$

Step 6: Compute the closeness coefficient (CC_v) by Eq. (18) for each option.

With application of distances (d_v^*) and (d_v^-), we can calculate the closeness coefficient of the options. For example, the closeness coefficient of option O_1 is given by:

$$CC_1 = \frac{d_1^-}{d_1^- + d_1^*} = \frac{0.751}{0.751 + 1.581} = 0.322$$

Similarly, CC_v for options $O_{2–5}$ are calculated as presented in Table 8.

Step 7: Rank the options.

Different options are ranked according to their CC_v in decreasing order ($O_5 \succ O_2 \succ O_4 \succ O_3 \succ O_1$). Therefore, O_5: drive-sharing is the best car sharing option while O_1: rental is the worst one.

5.4. Sensitivity analysis

In order to find out the sensitivity of decision making process to slight changes in individual weights, sensitivity analysis experiments are conducted. The values of the weights are changed slightly to figure out their influence on the final decision. Under uncertain conditions, sensitivity analysis is particularly useful in determining indicator weights and choosing appropriate car sharing option.

Thirty-one experiments are conducted and Appendix H demonstrates the details of the 31 experiments. In the first 5 experiments, we set the same weights for all indicators, i.e. 1, 3, 5, 7, and 9 respectively. In experiments 6–29, the weight of one indicator is set to be the highest (9) one by one while the others are set to be the lowest (1), with the aim to find out the effect of slight changes of each indicator in the process of decision making. Then, in experiment 30, we set the weights of benefit indicators as the highest (9) and those of cost indicators to be lowest (1). In experiments 31, we set the weights of benefit indicators as the lowest (1) and those of cost

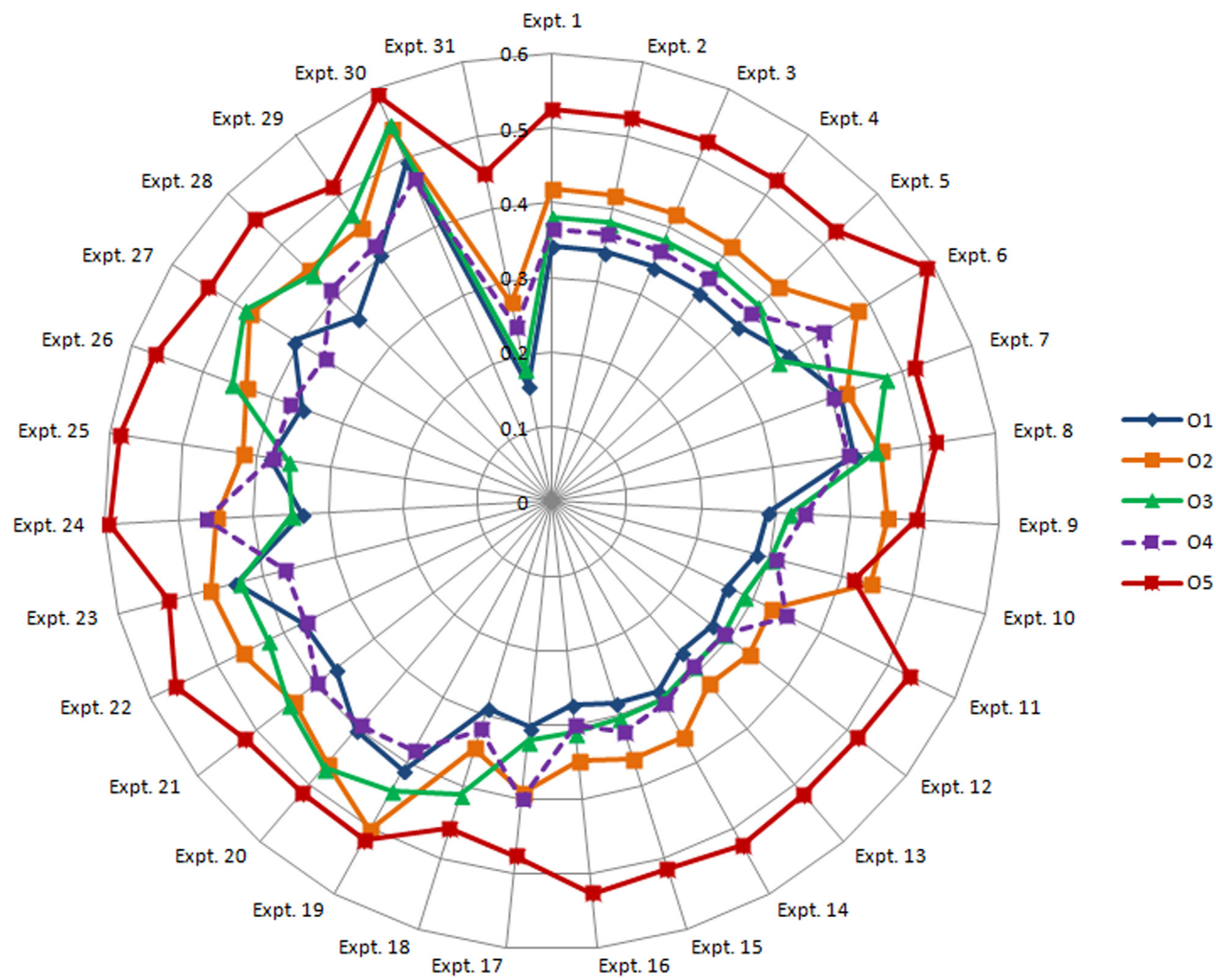

Fig. 5. Results of sensitivity analysis experiments.

indicators to be highest (9). Fig. 5 displays the results of sensitivity analysis. We can easily find that out of the 31 experiments, option O_5: drive-sharing has the highest score in all of the experiments, showing that drive-sharing is definitely the best way of car sharing. Option O_2: leasing is better than O_3: driving-for-you in 23 experiments at a ratio of 74.19%. Option O_1: rental has the least score in 21 experiments, showing that it is the worst car sharing option. Therefore, we can safely arrive at the conclusion that option O_5: drive-sharing can be recommended as the best car sharing mode from a comprehensive point of view. Besides, in the current operational system of CAR Inc., there are four options, namely, rental, leasing, driving for you, and piggy-backing. They do not offer drive-sharing at the present time. Among the four transportation modes, Option O_2: leasing performs better than the other three modes in 21 experiments, demonstrating its dominant advantage in current operational systems of Company C.

6. Conclusions

We develop an improved approach to evaluate car sharing options with application of F-AHP and F-TOPSIS under uncertain environments. There are three steps in the approach. In step 1, appropriate indicators of car sharing options are identified from four dimensions, economic, environmental, car sharing system performance, and social dimension. And we divide these indicators into two categories with an aim to normalize the fuzzy decision matrix, viz., cost category and benefit category. For cost category, the lower the value, the better the option; for benefit category, the higher the value, the better the option is. Indicators I_{1-3} and I_{14-24} belong to benefit category while the others (I_{4-13}) are cost ones. In step 2, decision makers are asked to compare the indicators in terms of linguistic variables and the weight for each indicator is settled by means of F-AHP. In step 3, we invite the decision makers to compare different options and rank them with the aid of F-TOPSIS. Then we perform a case study to show the applicability of the proposed framework and conduct sensitivity analysis experiments to figure out the effect of indicators on decision making process.

The approach is capable of evaluating car sharing options with uncertainty and vagueness. It helps managers of car sharing companies and customers in their decision making process. F-AHP demonstrates its advantage over determining the weight for each selected indicator while F-TOPSIS is useful to compare different options and rank them according to their distance to positive ideal solution and negative ideal solution. It is of vital importance to choose the experienced decision makers and appropriate indicators in order to make the right choice. However, the improved approach also has some limitations. Firstly, detailed information of the five proposed options is not considered, for example, construction and distribution of stations/parking lots; vehicles relocation strategies to maintain balance; influence of mobile technologies on car sharing systems, and so on. Secondly, three decision makers are invited to participate in this study mainly for research purpose. In actual industrial practices, three decision makers are far from enough and decisions are usually made by board of directors in most cases, who are not so concerned about sustainability. Thirdly, we assume the same weight for these decision makers and the four dimensions. Actually, this may not represent the real case very well. Last but not least, it calls for the cooperation of people from all walks of life and a thorough change in their consuming habits from ownership to sharing in order to implement a car sharing system successfully. The improved approach did not address these conflicts. Research can be conducted in the future to handle the above-mentioned issues.

Acknowledgements

This research was funded by National Key Technology R&D Program, China (Grant No. 2015BAH21F01) and the 111 Project, Grant No.B13044. The authors really appreciate the support of Company C for providing us first-hand data and opportunity to conduct case study. However, all views and comments presented in this paper do not represent the company and belong only to the authors. Many thanks also go to Felix Mueller, Co-Editor-in-Chief and the anonymous referees for their valuable comments.

Appendix A.

Crisp values of pair-wise comparison matrixes as to indicators I_1–I_6.

I	Decision maker 1(CR_1 = 0.052)						Decision maker 2(CR_2 = 0.082)						Decision maker 3(CR_3 = 0.095)					
	I_1	I_2	I_3	I_4	I_5	I_6	I_1	I_2	I_3	I_4	I_5	I_6	I_1	I_2	I_3	I_4	I_5	I_6
I_1	1.000	7.000	3.000	8.667	5.000	6.000	1.000	7.000	2.333	7.667	3.000	4.000	1.000	6.000	2.333	8.667	4.000	5.000
I_2	0.147	1.000	0.422	2.333	0.278	0.458	0.147	1.000	0.278	3.000	0.422	0.458	0.174	1.000	0.147	2.333	0.174	0.422
I_3	0.422	3.000	1.000	7.000	2.333	3.000	0.458	4.000	1.000	7.667	2.333	3.000	0.458	7.000	1.000	7.667	3.000	5.000
I_4	0.116	0.458	0.147	1.000	0.213	0.278	0.132	0.422	0.132	1.000	0.174	0.213	0.116	0.458	0.132	1.000	0.174	0.422
I_5	0.213	4.000	0.458	0.422	1.000	2.333	0.422	3.000	0.458	6.000	1.000	3.000	0.278	6.000	0.422	6.000	1.000	4.000
I_6	0.174	2.333	0.422	4.000	0.458	1.000	0.278	2.333	0.422	5.000	0.422	1.000	0.213	3.000	0.213	3.000	0.278	1.000

Appendix B.

Synthetic pair-wise comparison matrix of decision makers for indicators I_1–I_6.

	I_1	I_2	I_3	I_4	I_5	I_6
I_1	(1.000,1.000,1.000)	(4.642,6.649,8.653)	(1.587,2.289,4.309)	(6.649,8.653,8.653)	(1.817,3.915,5.944)	(2.884,4.932,6.952)
I_2	(0.116,0.150,0.215)	(1.000,1.000,1.000)	(0.155,0.228,0.646)	(1.587,2.289,4.309)	(0.161,0.240,0.500)	(0.232,0.437,0.630)
I_3	(0.232,0.437,0.630)	(2.154,4.380,6.463)	(1.000,1.000,1.000)	(5.646,7.652,8.320)	(1.587,2.289,4.309)	(1.442,3.557,5.593)
I_4	(0.116,0.116,0.150)	(0.232,0.437,0.630)	(0.120,0.131,0.177)	(1.000,1.000,1.000)	(0.131,0.177,0.275)	(0.168,0.255,0.550)
I_5	(0.168,0.255,0.550)	(2.000,4.160,6.214)	(0.232,0.437,0.630)	(1.474,2.289,4.000)	(1.000,1.000,1.000)	(1.587,2.884,4.932)
I_6	(0.144,0.203,0.347)	(1.587,2.289,4.309)	(0.179,0.281,0.693)	(1.817,3.915,5.944)	(0.203,0.347,0.630)	(1.000,1.000,1.000)

Appendix C.

Pair-wise comparison matrix of all selected indicators.

D	I	Decision maker 1 (CR_{11} = 0.052)						Decision maker 2 (CR_{12} = 0.082)						Decision maker 3 (CR_{13} = 0.095)					
		I_1	I_2	I_3	I_4	I_5	I_6	I_1	I_2	I_3	I_4	I_5	I_6	I_1	I_2	I_3	I_4	I_5	I_6
D_1	I_1	1	$\tilde{7}$	$\tilde{3}$	$\tilde{9}$	$\tilde{5}$	$\tilde{6}$	1	$\tilde{7}$	$\tilde{2}$	$\tilde{8}$	$\tilde{3}$	$\tilde{4}$	1	$\tilde{6}$	$\tilde{2}$	$\tilde{9}$	$\tilde{4}$	$\tilde{5}$
	I_2	$\tilde{7}^{-1}$	1	$\tilde{3}^{-1}$	$\tilde{2}$	$\tilde{4}^{-1}$	$\tilde{2}^{-1}$	$\tilde{7}^{-1}$	1	$\tilde{4}^{-1}$	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{2}^{-1}$	$\tilde{6}^{-1}$	1	$\tilde{7}^{-1}$	$\tilde{2}$	$\tilde{6}^{-1}$	$\tilde{3}^{-1}$
	I_3	$\tilde{3}^{-1}$	$\tilde{3}$	1	$\tilde{7}$	$\tilde{2}$	$\tilde{3}$	$\tilde{2}^{-1}$	$\tilde{4}$	1	$\tilde{8}$	$\tilde{2}$	$\tilde{3}$	$\tilde{2}^{-1}$	$\tilde{7}$	1	$\tilde{8}$	$\tilde{3}$	$\tilde{5}$
	I_4	$\tilde{9}^{-1}$	$\tilde{2}^{-1}$	$\tilde{7}^{-1}$	1	$\tilde{5}^{-1}$	$\tilde{4}^{-1}$	$\tilde{8}^{-1}$	$\tilde{3}^{-1}$	$\tilde{8}^{-1}$	1	$\tilde{6}^{-1}$	$\tilde{5}^{-1}$	$\tilde{9}^{-1}$	$\tilde{2}^{-1}$	$\tilde{8}^{-1}$	1	$\tilde{6}^{-1}$	$\tilde{3}^{-1}$
	I_5	$\tilde{5}^{-1}$	$\tilde{4}$	$\tilde{2}^{-1}$	$\tilde{5}$	1	$\tilde{2}$	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{2}^{-1}$	$\tilde{6}$	1	$\tilde{3}$	$\tilde{4}^{-1}$	$\tilde{6}$	$\tilde{3}^{-1}$	$\tilde{6}$	1	$\tilde{4}$
	I_6	$\tilde{6}^{-1}$	$\tilde{2}$	$\tilde{3}^{-1}$	$\tilde{4}$	$\tilde{2}^{-1}$	1	$\tilde{4}^{-1}$	$\tilde{2}$	$\tilde{3}^{-1}$	$\tilde{5}$	$\tilde{3}^{-1}$	1	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{4}^{-1}$	1

		Decision maker 1 (CR_{21} = 0.028)						Decision maker 2 (CR_{22} = 0.058)						Decision maker 3 (CR_{23} = 0.065)					
		I_7	I_8	I_9	I_{10}	I_{11}	I_{12}	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}
D_2	I_7	1	$\tilde{2}$	$\tilde{7}$	$\tilde{9}$	$\tilde{5}$	$\tilde{8}$	1	$\tilde{1}$	$\tilde{4}$	$\tilde{8}$	$\tilde{3}$	$\tilde{6}$	1	$\tilde{2}$	$\tilde{5}$	$\tilde{7}$	$\tilde{4}$	$\tilde{6}$
	I_8	$\tilde{2}^{-1}$	1	$\tilde{4}$	$\tilde{7}$	$\tilde{2}$	$\tilde{5}$	$\tilde{1}^{-1}$	1	$\tilde{2}$	$\tilde{6}$	$\tilde{1}$	$\tilde{4}$	$\tilde{2}^{-1}$	1	$\tilde{3}$	$\tilde{6}$	$\tilde{2}$	$\tilde{4}$
	I_9	$\tilde{7}^{-1}$	$\tilde{4}^{-1}$	1	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{2}$	$\tilde{4}^{-1}$	$\tilde{2}^{-1}$	1	$\tilde{2}$	$\tilde{2}^{-1}$	$\tilde{3}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	1	$\tilde{3}$	$\tilde{2}^{-1}$	$\tilde{1}$
	I_{10}	$\tilde{9}^{-1}$	$\tilde{7}^{-1}$	$\tilde{3}^{-1}$	1	$\tilde{4}^{-1}$	$\tilde{2}^{-1}$	$\tilde{8}^{-1}$	$\tilde{6}^{-1}$	$\tilde{2}^{-1}$	1	$\tilde{5}^{-1}$	$\tilde{1}^{-1}$	$\tilde{7}^{-1}$	$\tilde{6}^{-1}$	$\tilde{3}^{-1}$	1	$\tilde{5}^{-1}$	$\tilde{2}^{-1}$
	I_{11}	$\tilde{5}^{-1}$	$\tilde{2}^{-1}$	$\tilde{3}$	$\tilde{4}$	1	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	$\tilde{2}$	$\tilde{5}$	1	$\tilde{4}$	$\tilde{4}^{-1}$	$\tilde{2}^{-1}$	$\tilde{2}$	$\tilde{5}$	1	$\tilde{3}$
	I_{12}	$\tilde{8}^{-1}$	$\tilde{5}^{-1}$	$\tilde{2}^{-1}$	$\tilde{2}$	$\tilde{3}^{-1}$	1	$\tilde{6}^{-1}$	$\tilde{4}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{4}^{-1}$	1	$\tilde{6}^{-1}$	$\tilde{4}^{-1}$	$\tilde{1}^{-1}$	$\tilde{2}$	$\tilde{3}^{-1}$	1

		Decision maker 1 (CR_{31} = 0.068)						Decision maker 2 (CR_{32} = 0.092)						Decision maker 3 (CR_{33} = 0.1)					
		I_{13}	I_{14}	I_{15}	I_{16}	I_{17}	I_{18}	I_{13}	I_{14}	I_{15}	I_{16}	I_{17}	I_{18}	I_{13}	I_{14}	I_{15}	I_{16}	I_{17}	I_{18}
D_3	I_{13}	1	$\tilde{6}$	$\tilde{8}$	$\tilde{2}$	$\tilde{9}$	$\tilde{4}$	1	$\tilde{5}$	$\tilde{7}$	$\tilde{2}$	$\tilde{8}$	$\tilde{3}$	1	$\tilde{4}$	$\tilde{6}$	$\tilde{1}$	$\tilde{7}$	$\tilde{2}$
	I_{14}	$\tilde{6}^{-1}$	1	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{4}$	$\tilde{2}^{-1}$	$\tilde{5}^{-1}$	1	$\tilde{2}$	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{4}^{-1}$	1	$\tilde{4}$	$\tilde{4}^{-1}$	$\tilde{5}$	$\tilde{2}^{-1}$
	I_{15}	$\tilde{8}^{-1}$	$\tilde{3}^{-1}$	1	$\tilde{4}^{-1}$	$\tilde{2}$	$\tilde{3}^{-1}$	$\tilde{7}^{-1}$	$\tilde{2}^{-1}$	1	$\tilde{3}^{-1}$	$\tilde{1}$	$\tilde{2}^{-1}$	$\tilde{6}^{-1}$	$\tilde{4}^{-1}$	1	$\tilde{5}^{-1}$	$\tilde{3}$	$\tilde{3}^{-1}$
	I_{16}	$\tilde{2}^{-1}$	$\tilde{3}$	$\tilde{4}$	1	$\tilde{7}$	$\tilde{2}$	$\tilde{2}^{-1}$	$\tilde{5}$	$\tilde{3}$	1	$\tilde{6}$	$\tilde{3}$	$\tilde{1}^{-1}$	$\tilde{4}$	$\tilde{5}$	1	$\tilde{5}$	$\tilde{2}$
	I_{17}	$\tilde{9}^{-1}$	$\tilde{4}^{-1}$	$\tilde{2}^{-1}$	$\tilde{7}^{-1}$	1	$\tilde{5}^{-1}$	$\tilde{8}^{-1}$	$\tilde{3}^{-1}$	$\tilde{1}^{-1}$	$\tilde{6}^{-1}$	1	$\tilde{4}^{-1}$	$\tilde{7}^{-1}$	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	1	$\tilde{3}^{-1}$
	I_{18}	$\tilde{4}^{-1}$	$\tilde{2}$	$\tilde{3}$	$\tilde{2}^{-1}$	$\tilde{5}$	1	$\tilde{3}^{-1}$	$\tilde{3}$	$\tilde{2}$	$\tilde{3}^{-1}$	$\tilde{4}$	1	$\tilde{2}^{-1}$	$\tilde{2}$	$\tilde{3}$	$\tilde{2}^{-1}$	$\tilde{3}$	1

		Decision maker 1 (CR_{41} = 0.064)						Decision maker 2 (CR_{42} = 0.079)						Decision maker 3 (CR_{43} = 0.078)					
		I_{19}	I_{20}	I_{21}	I_{22}	I_{23}	I_{24}	I_{19}	I_{20}	I_{21}	I_{22}	I_{23}	I_{24}	I_{19}	I_{20}	I_{21}	I_{22}	I_{23}	I_{24}
D_4	I_{19}	1	$\tilde{5}$	$\tilde{2}$	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{4}^{-1}$	1	$\tilde{4}$	$\tilde{1}$	$\tilde{2}$	$\tilde{1}^{-1}$	$\tilde{3}^{-1}$	1	$\tilde{6}$	$\tilde{2}$	$\tilde{4}$	$\tilde{2}^{-1}$	$\tilde{2}^{-1}$
	I_{20}	$\tilde{5}^{-1}$	1	$\tilde{4}^{-1}$	$\tilde{2}^{-1}$	$\tilde{7}^{-1}$	$\tilde{9}^{-1}$	$\tilde{4}^{-1}$	1	$\tilde{5}^{-1}$	$\tilde{3}^{-1}$	$\tilde{6}^{-1}$	$\tilde{8}^{-1}$	$\tilde{6}^{-1}$	1	$\tilde{4}^{-1}$	$\tilde{3}^{-1}$	$\tilde{8}^{-1}$	$\tilde{7}^{-1}$
	I_{21}	$\tilde{2}^{-1}$	$\tilde{4}$	1	$\tilde{2}$	$\tilde{4}^{-1}$	$\tilde{6}^{-1}$	$\tilde{1}^{-1}$	$\tilde{5}$	1	$\tilde{3}$	$\tilde{3}^{-1}$	$\tilde{5}^{-1}$	$\tilde{2}^{-1}$	$\tilde{4}$	1	$\tilde{2}$	$\tilde{3}^{-1}$	$\tilde{4}^{-1}$
	I_{22}	$\tilde{3}^{-1}$	$\tilde{2}$	$\tilde{2}^{-1}$	1	$\tilde{5}^{-1}$	$\tilde{8}^{-1}$	$\tilde{2}^{-1}$	$\tilde{3}$	$\tilde{3}^{-1}$	1	$\tilde{4}^{-1}$	$\tilde{7}^{-1}$	$\tilde{4}^{-1}$	$\tilde{3}$	$\tilde{2}^{-1}$	1	$\tilde{6}^{-1}$	$\tilde{6}^{-1}$
	I_{23}	$\tilde{3}$	$\tilde{7}$	$\tilde{4}$	$\tilde{5}$	1	$\tilde{2}^{-1}$	$\tilde{1}$	$\tilde{6}$	$\tilde{3}$	$\tilde{4}$	1	$\tilde{2}^{-1}$	$\tilde{2}$	$\tilde{8}$	$\tilde{3}$	$\tilde{6}$	1	$\tilde{3}^{-1}$
	I_{24}	$\tilde{4}$	$\tilde{9}$	$\tilde{6}$	$\tilde{8}$	$\tilde{2}$	1	$\tilde{3}$	$\tilde{8}$	$\tilde{5}$	$\tilde{7}$	$\tilde{2}$	1	$\tilde{2}$	$\tilde{7}$	$\tilde{4}$	$\tilde{6}$	$\tilde{3}$	1

Appendix D.

Linguistic assessments of the five options.

Indicator	Options														
	O_1			O_2			O_3			O_4			O_5		
	No. of Decision maker			No. of Decision maker			No. of Decision maker			No. of Decision maker			No. of Decision maker		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
I_1	P	F	G	VG	G	F	P	F	VP	G	G	F	VG	G	VG
I_2	G	VG	F	F	P	VP	VG	G	VG	P	F	P	VP	P	F
I_3	VG	G	G	G	F	VG	VG	G	G	F	F	G	P	G	F
I_4	G	F	G	P	VP	F	F	G	G	P	G	F	P	VP	G
I_5	F	G	VG	P	P	F	G	VG	G	F	G	G	VG	G	G
I_6	VG	G	G	F	G	G	VG	VG	G	F	P	P	VP	VP	P
I_7	F	G	G	F	F	G	G	G	VG	F	G	G	P	VP	P
I_8	F	G	VG	G	F	VG	G	VG	G	G	F	G	P	P	VP
I_9	G	F	G	F	G	F	G	VG	G	G	F	G	VP	F	P
I_{10}	VG	G	F	G	F	F	G	G	VG	G	F	F	P	P	F
I_{11}	G	VG	G	G	F	G	VG	G	F	VG	G	F	F	P	VP
I_{12}	F	VG	VG	G	G	F	VG	G	VG	P	F	G	G	F	G
I_{13}	G	F	G	G	G	F	P	F	P	F	G	F	P	F	G
I_{14}	G	VG	F	VG	VG	G	G	F	G	VP	P	F	P	F	P
I_{15}	F	G	VG	G	G	F	VG	G	VG	P	F	VP	VP	P	F
I_{16}	G	G	F	F	G	VG	VG	VG	G	F	G	G	G	F	F
I_{17}	F	F	G	G	VG	F	F	P	G	P	G	F	VG	G	G
I_{18}	G	VG	G	G	F	G	G	G	F	P	VP	F	P	F	F
I_{19}	P	P	F	F	G	F	VP	F	P	G	VG	G	VG	VG	G
I_{20}	F	G	F	F	P	G	P	VP	G	G	F	P	G	VG	VG
I_{21}	F	F	G	G	G	F	VG	VG	G	F	G	F	VG	G	VG
I_{22}	G	G	F	G	VG	F	VG	G	VG	P	F	VP	P	F	G
I_{23}	G	F	F	F	G	VG	VG	G	G	G	F	G	F	G	VG
I_{24}	F	G	VG	G	G	F	VG	G	VG	F	G	F	P	VP	F

Appendix E.

Aggregate fuzzy decision matrix of decision makers as to the five options.

Indicator	O_1			O_2			O_3			O_4			O_5		
	O_{1a}	O_{1b}	O_{1c}	O_{2a}	O_{2b}	O_{2c}	O_{3a}	O_{3b}	O_{3c}	O_{4a}	O_{4b}	O_{4c}	O_{5a}	O_{5b}	O_{5c}
I_1	3.000	5.000	7.000	5.000	7.000	8.333	1.667	3.000	5.000	4.333	6.333	8.333	6.333	8.333	9.000
I_2	5.000	7.000	8.333	1.667	3.000	5.000	6.333	8.333	9.000	1.667	3.667	5.667	1.667	3.000	5.000
I_3	5.667	7.667	9.000	5.000	7.000	8.333	5.667	7.667	9.000	3.667	5.667	7.667	3.000	5.000	7.000
I_4	4.333	6.333	8.333	1.667	3.000	5.000	4.333	6.333	8.333	3.000	5.000	7.000	2.333	3.667	5.667
I_5	5.000	7.000	8.333	1.667	3.667	5.667	5.667	7.667	9.000	4.333	6.333	8.333	5.667	7.667	9.000
I_6	5.667	7.667	9.000	4.333	6.333	8.333	6.333	8.333	9.000	1.667	3.667	5.667	1.000	1.667	3.667
I_7	4.333	6.333	8.333	3.667	5.667	7.667	5.667	7.667	9.000	4.333	6.333	8.333	1.000	2.333	4.333
I_8	5.000	7.000	8.333	5.000	7.000	8.333	5.667	7.667	9.000	4.333	6.333	8.333	1.000	2.333	4.333
I_9	4.333	6.333	8.333	3.667	5.667	7.667	5.667	7.667	9.000	4.333	6.333	8.333	1.667	3.000	5.000
I_{10}	5.000	7.000	8.333	3.667	5.667	7.667	5.667	7.667	9.000	3.667	5.667	7.667	1.667	3.667	5.667
I_{11}	5.667	7.667	9.000	4.333	6.333	8.333	5.000	7.000	8.333	5.000	7.000	8.333	1.667	3.000	5.000
I_{12}	5.667	7.667	8.333	4.333	6.333	8.333	6.333	8.333	9.000	3.000	5.000	7.000	4.333	6.333	8.333
I_{13}	4.333	6.333	8.333	4.333	6.333	8.333	1.667	3.667	5.667	3.667	5.667	7.667	3.000	5.000	7.000
I_{14}	5.000	7.000	8.333	6.333	8.333	9.000	4.333	6.333	8.333	1.667	3.000	5.000	1.667	3.667	5.667
I_{15}	5.000	7.000	8.333	4.333	6.333	8.333	6.333	8.333	9.000	1.667	3.000	5.000	1.667	3.000	5.000
I_{16}	4.333	6.333	8.333	5.000	7.000	8.333	6.333	8.333	9.000	4.333	6.333	8.333	3.667	5.667	7.667
I_{17}	3.667	5.667	7.667	5.000	7.000	8.333	3.000	5.000	7.000	3.000	5.000	7.000	5.667	7.667	9.000
I_{18}	5.667	7.667	9.000	4.333	6.333	8.333	4.333	6.333	8.333	1.667	3.000	5.000	2.333	4.333	6.333
I_{19}	1.667	3.667	5.667	3.667	5.667	7.667	1.667	3.000	5.000	5.667	7.667	9.000	6.333	8.333	9.000
I_{20}	3.667	5.667	7.667	3.000	5.000	7.000	2.333	3.667	5.667	3.000	5.000	7.000	6.333	8.333	9.000
I_{21}	3.667	5.667	7.667	4.333	6.333	8.333	6.333	8.333	9.000	3.667	5.667	7.667	6.333	8.333	9.000
I_{22}	4.333	6.333	8.333	5.000	7.000	8.333	6.333	8.333	9.000	1.667	3.000	5.000	3.000	5.000	7.000
I_{23}	3.667	5.667	7.667	5.000	7.000	8.333	5.667	7.667	9.000	4.333	6.333	8.333	5.000	7.000	8.333
I_{24}	5.000	7.000	8.333	4.333	6.333	8.333	6.333	8.333	9.000	3.667	5.667	7.667	1.667	3.000	5.000

O_{1a}, O_{1b}, O_{1c} stand for the lower, medium, and upper limits of the fuzzy number respectively.

Appendix F.

Normalized fuzzy decision matrix.

Indicator	O_1			O_2			O_3			O_4			O_5		
	O_{1a}	O_{1b}	O_{1c}	O_{2a}	O_{2b}	O_{2c}	O_{3a}	O_{3b}	O_{3c}	O_{4a}	O_{4b}	O_{4c}	O_{5a}	O_{5b}	O_{5c}
I_1	0.333	0.556	0.778	0.556	0.778	0.926	0.200	0.360	0.600	0.481	0.704	0.926	0.704	0.926	1.000
I_2	0.556	0.778	0.926	0.294	0.529	0.882	0.704	0.926	1.000	0.294	0.647	1.000	0.333	0.600	1.000
I_3	0.630	0.852	1.000	0.556	0.778	0.926	0.630	0.852	1.000	0.478	0.739	1.000	0.429	0.714	1.000
I_4	0.200	0.263	0.385	0.333	0.556	1.000	0.200	0.263	0.385	0.238	0.333	0.556	0.294	0.455	0.714
I_5	0.200	0.238	0.333	0.294	0.455	1.000	0.185	0.217	0.294	0.200	0.263	0.385	0.185	0.217	0.294
I_6	0.111	0.130	0.176	0.120	0.158	0.231	0.111	0.120	0.158	0.176	0.273	0.600	0.273	0.600	1.000
I_7	0.120	0.158	0.231	0.130	0.176	0.273	0.111	0.130	0.176	0.120	0.158	0.231	0.231	0.429	1.000
I_8	0.120	0.143	0.200	0.120	0.143	0.200	0.111	0.130	0.176	0.120	0.158	0.231	0.231	0.429	1.000
I_9	0.200	0.263	0.385	0.217	0.294	0.455	0.185	0.217	0.294	0.200	0.263	0.385	0.333	0.556	1.000
I_{10}	0.200	0.238	0.333	0.217	0.294	0.455	0.185	0.217	0.294	0.217	0.294	0.455	0.294	0.455	1.000
I_{11}	0.185	0.217	0.294	0.200	0.263	0.385	0.200	0.238	0.333	0.200	0.238	0.333	0.333	0.556	1.000
I_{12}	0.360	0.391	0.529	0.360	0.474	0.692	0.333	0.360	0.474	0.429	0.600	1.000	0.360	0.474	0.692
I_{13}	0.200	0.263	0.385	0.200	0.263	0.385	0.294	0.455	1.000	0.217	0.294	0.455	0.238	0.333	0.556
I_{14}	0.556	0.778	0.926	0.704	0.926	1.000	0.520	0.760	1.000	0.294	0.529	0.882	0.294	0.647	1.000
I_{15}	0.556	0.778	0.926	0.520	0.760	1.000	0.704	0.926	1.000	0.333	0.600	1.000	0.333	0.600	1.000
I_{16}	0.481	0.704	0.926	0.556	0.778	0.926	0.704	0.926	1.000	0.520	0.760	1.000	0.478	0.739	1.000
I_{17}	0.407	0.630	0.852	0.556	0.778	0.926	0.429	0.714	1.000	0.333	0.556	0.778	0.630	0.852	1.000
I_{18}	0.630	0.852	1.000	0.520	0.760	1.000	0.481	0.704	0.926	0.263	0.474	0.789	0.368	0.684	1.000
I_{19}	0.185	0.407	0.630	0.407	0.630	0.852	0.185	0.333	0.556	0.630	0.852	1.000	0.704	0.926	1.000
I_{20}	0.407	0.630	0.852	0.333	0.556	0.778	0.259	0.407	0.630	0.333	0.556	0.778	0.704	0.926	1.000
I_{21}	0.407	0.630	0.852	0.481	0.704	0.926	0.704	0.926	1.000	0.407	0.630	0.852	0.704	0.926	1.000
I_{22}	0.481	0.704	0.926	0.556	0.778	0.926	0.704	0.926	1.000	0.238	0.429	0.714	0.429	0.714	1.000
I_{23}	0.407	0.630	0.852	0.556	0.778	0.926	0.630	0.852	1.000	0.520	0.760	1.000	0.600	0.840	1.000
I_{24}	0.556	0.778	0.926	0.481	0.704	0.926	0.704	0.926	1.000	0.478	0.739	1.000	0.333	0.600	1.000

O_{1a}, O_{1b}, O_{1c} stand for the lower, medium, and upper limits of the fuzzy number respectively.

Appendix G.

Weighted normalized fuzzy decision matrix.

Indicator	O_1			O_2			O_3			O_4			O_5			$FNIS(O^-)$	$FPIS(O^*)$
I_1	0.017	0.060	0.167	0.029	0.084	0.199	0.010	0.039	0.129	0.025	0.076	0.199	0.037	0.100	0.215	0.010	0.215
I_2	0.004	0.010	0.030	0.002	0.007	0.028	0.005	0.012	0.032	0.002	0.008	0.032	0.002	0.008	0.032	0.002	0.032
I_3	0.018	0.055	0.135	0.016	0.051	0.125	0.018	0.055	0.135	0.013	0.048	0.135	0.012	0.046	0.135	0.012	0.135
I_4	0.001	0.002	0.006	0.001	0.004	0.016	0.001	0.002	0.006	0.001	0.003	0.009	0.001	0.004	0.011	0.001	0.016
I_5	0.003	0.008	0.028	0.005	0.016	0.083	0.003	0.008	0.024	0.003	0.009	0.032	0.003	0.008	0.024	0.003	0.083
I_6	0.001	0.003	0.010	0.001	0.003	0.013	0.001	0.003	0.009	0.002	0.006	0.033	0.003	0.013	0.055	0.001	0.055
I_7	0.006	0.016	0.048	0.007	0.018	0.056	0.006	0.013	0.037	0.006	0.016	0.048	0.012	0.044	0.207	0.006	0.207
I_8	0.003	0.009	0.025	0.003	0.009	0.025	0.003	0.008	0.022	0.003	0.010	0.029	0.007	0.027	0.127	0.003	0.127
I_9	0.002	0.006	0.020	0.002	0.006	0.023	0.002	0.005	0.015	0.002	0.006	0.020	0.003	0.012	0.051	0.002	0.051
I_{10}	0.001	0.002	0.007	0.001	0.003	0.009	0.001	0.002	0.006	0.001	0.003	0.009	0.001	0.005	0.020	0.001	0.020
I_{11}	0.003	0.009	0.025	0.003	0.011	0.033	0.003	0.010	0.028	0.003	0.010	0.028	0.006	0.022	0.085	0.003	0.085
I_{12}	0.003	0.005	0.018	0.003	0.007	0.024	0.002	0.005	0.016	0.003	0.008	0.034	0.003	0.007	0.024	0.002	0.034
I_{13}	0.010	0.026	0.079	0.010	0.026	0.079	0.015	0.045	0.205	0.011	0.029	0.093	0.012	0.033	0.114	0.010	0.205
I_{14}	0.006	0.019	0.052	0.008	0.022	0.056	0.006	0.018	0.056	0.003	0.013	0.049	0.003	0.016	0.056	0.003	0.056
I_{15}	0.004	0.011	0.032	0.004	0.011	0.035	0.005	0.013	0.035	0.002	0.008	0.035	0.002	0.008	0.035	0.002	0.035
I_{16}	0.013	0.048	0.126	0.016	0.053	0.126	0.020	0.063	0.136	0.015	0.052	0.136	0.013	0.050	0.136	0.013	0.136
I_{17}	0.002	0.006	0.018	0.003	0.007	0.019	0.002	0.006	0.021	0.002	0.005	0.016	0.003	0.008	0.021	0.002	0.021
I_{18}	0.010	0.032	0.086	0.008	0.028	0.086	0.008	0.026	0.080	0.004	0.018	0.068	0.006	0.025	0.086	0.004	0.086
I_{19}	0.003	0.015	0.055	0.007	0.024	0.075	0.003	0.013	0.049	0.011	0.032	0.088	0.013	0.035	0.088	0.003	0.088
I_{20}	0.002	0.005	0.015	0.001	0.004	0.014	0.001	0.003	0.011	0.001	0.004	0.014	0.003	0.007	0.018	0.001	0.018
I_{21}	0.004	0.016	0.049	0.005	0.018	0.053	0.008	0.023	0.057	0.004	0.016	0.049	0.008	0.023	0.057	0.004	0.057
I_{22}	0.003	0.010	0.029	0.004	0.011	0.029	0.005	0.013	0.031	0.002	0.006	0.022	0.003	0.010	0.031	0.002	0.031
I_{23}	0.011	0.040	0.113	0.015	0.049	0.123	0.017	0.054	0.133	0.014	0.048	0.133	0.016	0.053	0.133	0.011	0.133
I_{24}	0.028	0.080	0.192	0.025	0.072	0.192	0.036	0.095	0.207	0.024	0.076	0.207	0.017	0.062	0.207	0.017	0.207

Appendix H.

Sensitivity analysis experiments.

No	Definition	Overall score (CC_v)					Ranking
		O_1	O_2	O_3	O_4	O_5	
Expt. 1	$\omega_{I_{1-24}} = 1$	0.342	0.418	0.381	0.365	0.525	$O_5 \succ O_2 \succ O_3 \succ O_4 \succ O_1$
Expt. 2	$\omega_{I_{1-24}} = 3$	0.342	0.418	0.381	0.365	0.525	$O_5 \succ O_2 \succ O_3 \succ O_4 \succ O_1$
Expt. 3	$\omega_{I_{1-24}} = 5$	0.342	0.418	0.381	0.365	0.525	$O_5 \succ O_2 \succ O_3 \succ O_4 \succ O_1$
Expt. 4	$\omega_{I_{1-24}} = 7$	0.342	0.418	0.381	0.365	0.525	$O_5 \succ O_2 \succ O_3 \succ O_4 \succ O_1$
Expt. 5	$\omega_{I_{1-24}} = 9$	0.342	0.418	0.381	0.365	0.525	$O_5 \succ O_2 \succ O_3 \succ O_4 \succ O_1$
Expt. 6	$\omega_{I_1} = 9, \omega_{I_{2-24}} = 1$	0.372	0.482	0.355	0.428	0.592	$O_5 \succ O_2 \succ O_4 \succ O_1 \succ O_3$
Expt. 7	$\omega_{I_2} = 9, \omega_{I_1, I_{3-24}} = 1$	0.411	0.420	0.476	0.401	0.518	$O_5 \succ O_3 \succ O_2 \succ O_1 \succ O_4$
Expt. 8	$\omega_{I_3} = 9, \omega_{I_1, I_2, I_{4-24}} = 1$	0.408	0.446	0.439	0.402	0.520	$O_5 \succ O_2 \succ O_3 \succ O_1 \succ O_4$

Expt. 9	$\omega_{I_4}=9, \omega_{I_{1-3},I_{5-24}}=1$	0.289	0.449	0.318	0.338	0.489	$O_5 \succ O_2 \succ O_4 \succ O_3 \succ O_1$
Expt. 10	$\omega_{I_5}=9, \omega_{I_{1-4},I_{6-24}}=1$	0.282	0.440	0.304	0.310	0.417	$O_5 \succ O_2 \succ O_4 \succ O_3 \succ O_1$
Expt. 11	$\omega_{I_6}=9, \omega_{I_{1-5},I_{7-24}}=1$	0.261	0.327	0.286	0.349	0.533	$O_5 \succ O_4 \succ O_2 \succ O_3 \succ O_1$
Expt. 12	$\omega_{I_7}=9, \omega_{I_{1-6},I_{8-24}}=1$	0.271	0.335	0.290	0.290	0.517	$O_5 \succ O_2 \succ O_3 = O_4 \succ O_1$
Expt. 13	$\omega_{I_8}=9, \omega_{I_{1-7},I_{9-24}}=1$	0.265	0.322	0.290	0.290	0.517	$O_5 \succ O_2 \succ O_3 = O_4 \succ O_1$
Expt. 14	$\omega_{I_9}=9, \omega_{I_{1-8},I_{10-24}}=1$	0.291	0.361	0.304	0.310	0.527	$O_5 \succ O_2 \succ O_4 \succ O_3 \succ O_1$
Expt. 15	$\omega_{I_{10}}=9, \omega_{I_{1-9},I_{11-24}}=1$	0.282	0.361	0.304	0.323	0.516	$O_5 \succ O_2 \succ O_4 \succ O_3 \succ O_1$
Expt. 16	$\omega_{I_{11}}=9, \omega_{I_{1-10},I_{12-24}}=1$	0.274	0.349	0.311	0.301	0.527	$O_5 \succ O_2 \succ O_3 \succ O_4 \succ O_1$
Expt. 17	$\omega_{I_{12}}=9, \omega_{I_{1-11},I_{13-24}}=1$	0.304	0.392	0.322	0.401	0.477	$O_5 \succ O_4 \succ O_2 \succ O_3 \succ O_1$
Expt. 18	$\omega_{I_{13}}=9, \omega_{I_{1-12},I_{14-24}}=1$	0.289	0.346	0.412	0.320	0.459	$O_5 \succ O_3 \succ O_2 \succ O_4 \succ O_1$
Expt. 19	$\omega_{I_{14}}=9, \omega_{I_{1-13},I_{15-24}}=1$	0.411	0.503	0.442	0.381	0.519	$O_5 \succ O_2 \succ O_3 \succ O_1 \succ O_4$
Expt. 20	$\omega_{I_{15}}=9, \omega_{I_{1-14},I_{16-24}}=1$	0.404	0.463	0.470	0.395	0.514	$O_5 \succ O_3 \succ O_2 \succ O_1 \succ O_4$
Expt. 21	$\omega_{I_{16}}=9, \omega_{I_{1-15},I_{17-24}}=1$	0.366	0.438	0.445	0.399	0.520	$O_5 \succ O_3 \succ O_2 \succ O_4 \succ O_1$
Expt. 22	$\omega_{I_{17}}=9, \omega_{I_{1-16},I_{18-24}}=1$	0.370	0.462	0.424	0.367	0.562	$O_5 \succ O_2 \succ O_3 \succ O_1 \succ O_4$
Expt. 23	$\omega_{I_{18}}=9, \omega_{I_{1-17},I_{19-24}}=1$	0.438	0.473	0.432	0.369	0.531	$O_5 \succ O_2 \succ O_1 \succ O_3 \succ O_4$
Expt. 24	$\omega_{I_{19}}=9, \omega_{I_{1-18},I_{20-24}}=1$	0.335	0.450	0.348	0.464	0.594	$O_5 \succ O_4 \succ O_2 \succ O_3 \succ O_1$
Expt. 25	$\omega_{I_{20}}=9, \omega_{I_{1-19},I_{21-24}}=1$	0.383	0.419	0.356	0.379	0.585	$O_5 \succ O_2 \succ O_1 \succ O_4 \succ O_3$
Expt. 26	$\omega_{I_{21}}=9, \omega_{I_{1-20},I_{22-24}}=1$	0.358	0.436	0.457	0.375	0.567	$O_5 \succ O_3 \succ O_2 \succ O_4 \succ O_1$
Expt. 27	$\omega_{I_{22}}=9, \omega_{I_{1-21},I_{23,24}}=1$	0.407	0.476	0.485	0.359	0.542	$O_5 \succ O_3 \succ O_2 \succ O_1 \succ O_4$
Expt. 28	$\omega_{I_{23}}=9, \omega_{I_{1-22},I_{24}}=1$	0.358	0.450	0.442	0.410	0.548	$O_5 \succ O_2 \succ O_3 \succ O_4 \succ O_1$
Expt. 29	$\omega_{I_{24}}=9, \omega_{I_{1-23}}=1$	0.404	0.448	0.470	0.416	0.514	$O_5 \succ O_3 \succ O_2 \succ O_4 \succ O_1$
Expt. 30	$\omega_{I_{1-3},I_{14-24}}=9, \omega_{I_{4-13}}=1$	0.495	0.543	0.549	0.469	0.592	$O_5 \succ O_3 \succ O_2 \succ O_1 \succ O_4$
Expt. 31	$\omega_{I_{1-3},I_{14-24}}=1, \omega_{I_{4-13}}=9$	0.158	0.272	0.182	0.238	0.448	$O_5 \succ O_2 \succ O_4 \succ O_3 \succ O_1$

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