A Comparison of MCDA Techniques TOPSIS and MAROM in Evaluating Bus Alternative-fuel Modes

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Abstract. There are a great number of multi-criteria decision analysis (MCDA) methods used in practice. Most of them have been designed to evaluate alternatives on one particular scale of measurement only. But the alternatives are characterized by many attributes which, usually, correspond to different types of measurement scale. In this paper such a method called MAROM is compared to a classical MCDA procedure called TOPSIS. The problem of alternative-fuel modes of buses used for public transportation in urban areas is considered. The ranking and the evaluation procedures of the alternative-fuel modes are shown for an empirical study taken from the literature. Comparison of the two methods is made on the results of the numerical computations. The formal description of the method MAROM is also presented in detail.

Keywords: multiple attribute decision making, alternative-fuel modes of buses

1 Introduction

Multi-criteria decision analysis (MCDA) and multi-attribute decision making (MADM) may apply to many complex decision making processes. They are most applicable to solving problems that are characterized as a choice among alternatives. When used for group decision making MADM allows the respondents to consider the values that each views as being important. In this paper, two advanced MADM methods will be used to produce a meaningful solution to a transportation problem of world-wide interest.

Typical of the modern age is the phenomenon of urbanization, i.e. the physical growth of urban areas as a result of rural migration as well as the ever growing suburban concentration into many cities, particularly the very largest ones. The United Nations projected that half of the world's population live in urban areas by the end of 2008. By 2050, it is predicted that 64.1% and 85.9% of the developing and developed world, respectively, will be urbanised [6]. According to a revised UN World Urbanization Prospects report, the growth will be even faster, the total figure is estimated to rise to 60% (4.9 billion people) by 2030 [18].

Under such circumstances, increasing attention has been given to urban sustainability over the past decades. The sustainable development of cities largely depends upon a sound urban policy. Transport sector is considered one of the major contributors to air and noise pollution in urban world. Emissions from motor vehicles affect strongly the health of people who are living in a town. Also, there is a direct relationship between a transport system and the air pollution in a city [4]. In this context, sustainability is defined as protection of urban communities from adverse development effects with respect to human health and the environment [8]. In particular, this paper focuses on modern technology and its applicability to mass transit systems as major contributors to sustained urbanization. Of the various options, available for public transportation, efficient bus systems can be effective and affordable.

This paper will build on the excellent work of Tzeng et al. [17]. Their research along with a comprehensive empirical example attempted to summarize the most promising developments of alternative-fuel buses suitable for the urban area and to explore their favourable future directions by comparing these alternatives to the characteristics of the conventional bus with an internal combustion diesel engine. For this purpose, they presented a comprehensive multi-attribute investigation of these alternative-fuel modes with a set of data provided by different groups of Taiwanese experts representing both engineering bodies and academia. They used the method TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) which is one of the most popular compromise methods for evaluating and ranking different alternatives; see in [7] and [2]. TOPSIS defines the best option as the one that is closest to the ideal option and farthest away from the negative ideal point. The authors of [17] claimed the assessment of the performances of the alternative-fuel vehicles is based on experts' judgements without using mathematical models for the evaluations of criteria as their contribution.

Author of the present paper has considered another concept in his MCDA methodology called MultiAttRibute Object Measurement (MAROM) [5]. Although MAROM was also designed to be capable of involving mixed data, i.e. both tangible and intangible attributes, however, it requires that the non-quantifiable and quantifiable attributes be treated in different manners. In MAROM, the raw data, either elicited from experts' judgments or arisen from physical measurements, are preserved for the computations in forms of binary variables, rank numbers and quantitative data depending upon their corresponding scale of measurement, i.e. nominal, ordinal, interval or ratio. This way, they are not subject to any arbitrary transformation onto a higher or a lower order scale. Hence, to eliminate the different units of measurement by standardization or normalization, can only put through within the same type of scale of measurement. These features of MAROM are fundamentally different to those of comprised by the TOPSIS method.

Our major objective will be the comparison of the priority rankings and the aggregate scores of the alternative-fuel buses resulted from the use of the two methods MAROM and TOPSIS when they are applied to the same data set.

2 Choices and characteristics of alternative-fuel modes

In the seminal paper of Tzeng et al. [17], 12 alternative-fuel modes are considered. Cited from the papers [17], [10] and [16], the main characteristics of these twelve alternative-fuel modes, denoted by AF_ *k*, where *k* =1, … ,12, are now described:

AF 1: Conventional diesel engine
The conventional diesel engine bus is employed all over the world. It is the most efficient among all existing internal combustion engines, making it one of the major contenders as a power source in the 21st century. Its main advantages are the low purchasing costs, the flexibility to the speed of traffic and the low sensitivity to road facility. However, it has very high exhaust emission rates (PM, NO_x, CO_x). This vehicle is introduced in the set of alternatives in order to compare it with the new fuel modes. We mention here that bio-diesel fuels (e.g. Soy Diesel) as possible substitutes for petroleum diesel are not considered here.

AF 2: Compressed natural gas—CNG
Natural gas is used in several forms as vehicle fuel, stored on board, i.e., compressed natural gas (CNG), liquefied natural gas (LNG), and attached natural gas (ANG). The CNG vehicle has already been commercialized around the world and is matured in its technology (there are about four million CNG vehicles in the world). Natural gas is a mixture of hydrocarbons, mainly methane, produced either from gas wells or together with crude oil production. Interest for natural gas as an alternative fuel arises from its clean burning qualities, its wide resource base and its commercial availability to users. The compressed natural gas vehicle is widespread in countries with their own natural gas. Natural gas has numerous benefits in terms of economics, pollutants, greenhouse gases, safety, general abundance and costs less than that of the diesel oil. CNG vehicles emit only slight amounts of carbon dioxide and carbon monoxide and they have high-octane value; thus, they are suitable for utilization as public transportation vehicles.

AF 3: Liquefied propane gas—LPG
There are countries that have used this mode of fuel for public transportation. In Japan, Italy, and Canada, as much as 7% of the buses are powered by LPG, and several other European countries are also planning to employ LPG vehicles, mainly due to pollution considerations.

AF 4: Fuel cell (hydrogen)

The so called fuel cell battery can transform hydrogen and oxygen into power for vehicles, but hydrogen is not suitable for onboard storage. The research on fuel cell hydrogen buses has already been concluded with success, and test results with the experimental vehicle operating on hydrogen fuel indicate that this vehicle has a broad surface in the burning chamber, low burning temperature and the fuel is easily made inflammable. Daimler–Benz Company has already developed a prototype vehicle with a fuel cell. To date, the only vehicles offered for sale with fuel cell technology is the Zevco London taxi which was launched in London in July 1998. Due to the fact that the energy to operate this vehicle comes from the chemical reaction between hydrogen and oxygen, no detrimental substance is produced and only pure water, in the form of air, is emitted. A fully loaded fuel tank can last as far as 250 km. Fuel cells generate electricity in order to power the vehicle from an electrochemical reaction between hydrogen and oxygen under controlled conditions. The only waste generated in this process is water vapour. Hydrogen's energy density is very low compared to that of the methanol and especially when compared to gasoline's. However, this low density requires very large and heavy tanks on board of the vehicle. Additionally, it would be necessary to create an entire new infrastructure, i.e., to set up refueling stations.

AF 5: Methanol

The fuel of methanol is related to vehicles with gasoline engines. The combination rate of methanol in the fuel is 85% (so called M85). The engine that can use this fuel with different combination rates is termed as flexible fuel vehicle (FFV). The FFV engine can run smoothly with any combination rate of gas with methanol. This way, methanol will act as an alternative fuel and helps to reduce the emission of black smoke and nitrous oxides (NO_2). A great number of intense experiments are pursuing with methanol, especially in the US. Fuel stations providing methanol are already available in Japan since 1992. The thermal energy of methanol is lower than that of the gasoline, but the capability of continuous traveling by this vehicle is inferior to conventional vehicles. When methanol becomes usable as an alternative fuel, it will significantly reduce vehicle emissions of pollutants and greenhouse gases.

AF 6: Electric vehicle—opportunity charging

The source of power for the opportunity charging electric vehicle (OCEV) is the combination of a loaded battery and fast opportunity charging during the time the bus is idle when stopped. Whenever the bus starts from the depot, its loaded battery will be fully charged. During the 10–20 seconds when the bus is stopped, the power reception sensor on the electric bus (installed under the bus) will be lowered to the charging supply plate installed in front of the bus stop to charge the battery. Within 10 seconds of a stop, the battery is charged with 0.15 kWh power (depending on the design of the power supply facility), and the power supplied is adequate for it to move to the next bus stop.

AF 7: Direct electric charging

A zero-emission alternative to petroleum that has been available for many years is electricity, and is an option currently used in many cities with electric-cable buses. Recent technology, however, uses electricity independently of a fixed electric cable by using fuel cells or battery storage. The big appeal of electricity is having a clean and quiet operating system. Some cities and countries have begun to use electric buses, but their future is unlikely because of the high costs. This type of electric bus is in the prototype design stage. The power for this vehicle comes mainly from the loaded battery. Once the battery power is insufficient, the vehicle will have to return to the plant to conduct recharging. The development of a suitable battery is critical for this mode of vehicle. If a greater amount of electricity can be stored in the battery, the cruising distance by this vehicle will be longer.

AF 8: Electric bus with exchangeable batteries

The objective of an electric bus with an exchangeable battery is to affect a fast battery charge and to achieve a longer cruising distance. The bus is modified to create more on-board battery space and the number of on-board batteries is adjusted to meet the needs of different routes. The fast exchanging facility has to be ready to conduct a rapid battery exchange so that the vehicle mobility can be maintained.

AF 9: Hybrid electric bus with gasoline engine

The electric-gasoline vehicle has an electric motor as its major source of power and a small-sized gasoline engine. When electric power fails, the gasoline engine can take over its function and continue the trip. The kinetic energy rendered during the drive will be turned into electric power to increase the vehicles' cruising distance.

AF 10: Hybrid electric bus with diesel engine

The electric–diesel vehicle has an electric motor and a small-sized diesel engine as its major sources of power. When electric power fails, the diesel engine can take over and continue the trip, while the kinetic energy rendered during the drive will be turned into electric power to increase the vehicles' cruising distance.

AF 11: Hybrid electric bus with CNG engine

The electric-CNG vehicle has an electric motor and a small-sized CNG engine as its major sources of power. When electric power fails, the CNG engine takes over and provides the power, with the kinetic energy produced is converted to electric power to permit continuous travel.

AF 12: Hybrid electric bus with LPG engine

The electric-LPG vehicle has an electric motor and a small-sized LPG engine as its major sources of power. When electric power fails, the LPG engine takes over and provides the power, with the kinetic energy produced is converted to electric power to permit continuous travel.

A comprehensive literature review on alternative-fuels for mass transit shows a variety of approaches to new energy technologies for buses [9]. Perhaps the most important source of information on the development of alternative-fuels can be found in the U.S. Department of Energy's Alternative Fuels Data Center (AFDC) which maintains an "Alternative Fuels Data Base" [1]. This website provides a comprehensive source of information on alternative-fuels through collecting operation information from vehicles running on alternative-fuels, analyzes the data, and makes them available to the public. Insight into operation of alternative-fuel buses is provided in a CUTR report of alternative-fuels used by buses [11]. This report analyzed air quality data and identified the most pressing air quality problems that could be addressed by an alternative-fuel program in the US. It considered alternative-fuel vehicles in transit and evaluated advantages and disadvantages of each of eight fuel types: Reformulated gasoline and diesel fuel (RFG, RFD), Propane - being the main ingredient in liquefied petroleum gas (LPG), Compressed natural gas (CNG), Liquefied natural gas, Ethanol, Methanol, Bio-diesel, Electric vehicles (including EVs with solar recharging stations).

3 Weighting of criteria and evaluation of alternative-fuels

In the paper of Tzeng et al. [17], 11 evaluation criteria were established. This set of criteria (attributes) was revealed as a result of an interactive group decision making process in the course of which bus manufacturing professionals, academic community people, researchers and bus operations experts have participated. These eleven single criteria (attributes), with respect to which each alternative-fuel mode will be evaluated are as follows [17]:

C 1: *Energy supply* — Yearly amount of costs of supply, storage and fuel
C 2: Energy efficiency — Energy consumption related to fuel heating value
C 3: Air pollution — Chemical substance harmful to health
C4: Noise pollution — Noise effect produced during operation time
C5: Industrial relationship — Impact on other locomotive industry branches
C6: Costs of implementation — Costs of production, purchase and implementation
C 7: Costs of maintenance — Yearly costs of maintenance
C 8: Vehicle capability — Cruising distance, gradeability, speed of vehicle, etc.
C 9: Road facility — Necessary features of road for the vehicle, e.g. pavement, slope
C 10: Speed of traffic flow — Conformity to traffic flow
C 11: Sense of comfort — Traveling comfort and aesthetic appeal

In Table 1, the normalized average weights, i.e., the relative importance values for every criterion are indicated [17, p.1377], which were determined by groups of experts using the AHP method [12]. In Table 1, the averages of the assessed values for each alternative-fuel mode with respect to every criterion are also presented. These values, denoted by u_{ij}, $0 \leq u_{ij} \leq 1$, are taken from [17, p.1378]. The evaluation results have been derived through conducting a survey by applying a Delphi procedure that was repeated twice. The experts have been selected on a well-grounded manner. They represented manufacturing industries, governmental departments, energy committees, research institutes and academic staff from higher educational institutions.

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11
Weight	0.0313	0.0938	0.1661	0.0554	0.0629	0.0829	0.0276	0.1239	0.0805	0.1994	0.0761
AF 1	0.82	0.59	0.18	0.42	0.58	0.36	0.49	0.79	0.81	0.82	0.56
AF 2	0.77	0.70	0.73	0.55	0.55	0.52	0.53	0.73	0.78	0.66	0.67
AF 3	0.79	0.70	0.73	0.55	0.55	0.52	0.53	0.73	0.78	0.66	0.67
AF 4	0.36	0.63	0.86	0.58	0.51	0.59	0.74	0.56	0.63	0.53	0.70
AF 5	0.40	0.54	0.69	0.58	0.51	0.52	0.68	0.52	0.63	0.60	0.70
AF 6	0.69	0.76	0.89	0.60	0.72	0.80	0.72	0.54	0.35	0.79	0.73
AF 7	0.77	0.79	0.89	0.59	0.73	0.80	0.72	0.47	0.44	0.87	0.75
AF 8	0.77	0.79	0.89	0.59	0.73	0.80	0.72	0.51	0.48	0.87	0.75
AF 9	0.77	0.63	0.63	0.52	0.66	0.63	0.65	0.67	0.70	0.80	0.74
AF10	0.77	0.63	0.51	0.58	0.66	0.63	0.65	0.67	0.70	0.80	0.74
AF11	0.77	0.73	0.80	0.48	0.63	0.66	0.65	0.67	0.71	0.62	0.78
AF12	0.77	0.73	0.80	0.48	0.63	0.66	0.65	0.67	0.71	0.62	0.78

Table 1
Value assessment for the alternative-fuels and the criteria weights [17]

4 Comparison of the results from TOPSIS and MAROM

The MAROM procedure (see in the Appendix) requires that nature of the data of each criterion be adequate to the properties of the type of the scale of measurement to which these data correspond to. Therefore, as its first step, each criterion is assigned to the appropriate scale of measurement. Furthermore, we extended the number of criteria from 11 to 15, since in the paper of Tzang et al. [17] some additional information is also presented which were not directly captured in their analysis. These data relate to some important engineering/chemical characteristics of alternative-fuels which stem from reliable sources (physical measurements). They are given in [17, p.1382-1383] with their accompanying units of measurement. To preserve the uniformity of the two data sets as much as possible which were used by Tzang et al. [17] and the present author, see Table 1 and Table 2, respectively, minimal changes have been made only. This way, criteria C4, C5, C9, C10 and C11 of the original data set have been retained, but were assigned to ordinal scales so that their original performance values, u_{ij} given in Table 1, were converted to rank numbers using a nine-grade ordinal scale [1, 1.5, 2, 2.5, … , 5], where an ideally best performance, if there is any, would receive 5.

Table 2
Input data of the alternative fuel-modes for MAROM

		AF1	AF2	AF3	AF4	AF5	AF6	AF7	AF8	AF9	AF10	AF11	AF12
Nominal	Aggregated weight of nominal scale 0.0666												
scale	Criterion weight 0.0248												
	Best value on nominal scale for criterion C1 1												
	1.Depot	1	0	0	1	1	0	0	0	0	0	0	0
Ordinal	Aggregated weight of ordinal scale 0.3333												
scale	Criteria weights 0.0805 0.0554 0.0629 0.1994 0.0761												
	Best values on ordinal scale for criteria C2-C6 4.0 3.0 3.5 4.5 4..0												
	2.Road facility	4.0	4.0	4.0	3.0	3.0	1.5	2.0	2.5	3.5	3.5	3.5	3.5
	3.Noise pollution	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.5	3.0	2.5	2.5
	4.Indust. rel.ship	3.0	3.0	3.0	2.5	2.5	3.5	3.5	3.5	3.5	3.5	3.0	3.0
	5.Speed of traffic	4.0	3.5	3.5	2.5	3.0	4.0	4.5	4.5	4.0	4.0	3.0	3.0
	6.Sense of comfort	3.0	3.5	3.5	3.5	3.5	3.5	4.0	4.0	3.5	3.5	4.0	4.0
Interval	Aggregated weight of interval and ratio scales 0.6000												
scale	Criterion weight 0.0938												
	Best value on interval scale for criterion C7 10.9												
	Worst value on interval scale for criterion C7 0.7												
	7.Energy efficiency [dim.less]	1.0	0.8	0.7	1.9	0.8	10.9	5.5	3.2	1.5	1.5	1.5	1.5
Ratio	Criteria weights 0.0313 0.1661 0.0248 0.0248 0.0248 0.0248 0.0248 0.0829 0.0276												
scale	Best values on scale for criteria C8-C15 3875 0.30 500 80 120 10 100000 10410												
	Worst values on scale for criteria C8-C15 46600 30.15 80 40 60 360 624000 30720												
	8.Fuel costs [1000 NT$]	14000	11450	15000	46600	14495	3875	4000	8000	7880	7450	7250	7300
	9.Exhaust emission ($PM+NO_x+HC+CO_x$) [%]	30.15	19.27	8.2	6.78	12.71	0.30	0.35	0.38	9.97	11.25	10.30	10.55
	10.Cruising distance [km]	450	500	400	325	225	100	80	220	250	250	350	350
	11.Number of passengers [No]	80	70	70	60	60	50	40	40	50	50	55	55
	12..Max speed [km/h]	120	80	90	75	110	60	65	65	70	70	75	75
	13.Recharge time [min]	10	200	100	10	10	360	300	300	360	360	360	360
	14.Costs of implementation [1000 NT$]	100000	420000	300000	624000	144000	340000	360000	380000	400000	420000	440000	450000
	15.Costs of maintenance [1000 NT$]	11400	10410	12500	30720	14700	18495	19600	19200	22200	22400	23500	23800

Utilizing the technical data collected by [17], several new criteria are now introduced. As seen in Table 2, they are: 'Depot', which can be small or large characterizing the depositary needs of the buses, is a nominal variable [0 or 1], while 'Cruising distance', 'Number of passengers', 'Maximum speed' for urban/suburban services and 'Recharge time' are ratio scale variables with particular units of measurements. They constitute the extended form of the "old" criterion 'Vehicle capability' whose weight has been uniformly allocated to them. The "old" criterion 'Energy efficiency' is a dimensionless variable, since it gives the ratio of the alternative-fuel efficiency/fuel heating value related to that of the diesel bus, and hence, it is reasonable to assign it to an interval scale. We hope that establishing this new data base for the same problem will provide us more powerful and reliable evaluation outcomes. Table 2 presents this reformulation of the original data set that meets the requirements of the theory of measurement. Here, the characteristic values for the 12 alternative-fuel buses, the 15 partly modified criteria weights and the aggregated weights for the scales of measurement are given.

Table 3

Comparison of the rankings and the evaluation scores for TOPSIS [17] and MAROM

	TOPSIS				MAROM			
	Rank Basic	Score	Rank Compr.	Score	Rank Indiv.	Score	Rank Aggreg.	Score
Electric bus with exchangeable batteries	1	0.945	1	0.975	5	0.514	4	0.675
Electric bus with opportunity charging	2	0.933	3	0.964	7	0.498	3	0.677
Electric bus with direct charging	3	0.931	2	0.967	4	0.514	2	0.681
Hybrid electric with gasoline engine	4	0.749	9	0.756	9	0.482	7	0.630
Hybrid electric with CNG engine	5	0.700	4	0.889	11	0.449	11	0.599
Hybrid electric with LPG engine	6	0.700	5	0.889	12	0.448	12	0.599
Hybrid electric with diesel engine	7	0.700	11	0.488	8	0.484	8	0.629
Fuel cell (hydrogen)	8	0.563	6	0.865	3	0.733	10	0.601
Methanol	9	0.527	10	0.698	1	0.791	1	0.691
Compressed natural gas engine (CNG)	10	0.399	7	0.830	10	0.467	9	0.611
Liquidate propane gas engine (LPG)	11	0.345	8	0.830	6	0.499	5	0.670
Conventional diesel engine bus	12	0.301	12	0.097	2	0.785	6	0.650

The results of the multi-criteria evaluation of the 12 alternative-fuel buses are shown in Table 3. Here, both the ranks and the evaluation indices called relative standings or scores yielded by TOPSIS (basic and compromise solutions) and MAROM (for the individual and the aggregate weighting cases) are indicated on interval scales. As it does not come as a surprise, the two methods have produced rather different rankings and scores. Comparisons on the findings, however, should be made very carefully. As a remarkable outcome, observe the big differences in the ranks of the conventional diesel engine bus. The last position of the diesel engine in the TOPSIS rankings seems to be very strange regarding the fact that Tzeng et al.'s investigations refer to the year 2005. It is also striking that there are rather significant differences in the priority scores of the alternative-fuel modes produced by the two methods. We intend not to go into detailed technical explanations, only to mention that author, as being a vehicle engineer, strongly believes that the MAROM ranking reflects better the at that time existing situations than that of TOPSIS. The relative high positions of the conventional diesel engine bus in the MAROM rankings as opposed to those of the alternative-fuel modes follows mainly from the tardiness of the required engineering developments and the bus manufacturing capabilities as well as the weak achievements of the civil initiatives concerning environmental protection issues. However, there is no doubt as urban mass transit technology will get stronger and improve in the future, then more buses will be powered by alternative means in the search for more efficient energy use, cleaner air, quieter operations and more traveling convenience, especially, when they will be able to efficiently serve in suburban areas as well.

Conclusions

In this paper, two MADM methods the TOPSIS and the MAROM have been compared based on numerical experience. These methods have been applied to the same empirical example, the selection of alternative-fuel buses operating in urban areas. Although the results produced by the two methods were quite different, however, both approaches have shown that the use of alternative-fuel modes to improving human health and the environment offers huge opportunities for ensuring sustainable urban developments.

Appendix

The formal description of the method MAROM is presented below:

Consider the following data matrix:

$$A = [a_{ik}], \quad i = 1,2..,m; \; k = 1,\ldots,n, \qquad (1)$$

involving n options (alternatives). The n columns give for every option the values of m variables (row vectors) denoting various characteristics (attributes, criteria) of these alternatives. In (1), a value (crisp number) is assigned to each entry a_{ik} which is either elicited from respondents' judgments or arisen from physical measurements. Thereby, the nature of a particular data may be of a subjective type (qualitative) and/or an objective type (quantitative). A column vector a_k of matrix A represents a composite vector $a_k=(a_k^{(N)}, a_k^{(O)}, a_k^{(I)}, a_k^{(R)})$ which is partitioned into four blocks. Thus, A consists of variables of mixed type, where the superscript N refers to nominal (usually binary), O to ordinal, I to interval and R to ratio variables. Of course, in a concrete real-world case, variables of any type may be missing.

An additional column vector, denoted by b, and called a reference vector, is to be constructed which represents an ideal (hypothetical) option, entries of which are composed of the "best" values of the set of alternatives with respect to each attribute. It has the same element-wise structure as that of vector a_k. Numerical scales are: [0,1] on a nominal; [1,…,5] on an ordinal; [0,…,1] or [actual values, i.e. row data emerging from measurements] on an interval and/or on a ratio scale, respectively.

Because of ratio scale (and sometimes interval) variables have usually different units of measurements the row vectors $a_i^{(R)\mathrm{T}}$ (and $a_i^{(I)\mathrm{T}}$) are standardized so that their means are equal to 0 and their standard deviations are equal to 1. E.g., for the ratio variables, these standard deviations can be obtained as

$$s_i^{(R)} = \sqrt{\frac{1}{n-1}\left[\sum_{i=1^{(R)}}^{k(R)} a_{ik}^{(R)2} - \frac{1}{n}\left(\sum_{i=1^{(R)}}^{m(R)} a_{ik}^{(R)}\right)^2\right]}, \quad i = 1^{(R)},..,m^{(R)}; \quad k = 1,...,n. \quad (2)$$

With (2), the standardized elements are

$$a_{ik}^{'(R)} = \frac{1}{s_i^{(R)}}\left(a_{ik}^{(R)} - \overline{a}_{i.}^{(R)}\right), \qquad i = 1,..,m; \quad k = 1,\ldots,n. \qquad (3)$$

A representative group of respondents (experts, customers, users, etc.) is then formed. Every committee member should evaluate each alternative by supplying his judgments on each qualitative variable with respect to the nominal and ordinal scaled criteria. It is recommended that the number of voters l, l =1,…,q, to be at least 10 persons.

The multi-attribute decision making model for preference measuring is as follows

$$\overline{d}_k^l = \sum_{i=1}^{m} w_i^l d_{ki}^l + \varepsilon_k^l, \quad k = 1,..,n; \quad l = 1,\ldots,q, \qquad (4)$$

where $_k^l$ is the overall distance of alternative k from the "ideal" alternative for the lth voter; w_i^l is the weight of attribute i; d_{ki} is the distance of the kth alternative (object) from the reference point on attribute i; ε_k is the value of an error random variable which may include model misspecification, measurement errors and respondents' uncertainties. To determine the weights of the attributes, w_i^l, i=1,…,m, the analytic hierarchy process (AHP) method is proposed [12]. These weights are then usually normalized, so that $\sum_{k=1}^{n} w_i^l = 1$.

The distance measure d_{ki} in Eq. (4) takes on different functional forms for alternative k:

(a) For the nominal vectors, $d_{ki}^{(N)}(a_{ki}^{(N)}, b^{(N)})$, denoting them simply as x,y 0 N, the distance measure is the Tanimoto (also called Jaccard) coefficient [14]:

$$d_{ki}^{(N)}(x,y) = 1 - \frac{\alpha}{\alpha+\beta+\gamma} = \frac{\beta+\gamma}{\alpha+\beta+\gamma},$$

where

$$\alpha = \sum_i \min(x_i, y_i), \quad \beta = \sum_i x_i - \alpha, \quad \gamma = \sum_i y_i - \alpha, \quad i \in N.$$

(b) For the ordinal vectors $d_{ki}^{(O)}(a_{ki}^{(O)}, b^{(O)})$, denoting them as x,y 0 O, the distance measure is the Soergel measure [13]:

$$d_{ki}^{(O)}(x,y) = \frac{\sum_i x_i + \sum_i y_i - 2\sum_i \min(x_i, y_i)}{\sum_i x_i + \sum_i y_i - \sum_i \min(x_i, y_i)}, \quad i \in O.$$

(c) For the interval vectors and the ratio vectors, $d_{ki}^{(I,R)}(a_{ki}^{(I,R)}, b^{(I,R)})$, denoting them as either x,y 0 I, or x,y 0 R and introducing the L_2 norm of a vector x,

$$\|x\|_2 = \sqrt{\sum_i x_i^2} = \sqrt{x^T x}, \quad i \in I, \quad \text{or} \quad i \in R,$$

the distance measure is the well-known Euclidean-metric:

$$d_{ki}^{(I,O)}(x,y) = \|x - y\|_2 = \sqrt{(x-y)^T (x-y)}.$$

Since the metric properties hold for the above distance functions used in the model (4) (see the proofs in [15]), in which linear scales are applied, therefore, the additive type composite vector l_k^l is also metric. Furthermore, it is unique and for each of the partial vectors $0 \leq d_{ki}(a_k^{(\cdot)T}, b^T) \leq 1$. The distance between any two composite vectors is proportional to the degree of intensity. The proportionality unit is taken to be 1.

Once the overall pairwise distances between each composite vector and the reference vector have been determined, the (column) vector of the relative standings or scores, $s=(s_k)$, $k=1,2,...,n$, and thus the priority ranking of the alternatives simply yields as $s=1-d_k$, respectively. To establish either a [0–1] or a [1–100] interval scale, a simple normalization procedure should be performed. To aggregate the individual preferences into a compromise ranking the minimum variance method [3] is proposed.

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