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Model for Assessing Quality of Online Health Information: A Fuzzy VIKOR Based Method

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ABSTRACT

Today, tens and thousands of websites provide health-related information on various topics to a growing number of consumers. However, the lay user is often faced with a challenge of determining the quality of information provided by one site from the other. To ensure the protection of users from sites that provide unreliable and unsafe information, there has to be a competent reviewing body that rates and ranks the quality of information provided by each site. This paper (i) proposes a new criteria framework for assessing the quality of online health information and (ii) uses a fuzzy 'visekriterijumska optimicija i kompromisno resenje' method to demonstrate how online health information providers could be assessed and ranked based on their quality. The fuzzy modelling uses pre-defined linguistic variables parameterized by triangular fuzzy numbers in the assessment and subsequent ranking of providers under a particular health topic. A numerical example is demonstrated using diabetes online information providers to show how the assessment and ranking is carried out. The proposed framework provides functional basis for evaluating the quality of internet health information providers on any particular health topic. Copyright © 2015 John Wiley & Sons, Ltd.

KEY WORDS: online health information; decision making model; fuzzy VIKOR; unsafe information; health info websites

1. INTRODUCTION

The task of differentiating websites that provide accurate, reliable and safe health information from those that proffer inaccuracies, outdated and half-truth is often a daunting task for the lay user. To attempt to curb this situation, several articles have been written dedicated to guide users in accessing accurate information from reliable websites (Hesse *et al.*, 2005; Medical Library Association, MLA, n.d.). This approach although laudable has not been enough in protecting consumers from unreliable sources of online health information. There is therefore the need for a standardized framework that could be used in evaluating and ranking quality of online health information sources to aid consumers in their choices.

Medical professionals until the advent of the internet were exclusive custodians of health information especially in terms of its dissemination and interpretation. Today, with the internet having become a gold mine for health information seekers, the traditional norm of soliciting information from a medical professional in person is not always tenable. High-speed broadband, smart mobile devices and wireless networks that provide the means for consumers to use the internet for a wide range of health information support (AlGhamdi and Moussa, 2012; Fox, 2004; Suziedelyte, 2012) make it almost impossible and out of reach for medical professionals to control the flow of health information on the internet. Consequently, studies have shown that most users seek online health information without consulting medical practitioners to confirm the reliability of the information (Andreassen *et al.*, 2007; Siliquini *et al.*, 2011). Largely, most people surf the internet for health advice so as to be better informed and prepared when consulting their physicians or just to reassure themselves of the status of their health (Cohen and Stussman, 2010). Users mostly read about specific medical ailments and conditions, communicate in real-time with healthcare providers via chat rooms and answer health assessment questionnaires online (Fox and Duggan, 2013; Rozmovits and Ziebland, 2004). However,

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while most of the internet health information are authored by governmental agencies, research institutions, product vendors, medical centres and individual professionals (Ambre *et al*., 1997), a lot more also come from sources that although well-intentioned, tend to misinform, mislead and persuade users in their quest to sell their products (Cotten & Gupta, 2004). This phenomenon breeds mistrust and brings to the fore issues of credibility regarding the source or the websites from which information is sought. For instance, it may not be ethically correct for a medical drug company launching a new pill that cures diabetes in 5 days to also advice consumers about diabetes. It is highly probable that such information may be biased in terms of luring people to buy their product. For example, in China and Korea where online health information assists the aged in taking good care of themselves, adhering to personal care practices and avoiding illnesses (Chang and Im, 2014; Leung *et al*., 2007), any misleading information can be fatal to their health. Again, in the USA, increasing number of people especially those who are unable to access certain healthcare insurance support are reported to 'manage' their health mainly from the information they seek online (Centers for Disease Control and Prevention, 2010; Cohen and Stussman, 2010). Such people are prone and vulnerable to any misleading information, which can turn harmful to their health.

The growth in the number of people searching for health-related information online has seen a corresponding increase in the number of unregulated sites offering unprofessional advice especially to health anxious individuals (Baumgartner and Hartmann, 2011). According to Asmundson *et al*., (2001) and Salkovskis *et al*., (2002), health anxiety could be defined as the misunderstanding and fears that people have about bodily symptoms and the potential severity of their illnesses. Subsequent to the definition of health anxiety, the study in Baumgartner and Hartmann (2011) describes health anxious individuals as those who seek certain information online to reassure themselves and allay fears that they are not healthy often contrary to what they feel within their bodies. Such individuals often do not care about the credibility of the source of the online health information nor the reliability of the information they are seeking. In a similar study about changes occurring in the use of e-health services (Sillence *et al*., 2006), two thirds of the respondents admitted to not checking for assurances of privacy on the websites they sought information from, and 23% of the sample could not recollect the specific name of the site used. Whiles this is frightening, even more worrying is that majority of the authors of online health information are not health professionals nor have they received any training to author health information (Eachus, 1999; Eastin, 2001; Theodosiou and Green, 2003).

A number of research studies have come out with guidelines for assessing the quality of online health information (Ambre *et al*., 1997; American Public Health Association, 2001; Eysenbach *et al*., 2002; Healthcare Research and Quality, 1999; Jadad and Gagliardi, 1998). For example, Moreno *et al*. (2008) and Herrera-Viedma *et al*. (2006) use fuzzy modelling of users' perceptions over a number of criteria to assess health information quality. However, we are of the view that using perception of users whom most of them do not know what qualifies as a good health information website may not be ideal in capturing the 'whole picture' in terms of assessing quality. This study rather recommends a competent reviewing body to undertake the task of assessing quality of online health information providers. To do this, a new set of criteria is first proposed, and subsequently, a fuzzy mathematics-based visekriterijumska optimizacija i kompromisno resenje (VIKOR) multi-criteria decision-making (MCDM) technique is used in demonstrating the assessment of quality of online health information providers. The purpose of the study is to use such regular assessment and ranking to aid users in their choice of websites for health-related information. The following sections explain the concept of fuzzy MCDM and fuzzy VIKOR and its related applications. The outline of the steps in fuzzy VIKOR is each explained, and then a numerical example using the websites of top four online diabetes information providers is used to show how the technique can be useful in ranking health-related information providers in any health topical area.

1.1. Fuzzy multi-criteria decision-making

Decision makers are often faced with complex problems with incomplete and vague information. MCDM, a modelling and methodological tool, has become handy in dealing with complex decision-making problems making it one of the most well-known branches of decision-making (Kahraman, 2008; Lu *et al*., 2007). Fuzzy logic, an approach to computing based on continuum of membership rather than bivalent logic, has proven to be a useful and efficient way in approaching MCDM in situations of imprecise or subjective data. Fuzzy logic in decision-making deals with the vagueness and uncertainties in our natural language expression of thoughts and judgements. Bellman and Zadeh (1970) proposed decision-making in fuzzy environment. In health-

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related problems, a number of MCDM methods have been successfully applied to solve various forms of MCDM problems. Among few of these applications are Akdag *et al*., (2014) where a fuzzy MCDM method was applied in the evaluation of hospital service quality, while Liu *et al*. (2013) applied fuzzy VIKOR to assess healthcare waste disposal methods. Shanmugasundaram and Seshaiah (2014) applied intuitionistic fuzzy technique in medical diagnosis, and Kahraman *et al*., (2014) applied fuzzy VIKOR in evaluation of health research investments. Büyüközkan and Çifçi (2012) used a hybrid fuzzy analytic hierarchy process (AHP) and fuzzy technique for order preference by similarity to ideal solution (TOPSIS) method to analyse electronic service quality in healthcare industry, and Mahdevari *et al*. (2014) used fuzzy TOPSIS in human health and safety risks management in underground coal mines.

Fuzzy logic has been extended to almost all the widely used MCDA techniques. Notable among these are the AHP, analytic network process, elimination and choice expressing reality, grey relational analysis, preference ranking organization method for enrichment evaluation, TOPSIS, weighted product model and VIKOR. This paper uses the fuzzy VIKOR method to evaluate and rank quality of internet health information providers.

1.2. Fuzzy VIKOR method

VIKOR, which stands for 'VlseKriterijumska Optimizacija I Komprominso Resenje' in Serbian language and translates to multi-criteria optimization and compromise solution, was introduced by Opricovic (1998). The VIKOR method works by first establishing a compromise ranking-list, a compromise solution, and the weight stability intervals for the compromise solution (Opricovic, 1998; Opricovic and Tzeng, 2004). It then determines the positive-ideal solution and the negative-ideal solution to aid in ranking and selecting (Wu and Liu, 2011). The underlying principle of the VIKOR MCDM method is to deal with ranking and selection of alternatives, which have multi-conflicting or non-commensurable criteria (Chang, 2014).

As is usual of most of the MCDM techniques, the VIKOR method was also extended to accommodate subjectivity and imprecise data under fuzzy environment (Opricovic, 2011). Since then, a number of applications from various disciplines have been carried out using the fuzzy VIKOR method. In Yücenur and Demirel (2012), fuzzy VIKOR is used in selecting insurance companies in a group decision-making process and Wang and Chang (2005) also employed fuzzy VIKOR to resolve MCDM problems. The method is used by Sanayei *et al*. (2010) and Shemshadi *et al*. (2011) for supplier selection problems. In Shemshadi *et al*. (2011), however, the method is modified using entropy measure for objective weighting. In Chen and Wang (2009), fuzzy VIKOR is utilized for optimized partners' choice in IS/IT outsourcing projects. In San Cristóbal (2011), the compromise method is used to select renewable energy project in Spain. Similarly in Kaya and Kahraman (2010), an integrated fuzzy VIKOR and AHP methodology is used to plan renewable energy in Istanbul. In Kuo and Liang (2011), a combined form of fuzzy VIKOR and grey relational analysis techniques is utilized to evaluate service quality of airports. In Jahan *et al*. (2011), fuzzy VIKOR is again used for material selection, and Devi (2011) used fuzzy VIKOR method in a robot selection. Again in Ou Yang *et al*. (2013), fuzzy VIKOR based on DEMATEL and analytic network process is utilized in assessing information security risk control. Although the literature reviewed is not exhaustive, the trend together with the underlying principle of the VIKOR method points to a trend that the method is mostly used in selection and ranking problems but seldom applied in evaluation of the service quality. This study combines fuzzy sets and VIKOR to evaluate and rank the quality of internet health information providers.

1.3. Fuzzy set theory

The human language is filled with imprecision, subjectivities and vagueness when used to judge, describe and communicate information. In view of this, Zadeh (1997) introduced the fuzzy set theory to model human judgements. The following are some useful definitions of the fuzzy set theory.

Definition 1

Fuzzy Set. Let X be a nonempty set, the universe of discourse $X = \{x_1, x_2, \dots, x_n\}$. A fuzzy set A of X is a set of ordered pairs: $\{(x_1, f_A(x_1)), (x_2, f_A(x_2)), \dots, (x_n, f_A(x_n))\}$, characterized by a membership function $f_A(x)$ that maps each element x in X to a real number in the interval [0,1]. The function value $f_A(x)$ stands for the membership degree of x in A. To capture the vagueness and variations in the subjective ratings of a decision maker, a fuzzy number is used. A fuzzy number is an expression of membership functions of a linguistic term and ascribes a rating set between the interval [0, 1] for subjective ratings. The two most popular fuzzy numbers are the trapezoidal and triangular fuzzy numbers. In this paper, we use the triangular fuzzy number, which is defined below.

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Definition 2
Triangular fuzzy number. A triangular fuzzy number is expressed as a triplet (a, b, c). The membership function $f_A(x)$ of a triangular fuzzy number as defined in Eqn (1)

$$f_A(x) = \begin{cases} 0 & x < a, x > b \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \end{cases} \tag{1}$$

Fuzzy models that use triangular fuzzy numbers prove to be effective for solving decision-making problems where the available information is subjective and vague (Erol *et al*., 2014; Haleh and Hamidi, 2011).

Definition 3
Basic triangular fuzzy number operations: Assuming $A = (a, b, c)$ and $B = (a_1, b_1, c_1)$ are two triangular fuzzy numbers. Then, the basic operations on these two fuzzy triangular numbers are as follows:

$$\begin{aligned} A \oplus B &= (a, b, c) + (a_1, b_1, c_1) \\ &= (a + a_1, b + b_1, c + c_1) \end{aligned} \tag{2}$$

$$\begin{aligned} A - B &= (a, b, c) - (a_1, b_1, c_1) \\ &= (a - c_1, b - b_1, c - a_1) \end{aligned} \tag{3}$$

$$A \times B = (a, b, c) \times (a_1, b_1, c_1) = (aa_1, bb_1, cc_1) \tag{4}$$

$$A \div B = (a, b, c) \div (a_1, b_1, c_1) = \left(\frac{a}{c_1}, \frac{b}{b_1}, \frac{c}{a_1}\right) \tag{5}$$

Definition 4
Non-negative triangular fuzzy numbers: A triangular fuzzy number (a, b, c) is non-negative if and only if $c \ge b \ge a \ge 0$. The use of fuzzy numbers in this paper is premised on the assumption that all fuzzy numbers used are non-negative even though there are negative fuzzy numbers. In view of this, Eqns (4) and (5) were relevant to this application because the two triangular fuzzy numbers (a, b, c) and (a_1, b_1, c_1) are non-negative.

Definition 5
In classical set theory, intersection, union and complement are some of the basic operators used in connecting elements of sets (Klir and Yuan, 1995). These operations are extended to fuzzy sets as connectives involving sets with membership functions. The following define fuzzy basic connectives of intersection, union and complement respectively using two fuzzy sets.

I The fuzzy intersection operator ∩ (fuzzy and connective)

$$f_{A \cap B}(x) = \min\{f_A(x), f_B(x)\}, x \in X \tag{6}$$

II The *fuzzy union* operator ∪ (fuzzy or connective)

$$f_{A \cup B}(x) = \max\{f_A(x), f_B(x)\}, x \in X \tag{7}$$

III The fuzzy complement (fuzzy not operation)

$$f_{\bar{A}}(x) = 1 - f_A(x), x \in X \tag{8}$$

In Eqns (6) and (7), the connectives are based on the *min-max* operators where the *maximum* operator is used to select the maximum of two or more fuzzy numbers while the *minimum* operator selects the minimum of two or more fuzzy numbers. For example, the minimum of two elements f_A and f_B denoted formally as $\min(f_A, f_B)$, $\wedge(f_A, f_B)$ or $f_A \wedge f_B$ is as expressed below.

$$f_A \wedge f_B = \min(f_A, f_B) \equiv \begin{cases} f_A & if\, f_A \ge f_B \\ f_B & if\, f_A < f_B \end{cases}$$

Example: $\min(2, 3) = 2 \wedge 3 = 2$

Definition 6
Assuming K decision makers are formed to rate the performances of a set of alternatives measured against a set of criteria. Then, the fuzzy rating of each decision maker $D_k (k = 1, 2, \ldots, K)$ can be expressed as a positive triangular fuzzy number $R_k (k = 1, 2, \ldots, K)$ with membership function $f_{R_K}(x)$. The fuzzy rating R is aggregated as below:

$$\widetilde{R} = (a, b, c), k = 1, 2, \ldots, \; K \tag{9}$$

where $\tilde{a} = \min_k\{a_k\}$, $\widetilde{b} = \frac{1}{k}\sum_{k=1}^{K} b_k$, $\widetilde{c} = \max_k\{c_k\}$.

1.4. Evaluating quality of internet health information

The growing interests and efforts at assessing the quality of health information on the Internet have brought about several sets of criteria from a number of sources. However, little research work has been carried out at standardizing and harmonizing the several sets of criteria available today. This study first proposes a new set of criteria for evaluating quality of internet health information culled from several sources (Kim *et al*., 1999; Eysenbach *et al*., 2002; Jadad and

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Gagliardi, 1998; Healthcare Research and Quality, 1999; American Public Health Association, 2001; Ambre *et al*., 1997; Denning, 1999; Von Solms, 1999; Leonard, 2008; Moreno *et al*., 2008) as shown in Figure 1. Secondly, the criteria are used to construct a framework for evaluating the quality of internet health information using fuzzy VIKOR method.

We propose that the decision makers be composed of a consumer health information expert, self-help group representatives, clinical specialists, general practitioners, lay medical publisher, Community Health Council representative, health journalist and an information security expert. However, the numerical example in this paper uses three (3) decision makers to demonstrate how fuzzy VIKOR can be employed to evaluate and rank quality of health information providers.

The criteria used in this study are grouped into four main clusters, namely, (a) credibility, (b) content, (c) design and (d) security. With each cluster having a set of sub-criteria, the total criteria used in this study are fifteen (15). In the following section, the rationale for selecting the four clusters and their various sub-criteria for evaluating the quality of internet health information are explained.

A Credibility

This cluster looks at factors that offer reasonable grounds for a user to believe in health information provided on the internet (Jadad and Gagliardi, 1998; Moreno *et al*., 2008). There are four indicators to measure the credibility of a website providing health information. These are the source, context, relevance and disclosure. The most important criterion for judging the credibility of an online health information provider is the source. The source of health information helps to defuse user doubts about the credibility of the information they are accessing. An online health information provider must therefore provide such things as the name of the institution's or organization, logo, authors and their titles

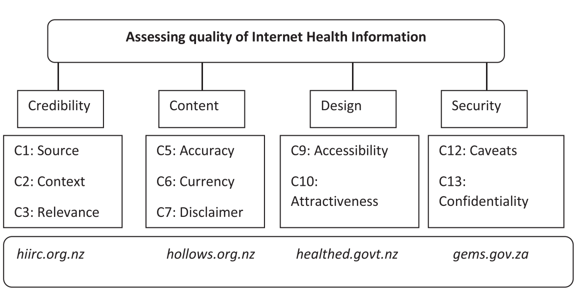

Figure 1. A framework for evaluating quality of internet Health Information.

B Content

The content of a website providing health-related information is very important as far as winning users trusts is concerned. This cluster is composed of sub-criteria such as accuracy, currency, disclaimer and authority (Healthcare Research and Quality, 1999; Ambre *et al*., 1997). Accuracy is often regarded the most important criteria for evaluating content and seeks for the scientific validity of the information provided. Users expect proven solutions that are rooted in scientific theory (Moreno *et al*., 2008).

C Design

Design defines the quality features and the ease of use of a health information website during a user visit (Healthcare Research and Quality, 1999). Although design does not directly impact the quality of information on a website, it is a necessary requirement to ensure frequent delivery of information to users. This is made possible through logical organization of the website information for easy user understanding (Ambre *et al*., 1997). The design cluster includes sub-criteria such as accessibility, attractiveness and links.

D Security

Security is essential in a website providing health-related information because of the sensitive and confidential information shared in real-time interactions (Moreno *et al*., 2008). Some websites provide chat rooms where users seek advice on a range of issues. It is therefore incumbent on the internet health information provider to assure users of their confidentiality. In this proposed framework, security is measured using caveat together with the CIA triad of confidentiality, integrity and availability. Caveat looks at a website's ability to assure consumers through statements that personal information would not be transferred to third parties or even stored (Ambre *et al*., 1997). CIA triad (Denning, 1999; Von Solms, 1999) is a widely applicable model designed to guide and evaluates information systems security policies. The most obvious element of the CIA triad is confidentiality, which ensures that data or an information system is accessed only by authorized

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persons. Confidentiality is achieved through user Id's and passwords and other policy based security measures (Ambre *et al.*, 1997).

1.5. Proposed fuzzy framework

We propose a fuzzy VIKOR framework to evaluate the quality of internet health information as shown in Figure 1. The fuzzy VIKOR approach used in this study is organized in the following order. First, the importance weights of the evaluation criteria are determined. Then the performance rating matrix is constructed. Following is the computation of the fuzzy best value and fuzzy worst value of the criteria. After this, the normalized fuzzy difference and the separation values are computed, the triangular fuzzy numbers are defuzzified into crisp values to determine rankings of the alternatives, and finally, a compromise solution is proposed.

Step 1

Determining linguistic variables

The first step in the fuzzy VIKOR method is to determine the linguistic variables; the criteria for evaluating the quality of internet health information. These linguistic variables (criteria) shown in Figure 1 are expressed in linguistic terms and used by the experts to rate each linguistic variable. The linguistic terms are then transformed into fuzzy numbers. Linguistic terms are qualitative words or phrases of a natural language that reflect the subjective view of an expert about the criteria per each alternative under consideration (Klir and Yuan, 1995). In this study, triangular fuzzy numbers are used as shown in Tables I and II, respectively, to capture the ratings of the criteria and alternatives on a scale of 0–1.

Step 2

Determining importance weights of criteria

The evaluation criteria for determining the quality of internet health information have different importance weights. To determine the importance or the weight of each criterion, the decision makers rate each criterion using the linguistic terms in Table I. This is expressed in Eqn (10) as vector $\widetilde{W}$:

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2 \ldots, \widetilde{w}_n] j = 1, 2, \ldots, n \qquad (10)$$

where $\widetilde{w}_j$ represents the weight of the *jth* criterion based on the linguistic preference assigned by a decision maker. Each weight is expressed as a triangular fuzzy number. These preferences signify the importance attributed to a criterion by a decision maker. The study uses the graded mean integration method to aggregate the decision makers' opinions. The fuzzy importance weight $\widetilde{w}_j$ for criterion C_j is computed using the graded mean integration method (Chou, 2003) as: $\widetilde{w}_j^k = (w_{j1}, w_{j2}, w_{j3})$where,

$$\widetilde{w}_{j1} = \min_k\{w_{j1}{}^k\}, \widetilde{w}_{j2} = \tfrac{1}{k}\sum_{k=1}^{k} w_{j2}{}^k, \widetilde{w}_{j3} = \max_k\{w_{j3}{}^k\}$$

$j = 1, 2, \ldots, nk$ is as usual is a *k*th decision maker and *j*, the *j*th criterion.

Table I. Linguistic scale for the importance of criteria

Linguistic terms	Triangular fuzzy number
Very low	(0.0,0.1,0.3)
Low	(0.1,0.3,0.5)
Medium	(0.3,0.5,0.7)
High	(0.5,0.7,0.9)
Very high	(0.7,0.9,1.0)

Table II. Linguistic scale for ratings of alternatives

Linguistic terms	Triangular fuzzy number
Very poor	(0.0,0.0,0.2)
Poor	(0.0,0.2,0.4)
Fair	(0.2,0.4,0.6)
Good	(0.4,0.6,0.8)
Very good	(0.6,0.8,1.0)
Excellent	(0.8,0.1,1.0)

Step 3

Constructing the fuzzy decision matrix

Consider a group of k decision makers ($D_1, D_2, \ldots, D_k$) presented with m alternatives ($A_1, A_2, \ldots, A_m$) against n set of criteria ($C_1, C_2, \ldots, C_n$) in a typical MCDM problem. A fuzzy MCDM is formally expressed as

$$\widetilde{D} = \begin{matrix} & C_1 & C_2 & \ldots & C_n \\ A_1 & \widetilde{x}_{11} & \widetilde{x}_{12} & \ldots & \widetilde{x}_{1n} \\ A_2 & \widetilde{x}_{21} & \widetilde{x}_{22} & \ldots & \widetilde{x}_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_m & \widetilde{x}_{m1} & \widetilde{x}_{m2} & \ldots & \widetilde{x}_{mn} \end{matrix} \; i \qquad (11)$$

$=1,2,\ldots,m; j=1,2,\ldots,n$

where, $\widetilde{x}_{mn}$ is the rating of alternative A_m with respect to criterion C_j. Note that for a decision maker k is a triangular fuzzy number. Similarly as in Step 2, the graded mean integration method is used to aggregate the opinions of the decision makers concerning the ratings of the alternatives (websites). This is formally expressed as $\widetilde{x}_{ij}^k = \left(a_{ij}^k, b_{ij}^k, c_{ij}^k\right)$ where

$$a_{ij} = \min_k\left\{a_{ij}^k\right\}, b_{ij} = {}^1\Big/_k \sum_{k=1}^{k} b_{ij}^k, c_{ij} = \max_k\left\{c_{ij}^k\right\} \quad (12)$$
$$i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$$

Step 4
Fuzzy best value f_j^* and fuzzy worst value f_j°

The fuzzy best value $f_j^* = \left(a_j^*, b_j^*, c_j^*\right)$ and the fuzzy worst values $f_j^\circ = \left(a_j^\circ, b_j^\circ, c_j^\circ\right)$ are computed, respectively, using Eqns (13) and (14) below (Opricovic and Tzeng, 2004; Shemshadi *et al.*, 2011):

$$\widetilde{f}_j^* = \max_i \widetilde{x}_{ij}, f_j^\circ = \min_i \widetilde{x}_{ij}, for\ \ j \in B \quad (13)$$

$$\widetilde{f}_j^* = \min_i \widetilde{x}_{ij}, f_j^\circ = \max_i \widetilde{x}_{ij},\ \ for\ \ j \in C \quad (14)$$

where B is the benefit criteria and C, the cost criteria. Further, the *max* and *min* operators as defined in Eqns (6) and (7) select the maximum and the minimum fuzzy triangular numbers from the aggregated fuzzy decision matrix across the alternatives respectively as the fuzzy best and worst values. This is shown in Tables 5 and 6.

Step 5
Normalized fuzzy difference $\widetilde{d}_{ij}$

To obtain the fuzzy difference $\widetilde{d}_{ij}$ between $\widetilde{x}_{ij}$ and fuzzy best value f_j^* or worst value, it is computed as shown below:

$$\widetilde{d}_{ij} = \left(\widetilde{f}_j^* - \widetilde{x}_{ij}\right) / \left(c_j^* - a_j^\circ\right) \rightarrow for\ \ j \in B \quad (15)$$

$$\widetilde{d}_{ij} = \left(\widetilde{x}_{ij} - \widetilde{f}_j^*\right) / \left(c_j^\circ - a_j^*\right)\ \ for\ \ j \in C \quad (16)$$

where B is the benefit criteria and C the cost criteria

Step 6
Computing separation measures $\widetilde{S}_i$ and $\widetilde{R}_i$

The next step computes the separation $\widetilde{S}_i$ of alternative A_i from the fuzzy best value f_j^*. Similarly, the separation of $\widetilde{R}_i$ of alternative A_i from the fuzzy worst value f_j° is also computed. These are respectively measured using Eqns (17) and (18):

$$\widetilde{S}_i = \sum_{j=1}^{n} \left(\widetilde{w}_j \otimes \widetilde{d}_{ij}\right) \quad (17)$$

$$\widetilde{R}_i = \max_j \left(\widetilde{w}_j \otimes \widetilde{d}_{ij}\right) \quad (18)$$

where $\widetilde{S}_i = \left(S_i^a, S_i^b, S_i^c\right)$ is a fuzzy weighted sum of the separation measure of A_i from the best value f_j^* (Chang, 2014). Similarly, $\widetilde{R}_i = \left(R_i^a, R_i^b, R_i^c\right)$ is a fuzzy max that refers to the separation measure of A_i from the worst value f_j° where w_j the importance weight of criterion is C_j.

Step 7
Computing the value of $\widetilde{Q}_i$

The value $\widetilde{Q}_i = (a_i, , b_i, , c_i)$ expressed in a triangular fuzzy number is computed as follows:

$$\{\widetilde{Q}_i = v\left(\widetilde{S}_i - \widetilde{S}^*\right) / \left(S^{\circ c} - S^{*a}\right) \oplus (1 - v) \left(\widetilde{R}_i - \widetilde{R}^*\right) / \left(R^{\circ c} - R^{*a}\right) \quad (19)$$

where $\widetilde{S}^* = MIN_i \widetilde{S}_i$, $S^{\circ c} = MAX_i S_i^c$, $\widetilde{R}^* = MIN_i \widetilde{R}_i$ $R^{\circ c} = MAX_i R_i^c$ and $v(v = n + 1/2n)$ is taken as a weight for the strategy of 'majority criteria' (or 'maximum utility'), where $1 - v$ represents the weight of the individual regret (Opricovic, 2011). The best values of S and R are, respectively, $\widetilde{S}^*$ and $\widetilde{R}^*$.

Step 8
Defuzzifying $\widetilde{S}_i$, $\widetilde{R}_i$ and $\widetilde{Q}_i$

In fuzzy logic, defuzzification is the process of converting the fuzzy numbers into crisp numbers (Klir and Yuan, 1995). The defuzzification is computed by locating the best non-fuzzy performance (BNP). A range of defuzzification methods have been suggested in literature. Notable among them are the centre of area (COA), mean of maximum and weighted average method (Opricovic and Tzeng, 2003). This paper uses the defuzzification method of COA for ranking fuzzy numbers by Opricovic and Tzeng (2003); Zhao and Govind (1991). The defuzzification process converts $\widetilde{S}_i$, $\widetilde{R}_i$ and $\widetilde{Q}_i$ into crisp numbers S, R and Q.

Step 9
Ranking the alternatives

This step ranks the alternatives by sorting the values of S, R and Q in descending order resulting in three ranking lists $\{A\}_S$, $\{A\}_R$ and $\{A\}_Q$, respectively. The index Q_i is

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the separation measure of A_i from the best alternative. That is the smaller Q_i, the better the alternative.

Step 10

Proposing a compromise solution

A compromised solution is proposed at this stage where alternative ($A^{(1)}$) is the best ranked by the measure Q (minimum) if the following two conditions are satisfied:[*Condition* (1)]: Acceptable advantage:

$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ \quad (20)$$

where $A^{(2)}$ represents the alternative with second position in the ranking list $\{A\}_Q$. Additionally, the threshold $DQ = 1/(n-1)$ where n indicates the number of feasible alternatives.[*Condition* (2)]: Acceptable stability in decision-making:The alternative $A^{(1)}$ must be the best ranked by S or/and R. Here if one of these conditions is not satisfied, then a set of compromise solution is proposed consisting of

1 Alternatives $A^{(1)}$ and $A^{(2)}$ if only condition (2) is not satisfied, or
2 Alternatives $A^{(1)}, A^{(2)}, \ldots, A^{(M)}$ if condition (1) is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) \leq DQ$ for maximum M (the positions of these alternatives are in 'closeness').

2. NUMERICAL EXAMPLE

This section demonstrates how the fuzzy VIKOR method can be used to evaluate and rank online health information providers. The numerical example in this paper assumes an eight-member decision-making team evaluating and ranking the websites of four DIABETES organizations. As internet penetration rates continue to rise, more people would be relying on the internet for a range of information. In view of this, the quality of information provided by a website on any subject but especially health related ones are crucial. The four websites used in this demonstration are *hiirc.org.nz*, *hollows.org.nz*, *healthed.govt.nz* and *gems.gov.za*. In the following steps, Fuzzy VIKOR is used to demonstrate how to arrive at decision makers' preferable compromise solution or alternative. The computational illustration of this numerical example is shown as follows:

Step 1

Determining linguistic variables

The linguistic variables and the alternatives used in this paper are as illustrated in Figure 1. The linguistic terms for the importance weight criteria and the ratings for the alternatives per each criterion are as shown in Tables I and II, respectively.

Step 2

Determining importance weights of criteria

The evaluation is organized into four main clusters comprising 15 sub-criteria for the evaluation of the quality of online health information as shown in Figure 1. This second step in the fuzzy VIKOR MCDM process offers evaluators the chance to choose by rating the most important criteria for the evaluation guided by the linguistic terms in Table I. The linguistic preferences for our assumed eight decision makers concerning the importance attached to each criterion is as shown in Table III below.

The graded mean integration method defined in Eqn (2) is used to aggregate the decision makers' opinions regarding the importance weightings of each criterion. The result of such aggregation is shown in Table IV.

To determine the importance of each criterion by ranking, the fuzzy numbers are defuzzified. The paper uses the centre of area (COA) method in computing the BNP value to rank the order of importance of each criterion. The BNP value of the fuzzy number $W_k = (L_{wk}, M_{wk}, U_{wk})$ is calculated using the expression in Eqn (17).

$$BNP_{wk} = L_{wk} + [(U_{wk} - L_{wk}) + (M_{wk} - L_{wk})]/3 \quad (21)$$

For example, the BNP value for Criteria 3 (C3) is computed as follows:

$$= 0.1 + [(0.9 - 0.1) + (0.475 - 0.1)]/3 \quad (22)$$
$$= 0.4917$$

By the BNP value computation, the major influential criteria out of the 15 are C6 with a rank of 1, C12 with a rank of 2 and C3 and C9 with a rank of 3. The least important criterion would be C1 with a rank of 15.

Step 3

Constructing the fuzzy decision matrix

Similarly as in Step 2, the decision makers rate the various online health information providers using linguistic terms in Table II. In our numerical example, we assume evaluators would judge the alternatives with the linguistic terms 'Very poor', 'Poor', 'Fair', 'Good', 'Very good' and 'Excellent'. These linguistic judgments would represent the opinions of the evaluators in rating and ranking the quality of online information of four DIABETES organizations. In

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Table III. Importance weights of criteria

	D1	D2	D3	D4	D5	D6	D7	D8
C1	VL	VL	M	M	L	M	L	M
C2	M	M	H	H	M	M	H	M
C3	H	H	M	L	L	L	M	M
C4	M	VH	H	M	M	VL	M	M
C5	H	L	H	L	M	M	M	L
C6	H	VH	H	VH	VH	H	VH	VH
C7	M	L	M	L	M	M	M	M
C8	L	VL	L	VL	VL	VL	L	VL
C9	H	M	H	M	M	M	H	M
C10	M	L	L	M	H	M	L	M
C11	VL	L	L	VL	L	VL	L	L
C12	VH	H	M	M	VH	H	H	M
C13	H	H	M	M	M	L	H	M
C14	M	M	L	L	L	L	VL	M
C15	M	M	L	M	M	L	M	M

C, criteria; VL, very low; L, low; M, medium; H, high; VH, very high.

Table IV. Fuzzy aggregated weights of criterion

		TFN		BNP	Rank
C1	0	0.35	0.7	0.3500	12
C2	0.3	0.575	0.9	0.5917	3
C3	0.1	0.475	0.9	0.4917	7
C4	0	0.525	1	0.5083	6
C5	0.1	0.475	0.9	0.4917	7
C6	0.5	0.825	1	0.7750	1
C7	0.1	0.45	0.7	0.4167	10
C8	0	0.175	0.5	0.2250	15
C9	0.3	0.575	0.9	0.5917	3
C10	0.1	0.45	0.9	0.4833	9
C11	0	0.225	0.5	0.2417	14
C12	0.3	0.675	1	0.6583	2
C13	0.1	0.55	0.9	0.5167	5
C14	0	0.35	0.7	0.3500	12
C15	0.1	0.45	0.7	0.4167	10

TFN, triangular fuzzy numbers; BNP, best non-fuzzy performance; C, criteria.

Table V, we demonstrate with assumed ratings of evaluators, which have been aggregated using Eqn (12).

Step 4

Fuzzy best value f_j^* and fuzzy worst value f_j°

The study utilizes Eqns (13) and (14) to determine the fuzzy best and fuzzy worst values for the evaluation criteria. The result of this process is shown in Table VI.

Step 5

Normalized fuzzy difference $\widetilde{d}_{ij}$

In this step, the normalized fuzzy difference $\widetilde{d}_{ij}$ is computed using Eqns (15) and (16). For example, $\widetilde{d}_{A1}$ is computed as shown below, and the final result is seen in Table VII.

$$\begin{aligned}\widetilde{d}_{A1} &= (5.28, 6.58, 7.89) - (4.44, 5.72, 7.00) \quad (23)\\ &= [(5.28\text{-}7.00), (6.58\text{-}5.72), (7.89\text{-}4.44)]\\ &= (-1.72, 0.86, 3.45)\end{aligned}$$

Step 6

Computing separation measures $\widetilde{S}_i$ and $\widetilde{R}_i$

The separation measures of $\widetilde{S}_i$ and $\widetilde{R}_i$ of alternative A_i from the fuzzy best and worst values, respectively,

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Table V. Aggregated fuzzy decision matrix

	A1			A2			A3			A4		
C1	4.44	5.72	7.00	3.50	4.81	6.11	5.28	6.58	7.89	4.67	5.81	6.94
C2	5.39	6.53	7.67	4.67	5.97	7.28	3.72	4.86	6.00	4.39	5.64	6.89
C3	3.61	4.86	6.11	3.33	4.67	6.00	3.17	4.58	6.00	3.67	5.00	6.33
C4	2.56	3.83	5.11	4.06	5.42	6.78	2.67	4.00	5.33	4.17	5.42	6.67
C5	3.44	4.78	6.11	4.83	6.06	7.28	2.89	4.25	5.61	3.94	5.17	6.39
C6	3.50	4.75	6.00	3.67	4.83	6.00	4.50	5.67	6.83	5.28	6.58	7.89
C7	5.00	6.08	7.17	2.89	4.25	5.61	5.17	6.33	7.50	3.94	5.17	6.39
C8	3.33	4.67	6.00	2.89	4.33	5.78	4.44	5.83	7.22	4.39	5.75	7.11
C9	2.78	4.08	5.39	3.00	4.33	5.67	4.50	5.75	7.00	5.11	6.42	7.72
C10	5.78	7.00	8.22	4.61	5.75	6.89	4.89	6.11	7.33	3.89	5.17	6.44
C11	6.06	7.25	8.44	4.89	6.14	7.39	3.61	4.94	6.28	3.39	4.75	6.11
C12	5.61	6.92	8.22	4.72	6.06	7.39	2.78	4.08	5.39	3.67	4.97	6.28
C13	4.72	6.00	7.28	4.50	5.75	7.00	2.39	3.75	5.11	4.11	5.33	6.56
C14	3.33	4.58	5.83	4.94	6.17	7.39	2.89	4.00	5.11	4.39	5.58	6.78
C15	4.28	5.47	6.67	4.33	5.67	7.00	4.44	5.56	6.67	5.39	6.58	7.78

Table VI. Fuzzy best value f_j^* and fuzzy worst value f_j°

		f_j^*			f_j°	
C1	5.28	6.58	7.89	3.50	4.81	6.11
C2	5.39	6.53	7.67	3.72	4.86	6.00
C3	3.67	5.00	6.33	3.33	4.67	6.00
C4	4.17	5.42	6.67	2.56	3.83	5.11
C5	4.83	6.06	7.28	2.89	4.25	5.61
C6	5.28	6.58	7.89	3.50	4.75	6.00
C7	5.17	6.33	7.50	2.89	4.25	5.61
C8	4.44	5.83	7.22	2.89	4.33	5.78
C9	5.11	6.42	7.72	2.78	4.08	5.39
C10	5.78	7.00	8.22	3.89	5.17	6.44
C11	6.06	7.25	8.44	3.39	4.75	6.11
C12	5.61	6.92	8.22	2.78	4.08	5.39
C13	4.72	6.00	7.28	2.39	3.75	5.11
C14	4.94	6.17	7.39	2.89	4.00	5.11
C15	5.39	6.58	7.78	4.28	5.47	6.67

are computed using Eqns (17) and (18). The resulting Table VIII is seen below:

Step 7

Computing the value of $\widetilde{Q}_i$

$\widetilde{S}^* = (-0.88, 1.07, 9.05)$; $\widetilde{R}^* = (0.00, 0.24, 0.90)$

S^{oc}=10.61; R^{oc}=1.00

For example, $\widetilde{Q}_{iA1}$ is computed using Eqn (19) as shown below, and the results are indicated in Table IX.

$$\widetilde{Q}_{iA1} = \{0.5[(-9.77 - 5.15, 0.32 - 0.15, 10.30 + 4.89)] /(10.61 + 0.88)\} + \{1 - 0.5[-0.9 - 0.5, 0.10 -0.05, 1 - 0]/(1.00 - 0.45)\} = (-0.88, 0.07, 0.95)$$

Step 8

Defuzifying $\widetilde{S}_i$, $\widetilde{R}_i$ and $\widetilde{Q}_i$

The defuzzification process converts $\widetilde{S}_i$, $\widetilde{R}_i$ and $\widetilde{Q}_i$ into crisp numbers S, R and Q. The results are shown in Table X below.

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Table VII. Normalized fuzzy difference

	A1			A2			A3			A4		
C1	−1.72	0.86	3.45	−0.83	1.78	4.39	−2.61	0.00	2.61	−1.67	0.78	3.22
C2	−2.28	0.00	2.28	−1.89	0.56	3.00	−0.61	1.67	3.94	−1.50	0.89	3.28
C3	−2.45	0.14	2.72	−2.33	0.33	3.00	−2.33	0.42	3.17	−2.67	0.00	2.67
C4	−0.94	1.58	4.11	−2.61	0.00	2.61	−1.17	1.42	4.00	−2.50	0.00	2.50
C5	−1.28	1.28	3.83	−2.44	0.00	2.44	−0.78	1.81	4.39	−1.56	0.89	3.33
C6	−0.72	1.83	4.39	−0.72	1.75	4.22	−1.56	0.92	3.39	−2.61	0.00	2.61
C7	−2.00	0.25	2.50	−0.44	2.08	4.61	−2.33	0.00	2.33	−1.22	1.17	3.56
C8	−1.56	1.17	3.89	−1.33	1.50	4.33	−2.78	0.00	2.78	−2.67	0.08	2.83
C9	−0.28	2.33	4.95	−0.56	2.08	4.72	−1.89	0.67	3.22	−2.61	0.00	2.61
C10	−2.45	0.00	2.45	−1.11	1.25	3.61	−1.56	0.89	3.33	−0.67	1.83	4.33
C11	−2.39	0.00	2.39	−1.33	1.11	3.56	−0.22	2.31	4.83	−0.06	2.50	5.06
C12	−2.61	0.00	2.61	−1.78	0.86	3.50	0.22	2.83	5.45	−0.67	1.94	4.56
C13	−2.56	0.00	2.56	−2.28	0.25	2.78	−0.39	2.25	4.89	−1.83	0.67	3.17
C14	−0.89	1.58	4.06	−2.44	0.00	2.44	−0.17	2.17	4.50	−1.83	0.58	3.00
C15	−1.28	1.11	3.50	−1.61	0.92	3.44	−1.28	1.03	3.33	−2.39	0.00	2.39

Table VIII. Index $\widetilde{S}_i$ and $\widetilde{R}_i$

	A1			A2			A3			A4		
C1	0.00	0.07	0.55	0.00	0.14	0.70	0.00	0.00	0.42	0.00	0.06	0.51
C2	−0.17	0.00	0.52	−0.14	0.08	0.68	−0.05	0.24	0.90	−0.11	0.13	0.75
C3	−0.08	0.02	0.82	−0.08	0.05	0.90	−0.08	0.07	0.95	−0.09	0.00	0.80
C4	0.00	0.20	1.00	0.00	0.00	0.64	0.00	0.18	0.97	0.00	0.00	0.61
C5	−0.03	0.14	0.79	−0.06	0.00	0.50	−0.02	0.20	0.90	−0.04	0.10	0.68
C6	−0.08	0.34	1.00	−0.08	0.33	0.96	−0.18	0.17	0.77	−0.30	0.00	0.60
C7	−0.04	0.02	0.38	−0.01	0.20	0.70	−0.05	0.00	0.35	−0.03	0.11	0.54
C8	0.00	0.05	0.45	0.00	0.06	0.50	0.00	0.00	0.32	0.00	0.00	0.33
C9	−0.02	0.27	0.90	−0.03	0.24	0.86	−0.11	0.08	0.59	−0.16	0.00	0.48
C10	−0.06	0.00	0.51	−0.03	0.13	0.75	−0.04	0.09	0.69	−0.02	0.19	0.90
C11	0.00	0.00	0.24	0.00	0.05	0.35	0.00	0.10	0.48	0.00	0.11	0.50
C12	−0.14	0.00	0.48	−0.10	0.11	0.64	0.01	0.35	1.00	−0.04	0.24	0.84
C13	−0.05	0.00	0.47	−0.05	0.03	0.51	−0.01	0.25	0.90	−0.04	0.08	0.58
C14	0.00	0.12	0.63	0.00	0.00	0.38	0.00	0.17	0.70	0.00	0.05	0.47
C15	−0.04	0.14	0.70	−0.05	0.12	0.69	−0.04	0.13	0.67	−0.07	0.00	0.48
$\widetilde{S}_i$	−0.72	1.38	9.42	−0.62	1.54	9.77	−0.55	2.03	10.61	−0.88	1.07	9.05
$\widetilde{R}_i$	0.00	0.34	1.00	0.00	0.33	0.96	0.01	0.35	1.00	0.00	0.24	0.90

Step 9

Ranking the alternatives

The crisp value of the alternatives for Q is ranked from the smallest value to the highest value. The alternatives are ranked as shown in Table XI below.

Step 10

Proposing a compromise solution

In Table XI, the best ranked alternative is A4, which happens to be the best compromise solution. According to the values of Q_j and S_j as shown in Table X, the ascending rank of the four diabetes online information providers is represented as follows:

$$Q_{A4} \succ Q_{A2} \succ Q_{A1} \succ Q_{A3}$$

$$S_{A4} \succ S_{A2} \succ S_{A1} \succ S_{A3}$$

Now by the ascending rank order, the diabetes support organization known as *gems.gov.za* (A4), which had the minimum of Q_i and S_i, would be said

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Table IX. Value of $\widetilde{Q}_i$

	$\widetilde{Q}_i$		
A1	−0.8752	0.0656	0.9484
A2	−0.8710	0.0647	0.9444
A3	−0.8620	0.0972	1.0000
A4	−0.8823	0.0000	0.8823

Table X. Defuzzified values of *S* and *Q*

	Q	*S*	*R*
A1	0.0463	3.3645	0.4482
A2	0.0460	3.5635	0.4304
A3	0.0784	4.0306	0.4545
A4	0	3.0814	0.3803

Table XI. Rank for alternatives

	Q	Rank
A1	0.0463	3
A2	0.0460	2
A3	0.0784	4
A4	0	1

to have the best quality in terms of provision of online diabetes information.

3. IMPLICATIONS

Most health information on the internet is not censored. To ensure that relevant quality online information is accessed by users, an evaluation of the providers of such health-related information is deemed important. This proposed fuzzy VIKOR framework could suffice in ranking health information providers to assist users in their choice of source of health information. Additionally, such ranking of health information providers would help generate a competitive instinct among health information providers and thereby help improve in all aspects of health information.

4. CONCLUSION

The paper rekindles interest in decision-making models that determine quality of health information. In particular, the research focused on first, proposing a standardized criteria framework relevant to the assessment of quality of online health information providers. Additionally, the fuzzy VIKOR method was used to demonstrate how the assessment and ranking could be carried out using diabetes online health information providers in a numerical example that brings out the relevance of the framework. Results on real world application of such assessment and ranking could be widely published in health magazines and other health information outlets to guide users in their choice of websites that provide health information on one topic or the other.

Because the criteria used are specific to health information only, it may not ideal to extend its use beyond health-related evaluation. Additionally in practical use, there could be some conflicting criteria that would have to be strategically resolved. For example, the criteria, disclosure (C4), accuracy (C5) and authority (C8) could affect adequate provision of most of the criteria under security. This challenge has to be resolved in a real world application that uses this framework. We also envisage the addition of some other relevant criteria in the future which may not be qualitative as in this model and so would require a method that can fuse both quantitative and qualitative information to aid in the assessment of quality online information. Fuzzy VIKOR method is not exhaustive as far as the assessment of quality of online health information is concerned. Other MCDM methods can also be useful in such ranking problem. In view of this, future work would use other methods and compare results.

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