Web-based Multi-Criteria Group Decision Support System with Linguistic Term Processing Function

Jie Lu, Guangquan Zhang & Fengjie Wu

Abstract— **Organizational decisions are often made in groups where group members may be distributed geographically in different locations. Furthermore, a decision-making process, in practice, frequently involves various uncertain factors including linguistic expressions of decision makers' preferences and opinions. This study first proposes a rational-political group decision-making model which identifies three uncertain factors involved in a group decision-making process: decision makers' roles in a group reaching a satisfactory solution, preferences for alternatives and judgments for assessment-criteria. Based on the model, a linguistic term oriented multi-criteria group decision-making method is developed. The method uses general fuzzy number to deal with the three uncertain factors described by linguistic terms and aggregates these factors into a group satisfactory decision that is in a most acceptable degree of the group. Moreover, this study implements the method by developing a web-based group decision support system. This system allows decision makers to participate a group decision-making through the web, and manages the group decision-making process as a whole, from criteria generation, alternative evaluation, opinions interaction to decision aggregation. Finally, an application of the system is presented to illustrate the web-based group decision support system.**

Index Terms— **Decision support systems, Group decision-making, Fuzzy decision-making, Web-based systems, Linguistic terms**

I. INTRODUCTION

MANY organizational decisions are made through evaluating a set of alternatives and then selecting the most satisfactory one from them based on the information at hand and the perspectives of decision makers. These alternatives may exist objectively such as a number of candidates for a position, or is nominated by decision makers such as several proposals for new product development, or is generated using a suitable decision model such as multi-objective programming. Multiple criteria are often used to evaluate the set of alternatives where some criteria could be more important than others in selecting the most satisfactory one. Also, in organizations, many decisions and the processes involved in making them are performed at a group level rather an individual, refereed to group decision-making (GDM) [1]. A group decision-making process is to find a group satisfactory solution which is one that is most acceptable by the group of individuals as a whole.

Three basic factors may influence the assessment of utility of alternatives and the deriving of the group satisfactory solution. The first one is individual's role (weight) in the selection of the satisfactory solution. The second factor is individual's preference for alternatives. The third factor is criteria used for assessing these alternatives and judged by decision makers [2]. The three factors are often expressed by linguistic terms in a group decision-making practice. For example, an individual role can be described using linguistic terms 'important person' or 'general person'. Similar, to express a decision maker's preference for an alternative linguistic terms 'low' and 'high' could be used, and to express a decision maker's judgment for comparison of a pair of assessment-criteria 'equally important' or 'A is more important than B' are often applied. As linguistic terms are too complex and ill-defined to be reasonably described in conventional quantitative expressions [3], a crucial requirement is proposed for linguistic information processing technique. The concept of linguistic variable was proposed by Zadeh [4] to deal with the situations and is described and operated by fuzzy set theory.

Due to the computational complexity of GDM methods, decision support systems (DSS) have been applied as a support tool for solving GDM problems [5], referred to group decision support systems (GDSS). When a GDSS applies fuzzy set technology to handle uncertainty issues it is normally referred to fuzzy GDSS (FGDSS) [6]. Traditionally, DSS, including GDSS, had to be installed in a specified location, such as a decision room. Now, the web is acting as a mechanism for the support of decision-making in organizations, particularly geographically distributed organizations [7, 8]. GDSS can therefore be implemented as a kind of web-based services, and thus have been moving to a global environment. Since the advance of web technology, which allows users fast and inexpensive access to an unprecedented amount of information provided by websites, digital libraries and other data sources, web-based DSS have been applied in a widespread decision activities with its unified graphical user interface [7, 9]. Although existing literature provides a way to build web-based GDSS, such as Wang and Chien [8], there is no report regarding to build a web-based GDSS to deal with decision members' linguistic term enter and processing.

This paper first establishes a rational-political group decision-making model which identifies three uncertain factors involved in a group decision-making process. It then proposes a linguistic term based group decision-making method to handle wholly the three fuzzy properties (uncertainty in decision makers' roles for reaching a satisfactory solution, their

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preferences for alternatives and their judgments for assessment-criteria) simultaneously in a group decision-making. It uses general type of fuzzy numbers to describe linguistic terms, so that users can choose any type of fuzzy number in applications. It also applies inference rules correcting inconsistency in individual preference explanation. Based on the method, a web-based fuzzy group decision support system (WFGDSS) is developed. An initial experiment shows that the WFGDSS can improve the effectiveness and application range of group decision-making, and use of linguistic terms can increase users' confidence in deriving a satisfactory solution from a set of alternatives in a group.

The rest of this paper is organised as follows. Section 2 shows a rational-political model of group decision-making with uncertainty and analyzes the features of web-based GDSS. Section 3 gives a fuzzy group decision-making method. The WFGDSS and an application for using the system are shown in Section 4. Conclusions are given in Section 5.

II. RATIONAL-POLITICAL GROUP DECISION-MAKING MODEL WITH UNCERTAINTY AND WEB FEATURES

Through literature reviewing this section proposes a rational-political group decision support model with uncertainty and analyses the main features of web-based decision support systems.

A. Rational-political group decision support model with uncertainty

Group decision-making is a key component to the functioning of an organization, because organizational performance involves more than just individual actions. It is the process of arriving at a satisfactory solution based upon the input and feedback of multiple individuals. It, therefore, is very important to determine what makes group decision-making effective and to increase the level of overall satisfaction for the final decision across the group [1]. Due to the importance and complexity of the group decision-making process, decision-making models are needed to establish a systematic means of supporting effective and efficient group decision-making [10].

There are two kinds of most popular and basic models of group decision-making. The first one is the rational model [11]. The kind of models is grounded on objectives, alternatives, consequences and optimality. It assumes that complete information regarding the decision to be made is available and one correct conception of the decision can be determined. Another kind of decision-making models is the political model. In contrast to the rational model, the individuals involved do not accomplish the decision task through rational choice in regard to business objectives. The decision makers are motivated by and act on their own needs and perceptions. This process involves a cycle of negotiation and idea sharing among the group members in order, for each one, to try to get his or her perspective to be the one of choices. More specifically, this process involves each decision maker trying to sway powerful people (such as a group leader) within the situation to adopt his or her viewpoint and influence the remaining members [11, 12].

In a real group decision-making process of an organization, decision makers are often involved in a group discussion to express their opinions for convincing other members and influencing final group decision. Obviously, decision makers' opinions will directly impact on the assessment of utility of alternatives and the deriving of an optimal group decision. In such a situation, the group optimal decision is in reality the group satisfactory decision. Three main factors regarding to decision maker opinion have been identified with a direct influence for the form of an optimal group decision [2].

The first one is individual's role (weight) in the selection of the optimal decision. There may be a group leader or leaders who play more important roles than others in a particular group decision-making. Although each decision maker tries to influence other members to adopt his or her viewpoint, powerful members will sway strongly the decision-making than other members. Group members thus have different 'weights' in a group decision-making, and the situation should be reflected on the generation process of the group satisfactory decision.

The second factor is individual's preference for alternatives. Group members may not know all information related to a decision problem or may not consider all relevant information to the decision problem. Also, they may have different understanding for same information, different experience in the area of current decision problem, and, therefore, different preferences for alternatives. The different preferences of group members impact directly on the deriving of the group optimal decision.

The third factor is criteria for assessing these alternatives. Assessment-criteria are usually determined through generation and discussion in decision groups. Goals or priorities of decision objectives are often as assessment-criteria for multi-objective decision problems. In a real situation, different group members may have different viewpoints in assessment-criteria for a decision problem because of workload, time and inexperience at assessing a problem all affect determining assessment-criteria. Different members may often have different judgments in comparing the importance between a pair of assessment-criteria. Obviously, what assessment-criteria are used and how priority of each assessment-criterion is will directly influence the selection of the group's satisfactory decision.

To deal with the three factors and support the achievement of consensus of group decision-making in a real environment, this research proposes a rational-political model which combines the advantages of both rational and political models. By inheriting the optimization property of rational model, it shows a sequential approach to make a group decision. By carry out the advantages of political model, it allows decision makers to have inconsistent assessment, incomplete information and inaccurate opinions for alternatives and assessment-criteria. The model, therefore, can deal with the three uncertain factors simultaneously.

As shown in Figure 1, the model is assumed that a set of alternatives for a decision problem has been conducted. A number of group members, including a group leader, will work together to select an optimal solution from these alternatives. A set of assessment-criteria for assessing these alternatives are nominated by these group members or generated through running a suitable model operated by them. Group members (including the leader) are awarded or assigned weights before or at the beginning of the decision-making process. It is often done by the leader. Although group members may have different experiences, opinions and information at hand for the decision problem, they must participate in the group aggregating process to ensure that the disparate individuals come to share the same decision objectives. These group members will be required to give their individual judgments for priority of proposed assessment-criteria and preferences for alternatives under these assessment-criteria by linguistic terms. The final group decision is made through optimizing and aggregating group members' preferences on alternatives under their weights and judgments on assessment-criteria.

B. Fuzzy group decision-making methods

The aggregation of group members' perceptions involves the presentation and operation of linguistic terms. Zadeh's fuzzy set theory [4] is naturally applied in the aggregation process with uncertainty and imprecision. Several typical fuzzy group decision-making methods have been developed and focused respectively on the three uncertain factors. Some researches such as [3], [13], [14], [15], and [16] have been done in describing the uncertainty of individual preferences for alternatives and aggregating imprecise individual preferences into a group consensus decision. The uncertainty on the judgment of assessment-criteria has also been paid attentions by researchers such as [17], [18] and [19]. The uncertainty of individual roles, or call it individual weights, in attempting to reach a group satisfactory solution has been discussed in the literature of this area such as [20] and [21]. Furthermore, our earlier research [2] has proposed a framework to identify uncertainty and imprecise related to the three factors and find a possible way to provide a representation of group members' perspectives in order to minimize their conflict in a decision-making process.

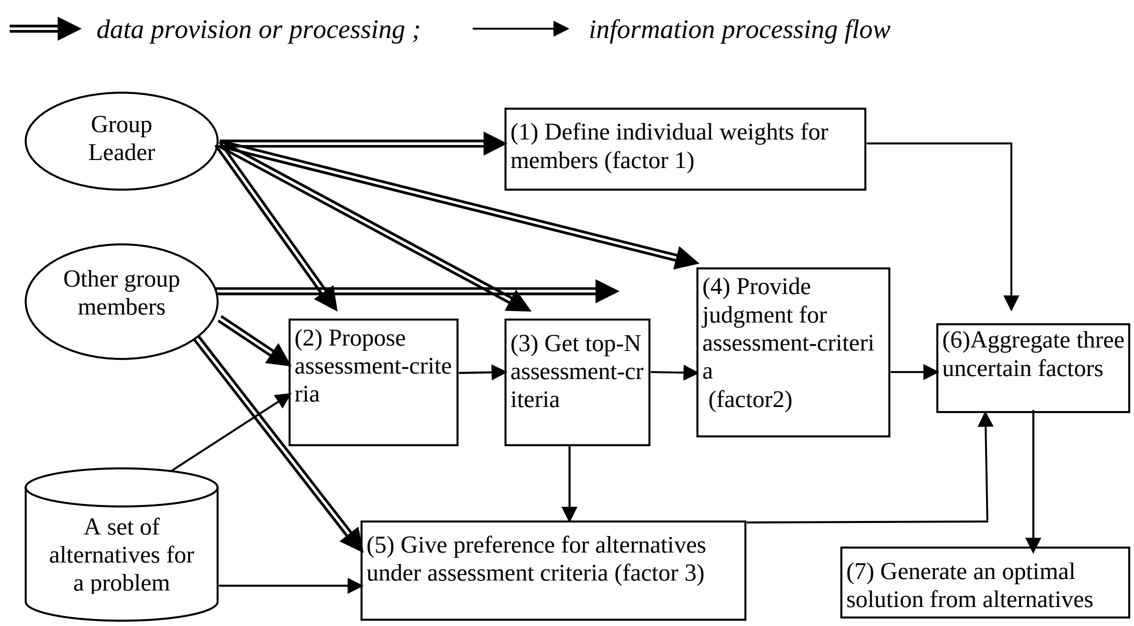

Fig. 1: Rational-political group decision-making model with uncertain factor

C. Features of web-based group decision support systems

GDSS, as a 'specific' type of systems within the broad family of DSS [22], have been successfully implemented in many organizations at different organizational levels [23]. Group members may be distributed in different locations therefore a group decision meeting need web-based tool support. Four features of web-based group decision support systems are identified as follows.

Supporting asynchronous communication among group members: An important feature provided by GDSS is to support interpersonal communication and coordination among group members. This feature aims at achieving a common understanding of the issues revealed and arriving at a group satisfactory decision. The communication and coordination activities of group members are facilitated by technologies that can be characterized along the three continua of time, space, and level of group support [24]. In general, group members could only communicate synchronously by face-to-face meetings without web technology. With the applications of the web and specific web-based GDSS, group members can communicate asynchronously in group decision-making, and also can obtained information through emails, bulletin board systems, Internet newsgroups and other web applications.

Extending application range of GDSS: Web-based GDSS can use web environment as a development and delivery platform [22]. More recently, both e-business and e-government are increasing their demands for more online data analysis and decision support. The web platform, which is also a platform for e-business and e-government development, lends web-based GDSS to have widespread use and adoption in organizations. Also, organizations can use web-based GDSS proving group decision support capability to managers over a proprietary Intranet, to customers and suppliers over an Extranet, or to any stakeholder over the global Internet.

Reducing technological barriers: web-based GDSS can reduce technological barriers and make less costly to develop and delivery itself and provide decision-relevant information [24]. Traditionally, GDSS required specific software on user computers, specific locations to set up, and users needed proper training to learn how to use a GDSS. From the web platform, GDSS do not require any specific support in software, location and user training. Further, by using the web, GDSS have a convenient and graphical user interface with visualization possibilities, and therefore are automatically available to large number of decision makers. As a result, managers who have not used GDSS before will find web-based GDSS powerful and convenient. Managers who have been exposed to traditional GDSS tools in the 1980s and 1990s will find that web-based GDSS have provided more support that the traditional techniques could not, including easily accessible and unique user interface.

Improving effectiveness of decision-making performance: Building web-based GDSS can increase the range and depth of information access, and therefore improve the solving of decision problems and the effectiveness of decision-making performance [25]. Decision-making, especially at upper management levels, relies heavily on data sources outside the organization. The web-based GDSS by using web mining and related web intelligence techniques allow decision makers to access internal and external data sources, such as competitor's product/service offerings, during the decision-making process. In particular, the organizations will find that web-based GDSS can more effectively assist their decision groups in making organizational strategic decisions where group members are distributed in different locations [22].

There is sufficient evidence showing that web-based GDSS can extend the applications of traditional GDSS and support more effectively organizational decision-making performance [26]. A number of web-based GDSS have been developed in the last few years. These include GEO-ELCA which is a web-based collaborative spatial DSS [27] and an agent-based Internet-based GDSS [8]. The development of our WFGDSS will extend current results by proving the ability of dealing with linguistic terms using general fuzzy number technique.

III. LINGUISTIC TERM ORIENTED FUZZY MULTI-CRITERIA GROUP DECISION-MAKING METHOD

This section introduces a fuzzy multi-criteria group decision-making method which consists of night steps within three levels.

Let $\boldsymbol{S} = \{\boldsymbol{S}_1, \boldsymbol{S}_2, \ldots, \boldsymbol{S}_m\}$, $m \geq 2$, be a given finite set of alternative solutions for a decision problem, and $\boldsymbol{P} = \{\boldsymbol{P}_1, \boldsymbol{P}_2, \ldots, \boldsymbol{P}_n\}$, $n \geq 2$, be a given finite set of group members to select a satisfactory solution from $\boldsymbol{S}$. The proposed method is described as follows.

Level 1: *Assessment-criteria and individual weight generation*

Step 1: Each group member $\boldsymbol{P}_k$ (k = 1, 2, ..., n) can propose one or more assessment-criteria $(C_{k_1}^k, C_{k_2}^k, \cdots, C_{k_p}^k)$, *p=1, 2… w*, for selecting a solution from alternatives. All members' assessment-criteria are put into a criterion pool and top-T criteria, $\boldsymbol{C} = \{\boldsymbol{C}_1, \boldsymbol{C}_2, \ldots, \boldsymbol{C}_t\}$, are chosen as assessment-criteria for the decision problem in the group.

Step 2: As group members play different roles in an organization and therefore have different degree of influence for the selection of the satisfactory solution. That means the relative importance of each group member may not equal in a decision group. Some members, in particular the group leader, are more powerful than the others for a specific decision problem. Therefore, in the method, each member is assigned with a weighting that is described by a linguistic term $\tilde{v}_k, k = 1, 2, \cdots, n$. These terms are determined through discussion in the group or assigned by higher management level before or at the beginning of the decision process. For example, $\boldsymbol{P}_k$ is assigned with 'strongly important person (SP)'. Possible linguistic terms used in the factor are shown in Table 1.

TABLE 1.
LINGUISTIC TERMS USED FOR DESCRIBING WEIGHTS OF GROUP MEMBERS

Linguistic terms	Fuzzy numbers
General decision person (GP)	f_1
Weakly important person (WP)	f_2
Strongly important person (SP)	f_3
The most important person (TP)	f_4

Level 2: *Individual Preference and Judgment Generation*

Step 3: Each group member $\boldsymbol{P}_k$ (k = 1, 2, ..., n) is required to express his/her opinion for assessment-criteria by pairwise comparison of the relative importance of these criteria using Analytic Hierarchy Process (AHP) method.

An initial pairwise comparison matrix $\boldsymbol{E} = [\tilde{e}_{ij}^k]_{t \times t}$ is first established, where $\tilde{e}_{ij}^k$ represents the quantified judgments on pairs of assessment-criteria $\boldsymbol{C}_i$ and $\boldsymbol{C}_j$ (i, j =1, 2, …, t, $i \neq j$). The comparison scale belongs to a set of linguistic terms that contain various degrees of preferences required by the group member $\boldsymbol{P}_k$ (k = 1, 2, ..., n), or take a value '*'. The linguistic terms are show in Table 2. Character '*' represents that group member $\boldsymbol{P}_k$ (k = 1, 2, ..., n) doesn't know or cannot compare the relative importance of assessment-criteria $\boldsymbol{C}_i$ and $\boldsymbol{C}_j$.

TABLE 2.
LINGUISTIC TERMS USED FOR THE COMPARISON OF ASSESSMENT-CRITERIA

Linguistic terms	Fuzzy numbers
Absolutely more unimportant (ANI)	a_1
Strongly more unimportant (SNI)	a_2
Weakly more unimportant (WNI)	a_3
Equally important (EI)	a_4
Weakly more important (WI)	a_5
Strongly more important (SI)	a_6
Absolutely more important (AI)	a_7

By using following linguistic variable inference rules, the inconsistence of each pairwise comparison matrix $\boldsymbol{E} = [\tilde{e}_{ij}^{k}]_{t\times t}$ is corrected:

Positive-Transitive rule: If $\tilde{e}_{ij}^{k} = a_s \ (s = 4, 5, 6, 7)$, and $\tilde{e}_{jm}^{k} = a_t \ (t = 4, 5, 6, 7)$, then $\tilde{e}_{im}^{k} = a_{\max(s,t)}$. For example, if $\boldsymbol{C}_i$ is '*equally important*' with $\boldsymbol{C}_j$ (s = 4), and $\boldsymbol{C}_j$ is '*strongly more important*' with $\boldsymbol{C}_m$ (t = 6) then $\boldsymbol{C}_i$ is '*strongly more important*' with $\boldsymbol{C}_m$.

Negative-Transitive rule: If $\tilde{e}_{ij}^{k} = a_s \ (s = 3, 2, 1)$, and $\tilde{e}_{jm}^{k} = a_t \ (t = 3, 2, 1)$, then $\tilde{e}_{im}^{k} = a_{\min(s,t)}$. For example, $\boldsymbol{C}_i$ is '*absolutely more unimportant*' than $\boldsymbol{C}_j$ (s = 1), $\boldsymbol{C}_j$ is a '*weakly more unimportant*' than $\boldsymbol{C}_m$ (t = 3), then $\boldsymbol{C}_i$ is '*absolutely more unimportant*' than $\boldsymbol{C}_m$.

De-In-Uncertainty rule: If $\tilde{e}_{ij}^{k} = a_s \ (s = 4, 5, 6, 7)$, $\tilde{e}_{jm}^{k} = a_t \ (t = 3, 2, 1,)$ or *, then $\tilde{e}_{im}^{k} = a_i$ for any $t \le i \le s$ or *. For example, $\boldsymbol{C}_i$ is '*weakly more important*' with $\boldsymbol{C}_j$ (s = 5) and $\boldsymbol{C}_j$ is '*strongly more unimportant*' with $\boldsymbol{C}_m$ (t = 2), then $\boldsymbol{C}_i$ can have any relationship between '*strongly more unimportant*' and '*weakly more important*', such as '*equally important* (i = 4)' or '*', with $\boldsymbol{C}_m$.

In-De-Uncertainty rule: If $\tilde{e}_{ij}^{k} = a_s, (s = 3, 2, 1)$ or *, and $\tilde{e}_{jm}^{k} = a_t \ (t = 4, 5, 6, 7)$, then $\tilde{e}_{im}^{k} = a_i$ for any $s \le i \le t$, or *. For example, $\boldsymbol{C}_i$ is '*weakly more unimportant*' with $\boldsymbol{C}_j$ (s = 3) and $\boldsymbol{C}_j$ is '*strongly more important*' with $\boldsymbol{C}_m$ (t = 6) then $\boldsymbol{C}_i$ can have any relationship between '*weakly more unimportant*' and '*strongly more important*', such as '*equally important* (i = 4)' or '*', with $\boldsymbol{C}_m$,

Consistent weights $w_i^k \ (i = 1, 2, \cdots, t)$ for every assessment-criterion can be determined by calculating the geometric mean of each row of the matrix $[\tilde{e}_{ij}^{k}]_{t\times t}$ where $e_{ij}^{k} \ (j = 1, 2, \cdots, i_k)$ is not '*', and then the resulting fuzzy numbers are normalized and denoted as $\tilde{w}_1^k, \tilde{w}_2^k, \cdots, \tilde{w}_t^k$, where $\tilde{w}_i^k \in F_T^*(R)$ and

$$\tilde{w}_i^k = \frac{w_i^k}{\sum_{i=1}^{t} w_{i\ 0}^{k\ R}}, \quad \text{for } i = 1, 2, \cdots, t; k = 1, 2, \cdots, n. \tag{10}$$

Step 4: Against every assessment-criterion $\boldsymbol{C}_j$ (j = 1, 2, ..., t), a belief level can be introduced to express the possibility of selecting a solution $\boldsymbol{S}_i$ under criterion $\boldsymbol{C}_j$ for a group member $\boldsymbol{P}_k$. The belief level $b_{ij}^k \ (i = 1, 2, \cdots, t, \ j = 1, 2, \cdots, m, k = 1, \ 2, ..., n)$ belongs to a set of linguistic terms that contain various degrees of preferences required by a group member $\boldsymbol{P}_k$ (k = 1, 2, ..., n) under jth assessment-criterion (j = 1, 2, ..., t). The linguistic terms for variable 'preference' are shown in Table 3. Notation '**' can be used to represent that group member $\boldsymbol{P}_k$ doesn't know or could not give a belief level for expressing the preference for a solution $\boldsymbol{S}_i$ under assessment-criterion $\boldsymbol{C}_j$.

Step 5: Belief level matrix $(b_{ij}^k)(k = 1, 2, \cdots, n)$ is aggregated in to belief vector $(\bar{b}_j^k)$ (j = 1, 2, ..., m, k = 1, 2, ..., n).

$$\bar{b}_j^k = \tilde{w}_{j_1}^k * b_{jj_1}^k + \tilde{w}_{j_2}^k * b_{jj_2}^k + \cdots + \tilde{w}_{j_s}^k * b_{jj_s}^k, \tag{11}$$

where $b_{jj_i}^k \ (i = 1, 2, \cdots, s)$ is not '**'. Based on belief vectors $(\bar{b}_j^k)$, the group member $\boldsymbol{P}_k$ (k = 1, 2, ..., n) can make an overall judgment on the alternatives, called an individual assessment vector. All individual selection vectors can compose a group of selection matrixes $(\bar{b}_j^k)_{n\times m}$.

TABLE 3.
LINGUISTIC TERMS USED FOR PREFERENCE BELIEF LEVELS FOR ALTERNATIVES

Linguistic terms	Fuzzy numbers
Very low (VL)	b_1
Low (L)	b_2
Medium low (ML)	b_3
Medium (M)	b_4
Medium high (MH)	b_5
High (H)	b_6
Very high (VH)	b_7

Level 3: *Group Decision Aggregation*:

Step 6: As each member $\boldsymbol{P}_k$ has been assigned with a weighting $\tilde{v}_k, k = 1, 2, \cdots, n$ as shown in Table 1, a weight vector is obtained:

$$V = \{\tilde{v}_k, k = 1, 2, \cdots, n\}.$$

The normalized weight of a group member $\boldsymbol{P}_k$ (k = 1, 2, ..., n) is denoted as

$$\tilde{v}_k^* = \frac{\tilde{v}_k}{\sum_{i=1}^{n} v_{i\ 0}^{\ R}}, \quad \text{for } k = 1, 2, \cdots, n. \tag{12}$$

Step 7: Considering the normalized weights of all group members, we can construct a weighted normalized fuzzy decision vector

$$(\tilde{r}_1, \tilde{r}_2, \cdots, \tilde{r}_m) = (\tilde{v}_1^*, \tilde{v}_2^*, \cdots, \tilde{v}_n^*)\begin{pmatrix} \bar{b}_1^1 & \bar{b}_2^1 & \cdots & \bar{b}_m^1 \\ \bar{b}_1^2 & \bar{b}_2^2 & \cdots & \bar{b}_m^2 \\ \vdots & \vdots & \ddots & \vdots \\ \bar{b}_1^n & \bar{b}_2^n & \cdots & \bar{b}_m^n \end{pmatrix}, \tag{13}$$

where $\tilde{r}_j = \sum_{k=1}^{n} \tilde{v}_k^* \bar{b}_j^k$.

Step 8: In the weighted normalized fuzzy decision vector the elements $\tilde{v}_j, \ j = 1, 2, \cdots, m$, are normalized positive fuzzy numbers and their ranges belong to closed interval [0, 1]. We can then define fuzzy positive-ideal solution (FPIS, r^*) and fuzzy negative-ideal solution (FNIS, r^-) as:

$$r^* = 1 \quad \text{and} \quad r^- = 0.$$

The positive and negative solution distances between each $\tilde{r}_j$ and r^*, $\tilde{r}_j$ and r^- can be calculated as:

$$d_j^* = d(\tilde{r}_j, r^*) \quad \text{and} \quad d_j^- = d(\tilde{r}_j, r^-), \quad j = 1, 2, \cdots, m, \qquad (14)$$

where $d(.,.)$ is the distance measurement between two fuzzy numbers.

Step 9: A closeness coefficient is defined to determine the ranking order of all solutions once the d_j^* and d_j^- of each decision solution $\boldsymbol{S}_j$ (j = 1, 2, ..., m) are obtained. The closeness coefficient of each solution is calculated as:

$$CC_j = \frac{1}{2}\left(d_j^- + (1 - d_j^*)\right), \quad j = 1, 2, \cdots, m. \qquad (15)$$

The solution $\boldsymbol{S}_j$ that corresponds to the $Max(CC_j$, j=1, 2, …, $m)$ is the satisfactory solution of the decision group.

If the selected solution cannot be accepted by the decision group two actions can be taken. One is to change assessment-criteria particularly when further information is available, and another is to remove the worst alternative solution and redo the decision-making process. The 'worst' solution is one that corresponds to the $Min(CC_j;\ j = 1, 2, \ldots, m)$.

IV. WFGDSS AND ITS APPLICATION

This section presents the design and implementation of WFGDSS. An illustrated example is given to demonstrate the application of WFGDSS.

A. Architecture and working process of the WFGDSS

The architecture of WFGDSS is shown in Fig. 2. The web server manages all web pages of the system, traces user information and provides simultaneously services to multiple group members through sessions, applications and coking facilities. All web pages developed in WFGDSS, for interacting dynamically to group members in solving multi-criteria group decision-making problems with linguistic terms, are created on the fly by the web server. Using a server side application program, the web server can manage and implement client tasks. The database sever interacts with the web sever by using an ODBC connection. The system is developed and implemented mainly in JSP combined with HTML and JavaScript.

The working process of a decision group using WFGDSS is described as follows.

The group leader first uses a browser to log in the system and define a decision-making group including the name of group and the decision problem through the web. The server checks the group's name assigned by the group leader. If the group name is valid, the server registers the group in the database and sends an approval to the client side. Other group members can then log in and register on the group through the web.

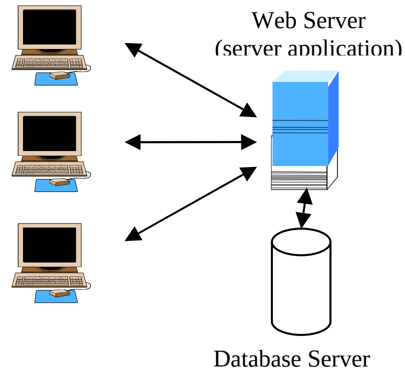

Fig. 2: Architecture of WFGDSS

The alternatives for the decision problem need to be stored into the database of WFGDSS before all members log in. After the group is set up the alternatives will be fetched from the database server and sent to client side by the server application. Based on these alternatives, each group member including the group leader proposes one or more assessment-criteria for selecting an alternative as the group satisfactory solution. All proposed assessment-criteria are then collected by the server application.

Referring to the assessment-criteria received from the server application, the group leader chooses top-T criteria as assessment-criteria for the decision problem in the group. As group members play different roles, the leader will assign weights, described by linguistic terms, to all group members. All data about top-T assessment-criteria and member's weights will be sent to the server, and then the database server for storage.

Based on the assessment-criteria and alternatives received, each group member is required to fill up a pairwise comparison matrix of the relative importance of these criteria and a belief level matrix to express the possibility of selecting a solution under some criteria. Once group members' two matrices are received, the server application first corrects the inconsistence of each pairwise comparison matrix of assessment-criteria based on linguistic inference rules, then calculate the belief level matrices, the belief vector, the normalized weights of group members, the weighted normalized fuzzy decision vector and the closeness coefficients of all alternatives consecutively. Finally, the web server constructs a final group decision page where the most satisfying group solution, which is corresponding to the maximum closeness coefficient, is displayed to all the group members.

B. An application of the WFGDSS

An executive group of a tourism company tries to determine which IT consulting firm to be hired in order to develop its e-tourism system. The main objectives to develop an e-tourism system are to present the company globally, build more interactive relationships with business partners and tourists, and reduce the costs of communication and market development. Four IT consulting firms have offered the e-tourism development services and each has submitted an e-tourism system development proposal. Each firm and its proposal have advantages and disadvantages. The four firms' development proposals $\boldsymbol{S}_1$, $\boldsymbol{S}_2$, $\boldsymbol{S}_3$ and $\boldsymbol{S}_4$ are as alternatives for the tourism company. The executive group consists of three members $\boldsymbol{P}_1$, $\boldsymbol{P}_2$ and $\boldsymbol{P}_3$, and $\boldsymbol{P}_1$ is the leader. The three members have different opinions for selecting which firm to take the work and how to select one. The group must evaluate each firm's proposal by considering how to meet the company's objectives through the development of an e-tourism system.

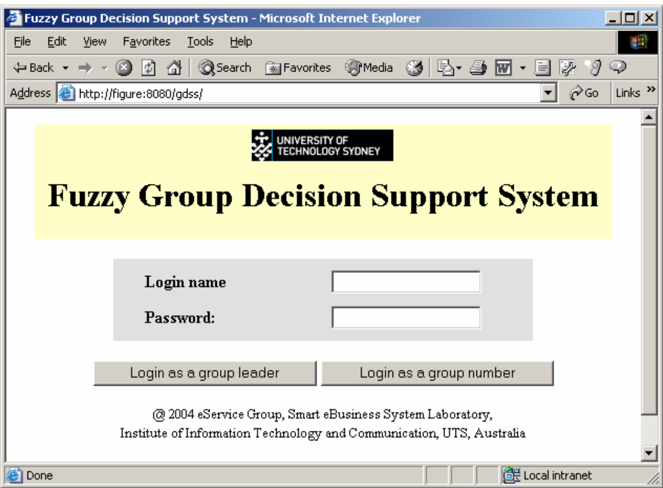

Fig. 3: Page for group member to log in

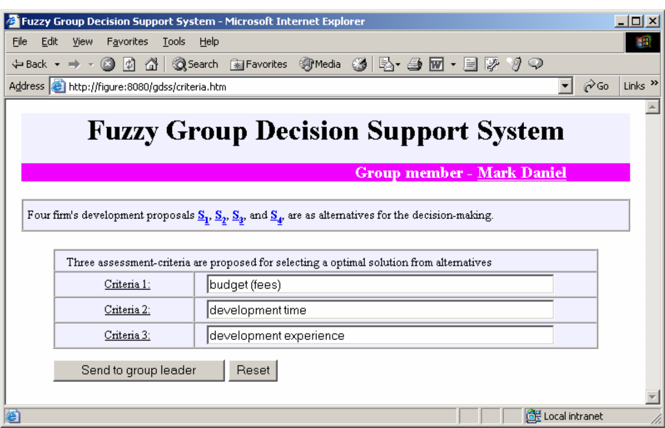

Fig. 4: Page for group member to propose assessment-criteria

Step 1: First of all, a group leader logs in to the system and defines a decision-making group as shown in Fig. 3. All other group members then join the group. Based on the four proposals, the three group members propose a number of assessment-criteria. For instance, a group member proposes budget (fees), development time and development experience as assessment-criteria for selecting a satisfactory firm from the four candidates which is shown as Fig. 4. The group leader collects all criteria as assessment-criteria and selects five: budget (fees), development time, development experience, quality of content support and quality of technique support as shown in Fig. 5.

Step 2: The group leader assigns weight "Strongly important person" to himself and "General decision maker" to other group members as shown in Fig. 5.

Step 3: Each member gives individual judgment for the five assessment-criteria by using AHP method. One group member's pairwise comparison matrix data is as shown in Fig. 6.

Step 4: Each group member gives a belief level of the possibility of selecting a solution under a criterion. One group member's belief level matrix data is shown in Fig. 6 as well.

By using linguistic inference rules, new comparison matrix and belief level matrix are shown as in Fig. 7.

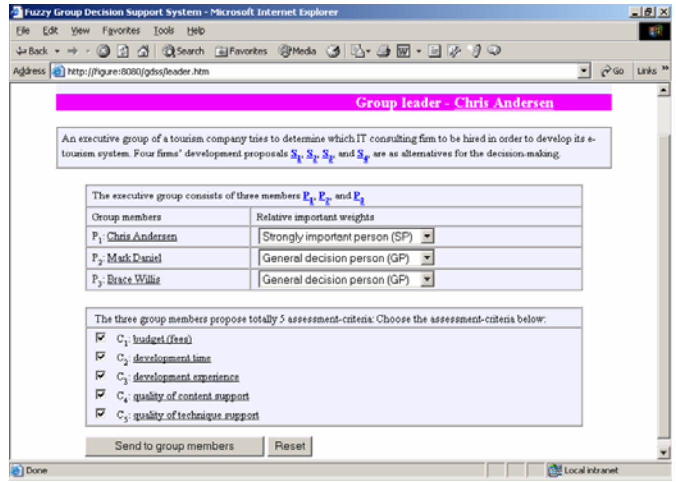

Fig. 5: Page for group leader to assign group members' weights and to choose the assessment-criteria

Step 5 –Step 9: After a series of calculation on belief vector, the weighted normalized fuzzy decision vector and the closeness coefficients of alternatives, Fig. 8 shows the closeness coefficient of all candidates and indicates the second one is the highest. That is, the second consulting firm is selected by the executive group.

The final group decision is the most acceptable by the group of individuals as a whole. A preliminary experiment has show that the model is appropriate for various multi-attribute decision problems, and can improve a group decision-making process and aid in functioning of a decision group.

V. CONCLUSION

This study first proposes a rational-political group decision-making model which carries out the advantages from both rational and political models, and therefore can handle inconsistent assessment, incomplete information and inaccurate opinions under a logical and sequential framework to get the best solution for a group decision. Based on the model, this study presents a linguistic term oriented fuzzy group decision-making method which allows group members to express their power, favor and judgment by linguistic terms. The method can use any type of fuzzy numbers to describe these linguistic terms. The method also uses inference rules to check preference consistence of each individual. The satisfactory group decision is derived as the most acceptable one for the decision group. It is very flexible and suitable for various group decision situations where alternatives are available. The method has been implemented by developing a web-based group decision support system, called WFGDSS, where the web is as a development and delivery platform. Group members can use the WFGDSS asynchronously or synchronously, and don't need any training. In particular, the WFGDSS can be embedded into existing e-business or e-government systems through simple specification.

ACKNOWLEDGMENT

This research is supported by Australian Research Council (ARC) under discovery grant DP0211701.

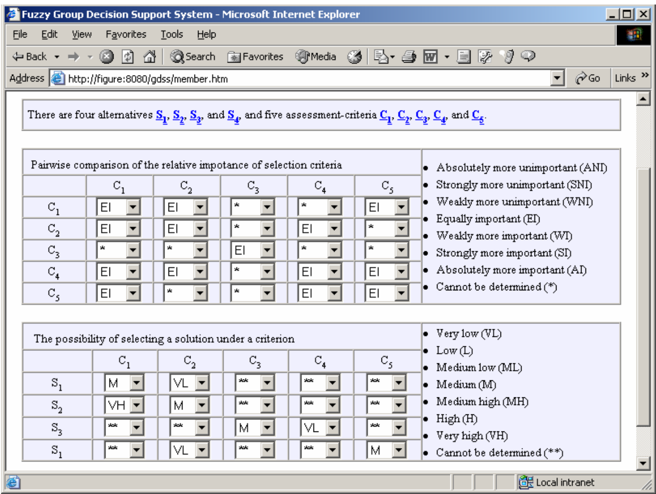

Fig. 6 Page for group member to input comparison of assessment-criteria and preferences

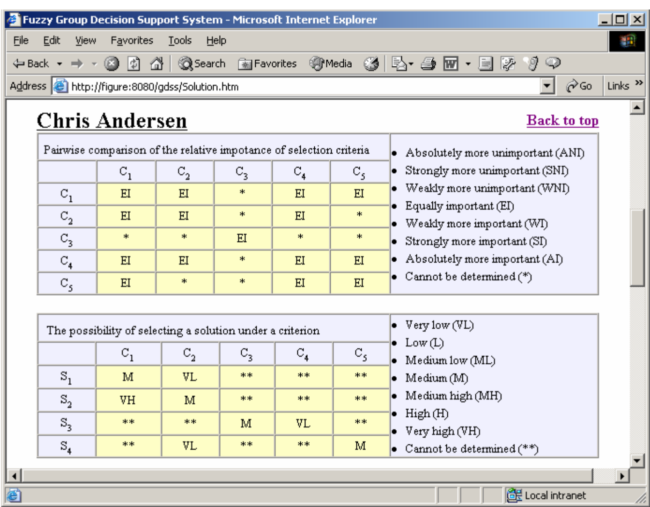

Fig. 7: Data for comparison of assessment-criteria and preferences after using linguistic inference

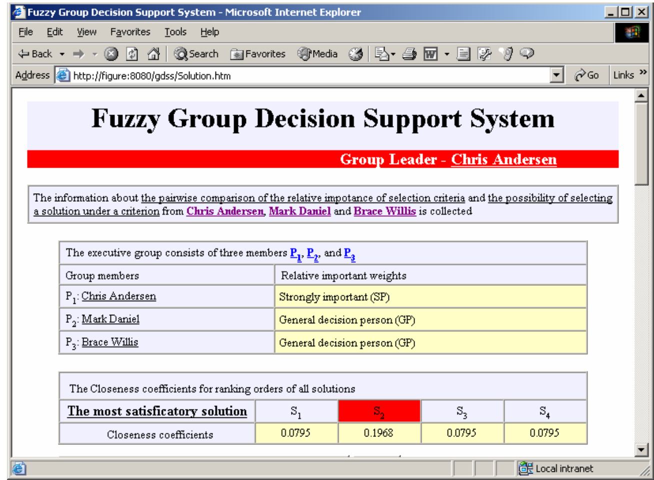

FIG. 8: PAGE FOR DISPLAYING CLOSENESS COEFFICIENTS AND THE GROUP SATISFACTORY SOLUTION

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