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On optimal decision for QoS-aware composite service selection

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ABSTRACT

The increasing popularity of employing web services for distributed systems contributes to the significance of service discovery. However, duplicated and similar functional features existing among services require service consumers to include additional aspects to evaluate the services. Generally, the service consumers would have different view on the quality of service (QoS) of service attributes. How to select the best composite service in theory among available service (WS) candidates for consumers is an interesting practical issue. This work proposes a QoS-aware service selection model based on fuzzy linear programming (FLP) technologies, in order to identify their dissimilarity on service alternatives, assist service consumers in selecting most suitable services with consideration of their expectations and preferences. This approach can obtain the optimal solution of consensual weight of QoS attribute and fuzzy positive ideal solution (FPIS) by extending LINMAP method, developed by Srinivasan and Shocker. Finally, two numerical examples are given to demonstrate the process of QoS-aware web service selection. The experimental results demonstrated that it is a feasible and supplementary manner in selecting the of web services.

1. Introduction

Web services enable business applications running on distinct platforms and exchanging data over the Internet, to be applied in business and daily life regardless of the platforms or locations. It has created unprecedented opportunities for organizations to shorten software development time by composing existing services across Internet. Effective mechanisms for supporting service discovery have considerable contribution to the success of web service composition. An efficient web service can bring a serious competitive advantage to the service providers as well as carry social welfare to the consumers. An application assisting in service selection based on certified QoS, cost and trust can bring essential benefits to the service consumers. Practically, the service providers are supposed to guarantee QoS of WS, which are advertised on the Internet for service consumers. When service providers announce their available services, current advertising approaches of web services create a WSDL or OWL-S document to subscribe the web service profile and service grounding, then promote it through UDDI registration, or other web services registries such as ebXML.

For emerging e-commerce business, the selected services are aggregated to form composite services. The composite service is a service produced by a composition of other services to complete the desired service activities (Anane, Chao, & Li, 2005). For example, Google research application are accepted as a web service and integrated with other services, such as Gmail, AdWords, You Tube and Google Maps service, to provide an integrated environment for service consumers. Microsoft and Yahoo also provide the services analogous to that of Google for business competition. The other example, consumer likes to discover the composite service, such as flight booking, restaurant reservation, and rent a car at a time, as illustrated in Fig. 1. What is the optimal approach of linking each service request to an approximate service? This problem may be nontrivial if the user requests multiple services at one time.

A number of works on composite service discovery and selection have been carried out to locate the required services and compose them to meet requirements using ontology (Zhou, Chin, & Lee, 2004, 2005) or service matchmaking techniques (Chao, Younas, Lo, & Tan, 2005; Huang et al., 2005a; Huang, Chao, & Lo, 2005b). Ontology technology is developed to answer the semantic confusion problem which could be effectively solved by semantic registration and discovery, by defining the appropriate meaning of the service's functionality. Part of researches (Ankolenkar, Burstein, & Hobbs, 2002; Borenstein & Fox, 2003; Jorge & Amit, 2006; Zhou, Chia, & Lee, 2005) on semantic service discovery were investigated via Semantics Web Service (SWS) technologies to locate the required services and compose them to meet requirements, as illustrated in Fig. 2.

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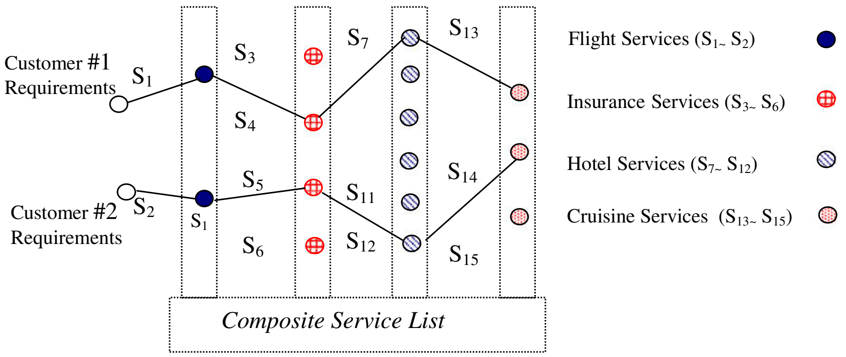

Fig. 1. The discovery and selection of composite services.

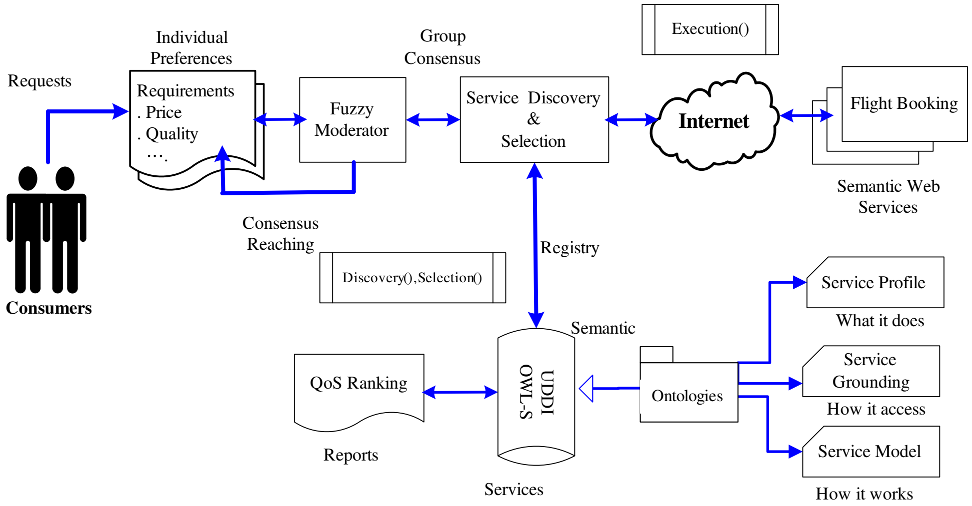

Fig. 2. The moderated fuzzy discovery, selection and execution using ontology.

The other approaches focus on fuzzy matchmaking technique that remains fuzzy semantics on terms and handle this problem via fuzzy theory. For example, moderated fuzzy discovery method (Huang et al., 2005a, 2005b), measures the similarity between services in terms of capability, syntax and semantics through a moderator initiates to minimize the differences among service consumers and providers.

For the consumer consensus of WS selection issue, service consumers and providers may have different expectations, experiences, and preferences about the services. Furthermore, consumer preferences often remain imprecise, uncertain or ambiguous on service QoS terms; the preferences over the QoS attributes are hard to be quantified especially in distinguishing the importance among these service attributes. Therefore, the adoption of fuzzy terms such as reasonable price, reliable service, and comfortable feeling in the requests becomes inevitable. Moreover, consumers usually have distinct view with providers for service terms, such as “*cheap flight ticket*”, “*comfortable leg-room*” or “*delicious food*”, simply because they have divergent perception of these terms.

From the consumers’ point of view WS providers usually advertise on the Internet exaggerating the features of web services for appealing to customers, which might lead to misunderstanding or confusing about some service terms for WS consumers. In addition, the providers prefer to advertise their services to customers in subjective terms, which might be short of considering the consumers’ expectations and preferences.

Hence, it is imperative to reach the consensus for service consumers on the specific specification terms (i.e., QoS), where they find and search WSDL document in the service discovery process. Based on these requirements, W3C working group has defined various QoS attributes for WS. That document comprises a number of generic and specific items for cross-referencing between the possible needs of service consumers and the functions supported by web services. Although regular QoS attributes have been listed, some unclear problems are yet to be clarified on selection of WS processes. For example, QoS attributes perception of importance is generally different from consumers and providers preferences. It is widely accepted that the consumers have been taking an active role in the expansion of e-commerce.

In this paper we consider optimal service selection based on a given set of service requests interacted with a set of service candidates using fuzzy linear programming (FLP) model (Li & Yang, 2004). This investigation leads to a need of developing a group consensus-centric approach to investigate QoS attribute preferences and determine the ranking order of service alternatives according to the distance from the positive ideal solution under group consensus. Consequently, service consumer is able to reduce redundancy in search, and service provider can improve the quality of services.

The remainder of the paper is organized as follows. Section 2 describes the existing QoS-aware selection of web service methods. Section 3 describes proposed method. Section 4 reports on two illustrational examples of selection of service alternatives. Finally, Section 5 illustrates the conclusion and the future work.

2. Available solutions for web service selection

A number of studies for web service selection have been carried out. One of the most well known techniques is ''matchmaking''. It is employed in the situation where services with semantic descriptions for their functional attributes are available in the Internet search system. How to ensure the QoS of web services for service consumers. Ran (2003) proposed a new QoS-based service registration and discovery model to explore the possibility of QoS involving into UDDI registry information. In this model, service providers have to send QoS claims to service QoS certifiers, responding to third party or forum web services, for certification. The service customer is responsible to verify QoS claims. The QoS information finally will be registered in the UDDI registry associated with function description, if QoS claims have passed QoS certifier verification.

The new UDDI registration mechanisms help customers to discover and locate the required service by looking up WSDL document as well as certified QoS. Moreover, consensus of service consumers on QoS attributes has to be considered for web service QoS certifier in the QoS computation process. Balke and Wagner (2003) introduced the ''cooperative discovery'' concept for evaluating web services in detail which composes three phases of interaction with services, i.e., (i) service discovery, (ii) service selection, and (iii) service execution. Based on Fig. 2 we reorganized three phases as Table 1, which specifies the extensive definition for selection of QoS-aware web services provisioning.

Several service matchmaking techniques have been developed to meet the needs of both consumers and providers. Zeng et al. (2004) addressed this issue of selecting web services by maximizing user satisfaction expressed as utility functions over QoS attributes; Kaufmann and Gupta (1991) and Sirin et al. (2004) developed a goal-oriented and interactive composition approach that uses matchmaking algorithms to help users filter and select services while building their composition service. Zhou et al. (2005) discriminated between functional and non-functional QoS properties of web services, where functional properties can be measured in terms of throughput, latency, response time; where non-functional properties are addressing of various issues including integrity, reliability, availability and security of web services. The current techniques and tools for measurement are more suitable to quantify functional QoS properties (for example, network throughput, latency, and response time) than non-functional properties. Basically, non-functional QoS properties rely heavily on the perceptions of service providers and consumers that are not easy to assess due to the fact of complexity and the involvement of ill-structured information. Liu, Ngu, and Zeng (2004) treated the selection of QoS-driven web service with dynamic composition as a fuzzy constraint satisfaction problem and applied an optimal search approach with adjustments to service composition; The ''matchmaking'' approach, however, relies on the advertisements from service providers' subjective views that could lead to divergent perception between consumers and providers. Consumer expectations and their common preferences (i.e., consensus) on QoS should be considered in the process of service selection. The aforementioned three major approaches are compared as illustrated in Table 2.

To see in detail, composite service search approaches solved by numerical methods can be generally divided into two categories: Multiple Attribute Decision Making (MADM) and mathematical programming. MADM methods (Huang et al., 2005a; Liu et al., 2004; Zhou et al., 2004) concentrates on that QoS attributes be collected and enforced objectively, then MADM theory can be applied to obtain a consistent ranking of service alternatives. Mathematical programming methods (Sirin, Parsia, & Hendler, 2004; Zeng et al., 2004) comprise linear programming (a single objective function) and multiple goal programming. It concerns about interactive composition selection that use a preset planning to optimally select component services during the execution of a composite service.

Those methods advanced the knowledge in QoS-aware service discovery and selection, but nevertheless, remained the following significant issues for debate: (i) The perception of QoS attributes needs to adjust according to consumer's preferences, (ii) How to objectively determine weights (importance) of QoS attributes and

Table 1
QoS-aware web services discovery and selection.

Phases	Operation	Tasks	Task description
Phase I	Service registry	Function definition Service registry	Specify the terms of WS functionalities using ontology language or WSDL Register and receive a official ID for applied service to publish to the Internet
Phase II	Service discovery	QoS certification Service advertisement Service discovery Service selection	Accept and certify the application of service QoS attributes Announce the features of WS Perform and find the related services based on a user's request Select one of the desired service
Phase III	Service execution	Service execution QoS monitoring	Carry out service binding and execution Collect customer opinions to QoS certifier for reflecting user expectation

Table 2
The comparison of three approaches for selection of web services.

	Matchmaking technique	Composite service search method	Consensus moderation approach
Assumptions	A service description may be booked in registry	Service specification is described with standard ontology tool such as WSDL and DAML-S	QoS recognized by consumer's expectations and group consensus are considered
Features	The research engine always makes use of a matching algorithm to retrieve some services	The selection of web service is an iterative process to discover and compose the services under some constraints	The fuzzy group decision-making methods is employed to assist service consumers in discovering appropriate services
Suitable for	The definition of QoS criteria are clear between consumers and providers	The definition of QoS criteria are clear The successive selection of web services to satisfy the requirements	QoS criteria may be vague between consumers and providers

(iii) The ranking order of service alternatives should be decided on the basis of group consensus. To enable effective QoS-aware composite service selection, a new web service model is proposed, which included the following important aspects:

- Vague preference. This model should be able to handle vague preferences or linguistic opinions for QoS attributes expressed by service consumers in the process of selecting web services.
- Weighting of QoS attributes. Be able to explore the optimal solution of weighting of QoS attributes.
- Service ranking. The approach should be capable of realistically gaining a consensual ranking on web service alternatives according to consistence and inconsistence measurement between individual ratings and ideal performance solution.

To fulfill these requirements, we extend our previous work (Wang, Chao, Lo, Huang, & Li, 2006), to select QoS-aware composite services using fuzzy linear programming techniques by minimizing the inconsistency measurement. More detailed information about this model is described in the next section.

3. An QoS-aware services selection model based on LINMAP

In this section, we introduce a new fuzzy group consensus-aware service selection model, which extends LINMAP (LINear programming techniques for Multidimensional Analysis of Preference) method, developed by Srinivasan and Shocker (1973). In the LINMAP, decision maker gives the performance ratings matrix of alternatives with a pair wise comparison form to obtain the best solution that has the shortest distance to positive ideal solution (PIS) (Hwang & Yoon, 1981). The aim of the model is to find the optimal weighting of QoS attribute for a set of web services and locate fuzzy positive ideal solution (FIPS) considering group consensus, and determine a rational ranking order of web service alternatives.

3.1. Basic definitions and notations

In this section, we review some arithmetic operations on fuzzy numbers for the purpose of representing the proposed algorithm in Section 3.2 (Kaufmann & Gupta, 1991).

Definition 1 (*Triangular fuzzy number (TFN)).* A triangular fuzzy number $\widetilde{A}$ can be defined by (a, b, c). The membership function is defined as

$$u_{\tilde{A}}(x) = \begin{cases} 0 & \text{for } x > a \\ \frac{x-a}{b-a} & \text{for } a \leqslant x < b \\ \frac{c-x}{c-b} & \text{for } b < x \leqslant c \\ 0 & \text{for } x < c \end{cases} \tag{1}$$

Definition 2 (*Fuzzy arithmetic operations*). The arithmetic operations of the positive fuzzy numbers described by the interval of confidence are expressed below:

$$\begin{aligned} &\text{Addition } \oplus : (a_1, b_1, c_1) \oplus (a_2, b_2, c_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2) \\ &\text{Subtraction } - : (a_1, b_1, c_1) - (a_2, b_2, c_2) = (a_1 - a_2, b_1 - b_2, c_1 - a_2) \\ &\text{Multiplication } \otimes : \tilde{A} \otimes \tilde{B} = (a_1, b_1, c_1) \otimes (a_2, b_2, c_2) = (a_1 a_2, b_1 b_2, c_1 c_2) \\ &\tilde{A} \otimes \tilde{B} = (a_1, b_1, c_1) \otimes (a_2, b_2, c_2) = (a_1 a_2, b_1 b_2, c_1 c_2) \\ &k \otimes \tilde{A} = k \otimes (a_1, b_1, c_1) = (ka_1, kb_1, kc_1) \quad \forall k \in R \\ &\text{Division } / : \tilde{A}/\tilde{B} = (a_1, b_1, c_1)/(a_2, b_2, c_2) = ((a_1/c_2, b_1/b_2, c_1/a_2)). \end{aligned} \tag{2}$$

Definition 3 (*The normalized Euclidean distance between two triangular fuzzy numbers).* If $\tilde{A}$ and $\tilde{B}$ are two TFNs, then the normalized Euclidean distance between $\tilde{A}$and $\tilde{B}$ can be calculated as

$$e(\tilde{A}, \tilde{B}) = \left(\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]\right)^{1/2} \tag{3}$$

Definition 4 (*The weighted square distance from positive ideal solution, $\tilde{r}_j^*$).* If $\tilde{r}_{ij}$ is an individual rating, then the *weighted square distance* between $\tilde{r}_{ij}$and $\tilde{r}_j^*$can be calculated as (Hwang & Yoon, 1981)

$$d_i = \sum_{j=1}^{n} w_j \left(\tilde{r}_{ij} - \tilde{r}_j^*\right)^2, \quad i = 1, 2, \ldots, m \tag{4}$$

3.2. Consistence and inconsistence measurements

Consider the problem of ranking WS alternatives a_i $(i = 1, \ldots, m)$. A group of decision makers $(d_p, p = 1, \ldots, q)$ is formed to identify n QoS attributes, say c_j $(j = 1, \ldots, n)$. Each decision maker has to assign performance rating $\tilde{x}_{ij}(d_p)$ to service alternatives, $\tilde{x}_{ij}(d_p)$ represents the rating of web service s_i with respect to criterion c_j evaluated by d_p. If $\tilde{x}_{ij}(d_p)$ is a fuzzy data expressed by linguistic terms, then it must be converted to a triangular fuzzy number (TFN) of the form (a_{ij}, b_{ij}, c_{ij}) defined in Definition 1, where a_{ij}, b_{ij}, c_{ij} are real numbers and $a_{ij} \leqslant b_{ij} \leqslant c_{ij}$. The performance rating matrix $\widetilde{X}$ assessed by decision maker d_p is shown as Eq. (4)

$$\widetilde{X}(d_p) = [\tilde{x}_{ij}(d_p)] = \begin{array}{c c} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \end{array} \\ \begin{array}{c} s_1 \\ s_2 \\ \vdots \\ s_m \end{array} & \left[\begin{array}{cccc} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{array}\right] \end{array} \tag{5}$$

where $\oplus$ and $\otimes$ represent fuzzy additive and multiplication operation that defined in Definition 2, respectively. $\tilde{x}_{ij}(d_p)$ might be crisp (nonfuzzy) or fuzzy form depending on the nature of QoS attributes. When $\tilde{x}_{ij}(d_p)$ is a nonfuzzy datum, it should be converted from the distinct scales of ratings to a numerically comparable scale. In contrast, if $\tilde{x}_{ij}(d_p)$ is a fuzzy form then it has to be normalized by using Eq. (5) to rank the web services compatibly between evaluation QoS attributes. For QoS attributes, two types simultaneously exist: *benefit*-oriented and *cost*-oriented. Both are mutually conflict and inconsistent and needs to be trade-off. To avoid generating an outbound condition, when $\tilde{r}_{ij}$ exceeds the value 1, it needs to be constrained by upper bound 1. The linear scale transformation is used for forming the normalized fuzzy matrix $\tilde{R}$ as (Chen, 2000)

$$\begin{aligned} &\tilde{R} = [\tilde{r}_{ij}]_{mxn} \\ &\tilde{r}_{ij} = \frac{\tilde{x}_{ij}}{\tilde{x}_j^*} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \wedge 1\right) \quad \forall \tilde{j}, \tilde{x}j \in B \\ &\tilde{r}_{ij}^- = \frac{\tilde{x}_i^-}{\tilde{x}_{ij}} = \left(\frac{a_j^-}{c_j^*}, \frac{b_j^-}{c_j^*}, \frac{c_j^-}{c_j^*} \wedge 1\right) \quad \forall j, \tilde{x}j \in B \end{aligned} \tag{6}$$

where

$$a_j^* = \max_i\ a_{ij}, \quad b_j^* = \max_i\ b_{ij}, \quad c_j^* = \max_i c_{ij}, \ \text{if } j \in B$$
$$a_j^- = \min_i\ a_{ij}, \quad b_j^- = \min_i\ b_{ij}, \quad c_j^- = \min_i c_{ij}, \ \text{if } j \in C$$

where U, C represent a set of *benefit-based* and *cost-based QoS* attributes, respectively.

Studies regarding distance-based consensus methods have been carried out (Cook, 2006; Cook, Kress, & Seiford, 1997), with focus on solving the nonfuzzy ranking order problems. Cook, Kress, and Seiford (1997) investigated two specific cases (i.e., $s = 1; s = 2$) to solve the consensus degree of group on ordinal rankings; the general form of consensus measurement function is constructed by minimizing a normalized weighted metric distance between individual opinions and positive ideal solution (PIS), D_i, that is,

$$\text{Min } D_i = \sum_{j=1}^{n} (w_j |r_{ij} - r_j^*|^s)^{1/s}, \quad i = 1, 2, \ldots, m \tag{7}$$

where w_j is the weighting of QoS attribute j, $(|r_{ij} - r_j^*|^s)^{1/s}$ is Minkowski metric, s is metric number. For example, $s = 2$, then D_i becomes as

$$d_i = \sum_{j=1}^{n} (w_j |r_{ij} - r_j^*|^2)^{1/2} \tag{8}$$

In this paper, we address the consistence measurement of service customers by aggregated difference between fuzzy performance ratings of each alternative and fuzzy positive ideal solution (FPIS). Then the square distance, s_i, defined in LANMAP, is used for assessing the weights of QoS attributes, that is,

$$s_i = \sum_{j=1}^{n} w_j (\tilde{r}_{ij} - \tilde{r}_j^*)^2, \quad i = 1, 2, \ldots, m. \tag{9}$$

As $\Omega = \{(k, l) | a_k P a_l, k, l = 1, \ldots, m\}$ denotes a set of preference relations which is composed of the ordered pairs (k, l) for service alternatives, where P represents a preference relation given by decision maker. There are $n(n-1)/2$ elements in Ω. Member $a_k P a_l$ represents that decision maker prefers a_k to a_l. Furthermore, analogous to s_i, the fuzzy form of square distance between a pair of alternative $(k, l), S_k$ and S_l, is defined by square distance using the normalized Euclidean distance, defined in Definition 3, as follows:

$$\begin{aligned} S_k &= \sum_{j=1}^{n} w_j [e(\tilde{r}_{kj}, \tilde{r}_j^*)]^2 \\ S_l &= \sum_{j=1}^{n} w_j [e(\tilde{r}_{lj}, \tilde{r}_j^*)]^2 \end{aligned} \tag{10}$$

By definition of inconsistence measurement, inconsistence index, $(S_l - S_k)^-$, measuring the discrepancy between $S_l$and S_k, is given by

$$(S_l - S_k)^- = \begin{cases} 0, & \text{if } (S_l \geqslant S_k) \\ S_k - S_l, & \text{if } (S_l < S_k) \end{cases} = \max\{0, (S_k - S_l)\} \tag{11}$$

Then, the inconsistence measurement for all the ordered pairs (k, l) for all service alternatives in Ω can be computed by

$$B = \sum_{(k,l)\in\Omega} (S_l - S_k)^- = \sum_{(k,l)\in\Omega} \max\{0, (S_k - S_l)\} \tag{12}$$

Similar to Eq. (11), the consistence measurement between S_l and S_k, $(S_l - S_k)^+$, is given by

$$(S_l - S_k)^+ = \begin{cases} S_l - S_k, & \text{if } (S_l \geqslant S_k) \\ 0, & \text{if } (S_l < S_k) \end{cases} \tag{13}$$

The consistence measurement for all the ordered pairs (k, l) in Ω is given by

$$G = \sum_{(k,l)\in\Omega} (S_l - S_k)^+ \tag{14}$$

3.3. Problem formulation

To avoid obtaining a trivial solution with $w_j = 0$, we add two additional constraints, $G - B = h$, where h is also an arbitrary positive number, and $w_j \geqslant \delta$, where δ may be zero or a sufficient positive number. Our goal is to obtain the optimal solution of weight of QoS attribute and fuzzy positive ideal solution (FIPS), $(w, \tilde{r}^*)$ in term of minimizing the inconsistence measurement B. The constraint, $G - B = h$, is needed to ensure the tolerance (h) between G and B. The problem of finding the optimal consensual weights and positive ideal values of solution can be formulated as a linear programming model as follows:

$$\begin{aligned} &\text{Min} \quad B \\ &\text{s.t.} \quad \begin{cases} G - B = h \\ w_j \geqslant \delta, \quad j = 1, \ldots, n \end{cases} \end{aligned} \tag{15}$$

By the definition of Eqs. (11) and (13), we have

$$(S_l - S_k)^+ - (S_l - S_k)^- = S_l - S_k \tag{16}$$

Substituting Eq. (16) into Eq. (15), then it can be rewritten as

$$G - B = \sum_{(k,l\in\Omega)} (S_l - S_k) = h. \tag{17}$$

Therefore, the optimal solution $(w, \tilde{r}^*)$ can be obtained by solving the constrained optimized problem of

$$\begin{aligned} &\text{Min} \quad \left\{ \sum_{(k,l)\in\Omega} \max\{0, \quad (S_k - S_l) \right\} \\ &\text{s.t.} \quad \begin{cases} \sum_{(k,l\in\Omega)} (S_l - S_k) = h \\ w_j \geqslant \delta, \quad j = 1, \ldots, n \end{cases} \end{aligned} \tag{18}$$

Let $z_{kl} = \max\{0, (S_k - S_l)\}$, we have $z_{kl} \geqslant 0$ and $z_{kl} \geqslant (S_k - S_l)$, then the third and the fourth constraints are obtained. $z_{kl} \geqslant (S_k - S_l)$ can be rewritten as

$$z_{kl} + (S_l - S_k) \geqslant 0 \tag{19}$$

Adding two constraints, then Eq. (18) is obtained as

$$\begin{aligned} &\text{Min} \quad \sum_{(k,l)\in\Omega} z_{kl} \\ &\text{s.t.} \quad \begin{cases} \sum_{(k,l\in\Omega)} (S_l - S_k) = h & \text{for } (k, l) \in \Omega \\ z_{kl} + (S_l - S_k) \geqslant 0 & \text{for } (k, l) \in \Omega \\ z_{kl} \geqslant 0 & \text{for } (k, l) \in \Omega \\ w_j \geqslant \delta, & j = 1, \ldots, n \end{cases} \end{aligned} \tag{20}$$

In the following, substituting Eqs. (10)–(20), then we have

$$\begin{aligned} &\text{Min} \quad \sum_{(k,l)\in\Omega} z_{kl} \\ &\text{s.t.} \quad \begin{cases} \sum_{(k,l\in\Omega)} \sum_{j=1}^{n} w_j [e(\tilde{r}_{lj}, \tilde{r}_j^*) - e(\tilde{r}_{kj}, \tilde{r}_j^*)] = h & \text{for } (k, l) \in \Omega \\ z_{kl} + \sum_{j=1}^{n} w_j [e(\tilde{r}_{lj}, \tilde{r}_j^*) - e(\tilde{r}_{kj}, \tilde{r}_j^*)] \geqslant 0 & \text{for } (k, l) \in \Omega \\ z_{kl} \geqslant 0 & \text{for } (k, l) \in \Omega \\ w_j \geqslant \delta & j = 1, \ldots, n \end{cases} \end{aligned} \tag{21}$$

Obviously, item $\tilde{r}_j^{*2}$ will be omitted in the computation process of the first constraint. Hence a new variable $\tilde{v}_j$ is introduced to replace $w_j \tilde{r}_j$ for simplification of computation, that is,

$$\tilde{v}_j = w_j \tilde{r}_j = [a_{v_j}, b_{v_j}, c_{v_j}] \tag{22}$$

By using Definition 3, Eq. (21) can be transformed into the following form

$$\begin{aligned} &\text{Min} \quad \sum_{(k,l)\in\Omega} z_{kl} \\ &\text{s.t.} \quad \forall \begin{cases} \frac{1}{3} \sum_{(k,l\in\Omega)} \sum_{j=1}^{n} w_j [(a_{r_{lj}}^2 - a_{r_{kj}}^2) + (b_{r_{lj}}^2 - b_{r_{kj}}^2) + (c_{r_{lj}}^2 - c_{r_{kj}}^2)] \\ \quad - \frac{2}{3} \sum_{(k,l\in\Omega)} \sum_{j=1}^{n} w_j [a_{v_j} (a_{r_{lj}} - a_{r_{kj}}) + b_{v_j} (b_{r_{lj}} - b_{r_{kj}}) \\ \quad + c_{v_j} (c_{r_{lj}} - c_{r_{kj}})] = h \quad \text{for } (k, l) \in \Omega \\ z_{kl} + \frac{1}{3} \sum_{(k,l\in\Omega)} \sum_{j=1}^{n} w_j [(a_{r_{lj}}^2 - a_{r_{kj}}^2) + (b_{r_{lj}}^2 - b_{r_{kj}}^2) + (c_{r_{lj}}^2 - c_{r_{kj}}^2)] \\ \quad - \frac{2}{3} \sum_{(k,l\in\Omega)} \sum_{j=1}^{n} w_j [a_{v_j} (a_{r_{lj}} - a_{r_{kj}}) + b_{v_j} (b_{r_{lj}} - b_{r_{kj}}) \\ \quad + c_{v_j} (c_{r_{lj}} - c_{r_{kj}})] \geqslant 0 \quad \text{for } (k, l) \in \Omega \\ z_{kl} \geqslant 0 \quad \text{for } (k, l) \in \Omega \\ w_j \geqslant \delta \quad j = 1, \ldots, n \\ 0 \leqslant a_{v_j} \leqslant b_{v_j} \leqslant c_{v_j} \leqslant 1 \quad j = 1, \ldots, n \end{cases} \end{aligned} \tag{23}$$

We solve the linear programming using Simplex method, and then the optimal solution of $(w, \tilde{r}^*)$ of linear programming is yielded. Once the optimal weights of QoS attributes $(w_j, j = 1 \dots n)$ and fuzzy positive ideal solution (FIPS) of web service i are obtained, one can easily decide a ranking order by distance from FPIS. It means that the shortest distance from FPIS is the best solution.

4. Cases study

In this section, two illustrational examples for selecting an appropriate web service are used as the application of the proposed model. To examine the process of solutions respectively, the former example is a case which emphases the selection of composite service alternatives using the traditional LINMAP method, wherein QoS attributes are crisp data assessed by a single decision maker; whereas, the latter example is regarded as a group decision problem where rating format is fuzzy form given by a set of decision makers.

4.1. Numerical Case I

A set of composite service for traveller comprises four primitive services – flight, hotel, insurance and car rental serves. For flight service, there are four service alternatives, a_i $(i = 1, \dots, 4)$, are assessed by user regarding QoS attributes c_j $(j = 1, \dots, 6)$ – maximum baggage allowance (c_1), check-in efficiency (c_2), flight safety ranking (c_3), payment for baggage lost (c_4), ticket price (c_5), and satisfaction on food quality (c_6). The check-in efficiency is a scale for the passenger and baggage service in airport regarding specific airliner, its rating range residues, 1–5. For rating of flight safety, International Civil Aviation Organization (ICAO) use formulate to count the following aircraft accident items: (1) million flights, (2) fatal events, (3) adjust fatal events, (4) last fatal accident, (5) accident rate, to decide the ranks of flight safety in overall rank 1–90. The increasing score means higher flight risk to take. The decision makers assign the performance ratings to all service candidates and determine the ranking order of four candidates. The proposed model is applied to solve this problem according to the following procedures:

Step 1. Three users assess the performance rating of each service candidate and generate the individual performance rating matrix as shown in Table 3. In addition, service consumer gives the paired comparison judgments among four service candidates as follows:

$$\Omega(d) = \{(1,2), (1,3), (4,1), (3,2), (2,4), (3,4)\}$$

Step 2. The performance ratings matrix has converted the distinct scales of ratings to a numerically comparable scale in $[10, -10]$ for comparison of relative importance of each attribute as

$$R = [r_{ij}] = \begin{bmatrix} 4.50 & 1.10 & 3.00 & 1.20 & 4.50 & 4.00 \\ 5.00 & 1.30 & 5.00 & 1.50 & 5.00 & 5.00 \\ 8.00 & 0.90 & 4.00 & 1.00 & 3.80 & 2.00 \\ 4.00 & 1.00 & 3.00 & 0.90 & 3.20 & 4.00 \end{bmatrix}$$

Step 3. Let $h = 1$, and $\delta = 0.01$. We can model the linear programming problem using the crisp form v_j to replace $\tilde{v}_j = [a_{v_j}, b_{v_j}, c_{v_j}]$ and substituting r_{ij} to $\tilde{r}_{ij}$ in Eq. (23), as follows

$$\text{Min} \quad \{z_{12} + z_{13} + z_{41} + z_{32} + z_{24} + z_{34}\}$$

$$\text{s.t.} \quad \begin{cases} -45.75w_1 + 0.64w_2 + 9.0w_3 + 0.62w_4 + 1.0w_5 + 21.0w_6 \\ \quad +7.0v_1 - 0.60v_2 - 2.0v_3 - 0.4v_4 - 6.0v_6 = 1 \\ z_{12} + 14.25w_1 + 0.353w_2 + 16.0w_3 + 0.81w_4 + 4.25w_5 \\ \quad +9.0w_6 - 3.0v_1 - 0.3v_2 - 4.0v_3 - 0.6v_4 + 1.0v_5 - 2.0v_6 \geqslant 0 \\ z_{13} + 56.25w_1 - 0.4w_2 + 7.0w_3 - 0.44w_4 - 3.75w_5 \\ \quad -12.0w_6 - 9.0v_1 + 0.4v_2 - 2.0v_3 + 0.4v_4 - 1.0v_5 + 4.0v_6 \geqslant 0 \\ z_{41} + 3.75w_1 + 0.108w_2 + 0.63w_4 + 7w_5 \\ \quad -1.0v_1 - 0.10v_2 - 0.60v_4 - 2.0v_5 \geqslant 0 \\ z_{32} - 42.0w_1 + 0.750w_2 + 9.0w_3 + 1.25w_4 + 8.0w_5 \\ \quad +21.0w_6 + 6.0v_1 - 0.70v_2 - 2.0v_3 - 1.0v_4 + 2.0v_5 - 6.0v_6 \geqslant 0 \\ z_{24} - 18.0w_1 - 0.46w_2 - 16.0w_3 - 1.44w_4 - 11.25w_5 \\ \quad -9.0w_6 + 4.0v_1 + 0.4v_2 + 4.0v_3 + 1.2v_4 - 3.0v_5 + 2.0v_6 \geqslant 0 \\ z_{34} - 60.0w_1 + 0294w_2 - 7.0w_3 - 0.19w_4 - 3.25w_5 \\ \quad +12.0w_6 + 10.0v_1 - 0.30v_2 + 2.0v_3 + 0.2v_4 \\ \quad -1.0v_5 - 4.0v_6 \geqslant 0 \\ z_{12} \geqslant 0, \quad z_{13} \geqslant 0, \quad z_{41} \geqslant 0 \\ z_{32} \geqslant 0, \quad z_{24} \geqslant 0, \quad z_{34} \geqslant 0 \\ w_j \geqslant 0, \quad j = 1, \dots, 6 \end{cases}$$

Step 4. Solve the optimal solution using Simplex method. This step produces $(w, \tilde{v}^*)$ as Table 4.
The fuzzy positive ideal solution (FIPS) is located using Eq. (22)

$$r_i^* = \frac{v^*}{w} = (r_1, \dots, r_6) = (6.71, 0.0, 0.0, 0.0, 0.0, 0.0)$$

Table 4
The optimal solution of Simplex method.

Paired comparison judgments	QoS attributes (c_j)	Variable $v_j^* = w_j^* r_j^*$
$z^* = (z_{12}, z_{13}, z_{41}, z_{32}, z_{24}, z_{34})$ (0.0, 0.0, 0.5, 0.0, 0.0,0.0)	$w^* = (w_1, \dots, w_6)^T$ $(0.17, 0.0, 0.09, 0.0, 0.0, 0.00)^T$	$v^* = (v_1, \dots, v_6)$ (1.14, 0.0, 0.0, 0.0, 0.0, 0.0)

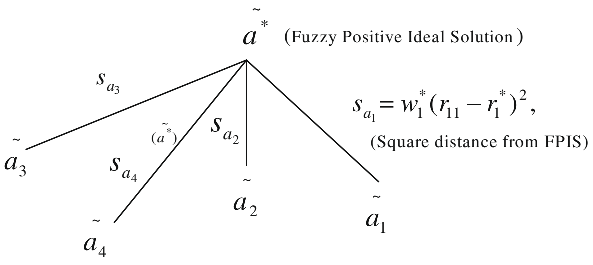

Fig. 3. The square distance of all service alternatives from FPIS $\tilde{a}^*$.

Table 3
Performance ratings of service alternatives.

Flight services (a_i)	QoS attributes (c_j)					
	Maximum baggage allowance c_1 (pounds)	Flight safety ranking c_3 (1–90)	Check-in efficiency c_2 (1–5)	Payment for baggage lost c_4 (\$) $\times 10^2$	Ticket price c_5 (\$) $\times 10^2$	Satisfaction on food quality c_6(1–5)
a_1	40	11	3	1.2	4.5	4.0
a_2	55	13	5	1.5	5.0	5.0
a_3	85	9	4	1.0	3.5	2.0
a_4	35	10	3	0.9	3.0	4.0

Step 5. Outrank the ranking of flight services.The square distance of service alternatives from PIS can be calculated using Eq. (9):

$$s_i = w_1^*(r_{i1} - r_1^*)^2, \quad i = 1, \ldots, 4, \quad j = 1$$
$$s_1 = 1.25, s_2 = 0.249, s_3 = 0.545, s_4 = 1.752.$$

From Fig. 3, we can judge the ranking order of service alternatives by the square distance of service alternatives from FPIS ($\tilde{a}^*$), that is, $\tilde{a}_2$ is the best solution. So the ranking order of flight service alternatives is generated as following: $a_2 > a_3 > a_1 > a_4$.

Step 6. Similarly way, we examine the rest of services: hotel, insurance, car rental services, obtain the complete sequence of composite web services, $a_2 - a_6 - a_9 - a_{13}$, as the recommendation which is expressed in Fig. 4.

4.2. Numerical Case II

Consider to automatically look and compose the delicacies from the available web services in Seattle. Focusing on the cuisine or fine food where we use the Google Map to specify the context, as illustrated in Fig. 5. A user requests Chinese dish service with service requests {PM 6:30–7:30, \$60–\$100, Chinese dish, distance: within 15KM}. If someone discovers no appropriate service to select, one may relax the constraints to enlarge the discovery scope, that is, Asia restaurants (including of Japan, Thai, Indian and Vietnamese cuisine). To relax constraints, it show users have some possible service alternatives and improves the quality of service provisioning from Fig. 5.

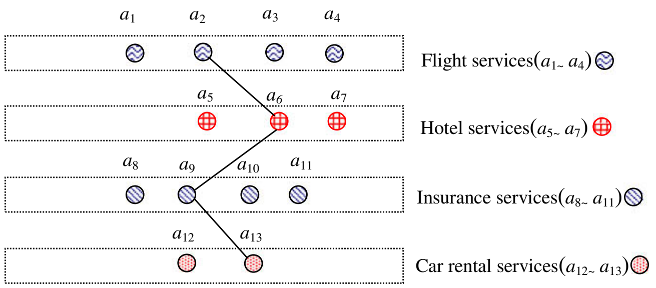

Fig. 4. Search result of a composite web service.

Three users d_p $(p = 1, \ldots, 3)$ offer their requests to select five possible service alternatives a_i $(i = 1, \ldots, 5)$ based on QoS attributes c_j $(j = 1, \ldots, 3)$—acceptable price of ticket (c_1), taste of food (c_2), service of crew (c_3). This case study focuses on the satisfaction evaluation on restaurant services for different service consumer's requests. The service customers have their different subjective preferences on the definition of the index on satisfaction. The QoS term, *satisfaction*, is defined to illustrate the preference of consumer.

Step 1. It is assumed that QoS term: *satisfaction* denoted as satisfaction ($\tilde{Q}$) combining from the following three primitive fuzzy terms,

(i) *Acceptable price*: As the cuisine price always varies on different seasons, an acceptable price range is judged by perception of customer, denoted as $\tilde{A}$ for short. For example, $\tilde{A}(a, b, c) = (100, 150, 180)$ represent the interval of acceptable price range for customer d_i by TFN.

(ii) *Taste of food*: it represents the satisfaction degree of food taste, quality and diversity service in the restaurant, denoted as $\tilde{F}$.

(iii) *Service of crew*: it means the satisfaction degree of cuisine service of crew represented as $\tilde{S}$.

So, the degree of satisfaction can be formulated by fuzzy simple additive weighting rule (Chen & Hwang, 1992), i.e. $\tilde{Q} = [(\tilde{w}_1 \otimes \tilde{A}) \oplus (\tilde{w}_2 \otimes \tilde{S}) \oplus (\tilde{w}_3 \otimes \tilde{F})]/(\tilde{w}_1 \oplus \tilde{w}_2 \oplus \tilde{w}_3)$. The weightings will be evolved to reflect the situation for a number of consumers' preferences. Then, acceptable price, expressed by TFN, $\tilde{r}_{ij} = [u_{\tilde{A}_i}] = (a_{ij}, b_{ij}, c_{ij})$, can be denoted as Fig. 6.

Fig. 5. Restaurant services selection.

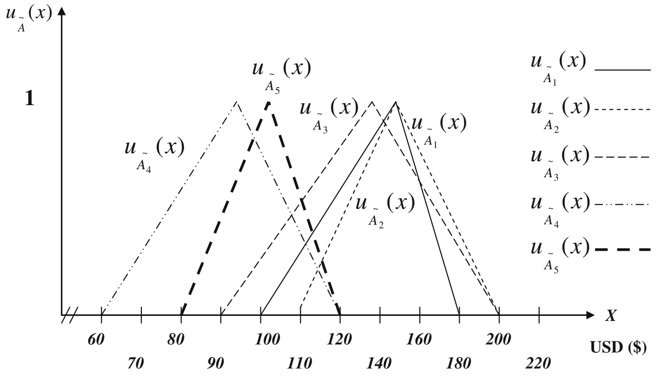

Fig. 6. *Acceptable price* expressed by fuzzy sets.

Step 2. In the following, each decision maker has to assign performance rating $\tilde{x}_{ij}(d_p)$ on *service of food* and *service of crew* with linguistic terms, defined in Table 5, to service alternatives. In Table 5, the membership function of linguistic terms for the rating of each service alternative is given by $(x-2, x, x+2)$ for $\tilde{x}_{ij} = (3, 5, 7)$ except $(0, 1, 3)$ for $\tilde{x}_{ij}$ is "*very poor*" and $(7, 9, 10)$ for $\tilde{x}_{ij}$ is "*very good*". The decision makers assign acceptable price to five service candidates as the first column of Tables 5–7. The individual fuzzy performance rating matrix is shown as Tables 6–8.

Three service consumers (d_1—d_3) give their paired comparison judgments among five service candidates as:

Table 5
Linguistic terms for the rating of service alternatives.

Linguistic term	Triangular fuzzy number a_{ij}, b_{ij}, c_{ij}
Very poor (VP)	$(0, 1, 3)$
Poor (P)	$(1, 3, 5)$
Fair (F)	$(3, 5, 7)$
Good (G)	$(5, 7, 9)$
Very good (VG)	$(7, 9, 10)$

Table 6
Ratings assigned by service customer.

Flight service (a_i)	QoS attributes (c_j)		
	Acceptable price c_1 ($)	Taste of food c_2	Service of crew c_3
a_1	$(100, 150, 180)$	Poor	Good
a_2	$(110, 150, 200)$	Good	Very good
a_3	$(90, 140, 200)$	Very good	Poor
a_4	$(60, 90, 120)$	Good	Fair
a_5	$(80, 100, 120)$	Fair	Good

Table 7
Ratings assigned by service customer d_2.

Flight service (a_i)	QoS Attributes (c_j)		
	Acceptable price c_1 ($)	Taste of food c_2	Service of crew c_3
a_1	$(70, 90, 110)$	Good	Fair
a_2	$(100, 120, 160)$	Fair	Fair
a_3	$(80, 100, 120)$	Good	Fair
a_4	$(100, 150, 180)$	Good	Fair
a_5	$(120, 160, 200)$	Good	Fair

Table 8
Ratings assigned by service customer d_3.

Flight service (a_i)	QoS attributes (c_j)		
	Acceptable price c_1 ($)	Taste of food c_2	Service of crew c_3
a_1	$(80, 110, 140)$	Good	Fair
a_2	$(100, 120, 150)$	Good	Good
a_3	$(110, 130, 160)$	Poor	Good
a_4	$(70, 90, 110)$	Good	Poor
a_5	$(90, 100, 130)$	Fair	Good

$$\Omega(d_1) = \{(1,2),(1,4),(2,3),(2,4),(2,5),(3,1),(3,5),(4,3),(4,5),(5,1)\},$$
$$\Omega(d_2) = \{(1,5),(2,1),(3,1),(2,3),(2,4),(2,5)(4,3),(5,3),(5,4)\},$$
$$\Omega(d_3) = \{(1,2),(1,3),(1,5),(2,3),(2,4),(2,5),(3,5)(3,4),(5,4)\}.$$

Step 3. By applying Eq. (6), the normalized performance ratings matrix by decision maker d_1 is formed as

$$\widetilde{R}(d_1) = [\tilde{r}_{ij}] = \begin{bmatrix} (0.50, 0.60, 1.00) & (0.10, 0.30, 0.50) & (0.50, 0.70, 0.90) \\ (0.45, 0.60, 1.00) & (0.30, 0.50, 0.70) & (0.70, 0.90, 1.00) \\ (0.45, 0.65, 1.00) & (0.70, 0.90, 1.00) & (0.10, 0.30, 0.50) \\ (0.75, 1.00, 1.00) & (0.50, 0.70, 0.90) & (0.30, 0.70, 0.70) \\ (0.75, 0.95, 1.00) & (0.30, 0.50, 0.70) & (0.50, 0.70, 0.90) \end{bmatrix}$$

Similarly, the normalized performance ratings matrix by decision makers d_2 and d_3 can be obtained, respectively.

Step 4. Let $h = 1$, and $\delta = 0.01$, we can formulate the linear programming problem using Eq. (23).

Step 5. Solve the optimal solution using Simplex method. This step produces $(w, \tilde{v}^*)$ as follows

$$\begin{aligned} z^* &= (z_{12}, z_{14}, z_{23}, z_{24}, z_{25}, z_{31}, z_{35}, z_{43}, z_{45}, z_{51}) \\ &= (0.37, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0) \\ w^* &= (w_1, w_2, w_3)^T = (0.00, 0.0, 1.0) \\ v^* &= (\tilde{v}_1, \tilde{v}_2, \tilde{v}_3) = ((0.0, 0.0, 0.0), (0.0, 0.0, 0.0), (0.89, 0.89, 0.89)) \end{aligned}$$

The fuzzy positive ideal solution (FIPS) is located using Eq. (22)

$$\begin{aligned} \tilde{r}^*(d_1) &= \tilde{v}^*/w^* = (\tilde{r}_1, \ldots, \tilde{r}_3)^T \\ &= ((0.0, 0.0, 0.0), (0.0, 0.0, 0.0), (0.89, 0.89, 0.89)) \end{aligned}$$

Step 6. Outrank the ranking of web services.The square distance of service alternatives from FPIS can be computed by using Eq. (10):

$$S_1(d_1) = 0.275, \quad S_2(d_1) = 0.026, \quad S_3(d_1) = 0.675, \quad S_4(d_1) = 0.515, \quad S_5(d_1) = 0.275$$

So the ranking order of service alternatives is generated as follows:

$$a_2 > a_1 \cong a_5 > a_4 > a_3.$$

Similarly, the optimal solution of $(w, \tilde{v}^*)$ is obtained as Tables 9 and 10 using Steps (1)–(5) for the ratings of decision makers d_2 and d_3, respectively.The fuzzy positive ideal solution (FIPS) is computed by

Table 9
The optimal solution of Simplex method for rating of decision maker d_2.

Paired comparison judgments	Weight of QoS attributes	Variable $v_j^* = w_j^* r_j^*$
$z^* = z_{12}, z_{14}, z_{23}, z_{24}, z_{25}, z_{31}, z_{35}, z_{43}, z_{45}, z_{51}$	$(w_1, w_2, w_3)^T$	$v^* = (v_1, \ldots, v_6)$
(0.33, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0)	(0.0, 1.0, 0.0)	((0.0,0.0,0.0) (0.23,0.23,0.23), (0.0,0.0,0.0))

Table 10
The optimal solution of Simplex method for rating of decision maker d_3.

Paired comparison judgments	Weight of QoS attributes	Variable $v_j^* = w_j^* r_j^*$
$z^* = z_{12}, z_{14}, z_{23}, z_{24}, z_{25}, z_{31}, z_{35}, z_{43}, z_{45}, z_{51}$ (0.0, 0.0, 0.0, 0.0, 0.0, 0.0,0.0, 0.0,0.0,0.0)	$(w_1, w_2, w_3)^T$ (0.187 0.813 0.0)	$v^* = (v_1, \ldots, v_6)$ ((0.0,0.1,0.1), (0.17,0.17,0 17), (0.0,0.0,0.0))

Table 11
Synthetic Judgment matrix.

Decision maker	Service alternatives (a_i)				
	a_1	a_2	a_3	a_4	a_5
d_1	2	3	0	1	2
d_2	3	2	0	1	2
d_3	4	3	0	1	2
Borda's scores	9	8	0	3	6

$$\begin{aligned}\tilde{r}^*(d_2) &= (\tilde{r}_1, \tilde{r}_2, \tilde{r}_3)^T \\ &= ((0.0, 0.0, 0.0), (0.23, 0.23, 0.23), (0.0, 0.0, 0.0)),\end{aligned}$$

The fuzzy positive ideal solution (FIPS) is calculated as

$$\begin{aligned}\tilde{r}^*(d_2) &= (\tilde{r}_1, \tilde{r}_2, \tilde{r}_3)^T \\ &= ((0.0, 0.53, 0.53), (0.21, 0.21, 0.21), (0.0, 0.0, 0.0)),\end{aligned}$$

The square distance of service alternatives from FPIS for rating of decision makers, d_2 and $d_3$can be calculated:

$$\begin{aligned}S_1(d_2) &= 0.064, \quad S_2(d_2) = 0.223, \quad S_3(d_2) = 0.714, \quad S_4(d_2) \\ &= 0.464, \quad S_5(d_2) = 0.223, \quad S_1(d_3) = 0.171, \quad S_2(d_3) \\ &= 0.298, \quad S_3(d_3) = 0.699, \quad S_4(d_3) = 0.555, \quad S_5(d_2) \\ &= 0.348\end{aligned}$$

Comparing the distance from FPIS using Eq. (10), the ranking order of five service alternatives for three decision makers is shown as, respectively.

$$a_2 > a_1 \cong a_5 > a_4 > a_3, \quad a_1 > a_2 \cong a_5 > a_4 > a_3, \quad a_1 > a_2 > a_5 > a_4 > a_3$$

Step 7. The prominent ranking approaches of group decision making problems include AHP, Borda count, and entropy method (Hwang & Lin, 1987). Here Borda count is selected for its equity, scores of all service alternatives assessed by three decision makers and the aggregation score are listed as the fourth row in Table 11. From Table 11, the complete ranking order of service alternatives is decided as

$$a_1 > a_2 > a_5 > a_4 > a_3.$$

5. Discussion

Even if the optimal solution is obtained, a significant issue of LINMAP is remained for debate, i.e., consistent solution. From the solution process of two cases, one could note that (i) LINMAP method need not require the complete paired comparison, it can gain a transitive ranking order for service alternatives, after computed, (ii) when the number of service alternatives (i) exceeds the number of attributes (j), then it is easy to yield a reliable solution of weight by the LIMAP, for example, six attributes are used for assessing four alternatives in case I, as well as three attributes are used for assessing five alternatives that is, $i = 5$ and $j = 3$ in case II, then the proposed model can gain a consistent solution when $i > j$, this method will obtain a well-fitting solution. Moreover, this method may try to set $w_j \geqq \delta$, intending to stimulate the feasible solutions for obtaining a non-trivial solution of weight of QoS attribute by adjusting δ. The target of consensual weight is to yield a compromise solution of weights among items of QoS attributes. From two distinct cases and trial and error examples, we knew that the optimal solution sometimes tends towards converging to a single item of weight value of QoS attribute in the resolution process of LANMAP method.

6. Conclusion

This paper presents a fuzzy group decision model to solve the selection of QoS-aware web services provisioning using a fuzzy linear program. The proposed model has the following features.

1. This proposed approach not only deals with the decision maker's imprecise perceptions under incomplete information, but also objectively determines the importance weights of QoS criteria. The weightings are based on group preferences for a group of participants and realistically attain a QoS-based ranking of a list of web services.
2. The proposed approach enables decision makers to select OoS-aware services from the marketplace. In the multiple attribute decision-making applications, our approach is a complement way to the extension works of Srinivasan and Shocker (1973) and Li and Sun (2007).

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References

Anane, R., Chao, K.-M., & Li, Y. (2005). Hybrid composition of web services and grid services. In *Proceedings of 2005 IEEE international conference on e-technology, e-commerce and e-service (EEE-05)* (pp. 426–431). Hong Kong: IEEE CS.

Ankolenkar, A., Burstein, M., Hobbs, J., Lassila, O., Martin, D., McDermatt, D., et al. (2002). DAMLS: Web service description for the semantic web. In *Proceedings of the international semantic web conference (ISWC'02), Sardinia, Italy*. *LNCS* (Vol. 2342). Springer.

Balke, W.T., & Wagner, M. (2003). Cooperative discovery for user-centered web service provisioning. In *International conference on web services (ICWS'03), Las Vegas, USA*.

Borenstein, J., & Fox, J. (2003). Semantic discovery for web services. *Web Services Journal, 3*(4).

Chao, K.-M., Younas, M., Lo, C.-C., & Tan, T.-H. (2005). Fuzzy matchmaking for web services. In *Proceedings of 19 IEEE conference on advanced network and information applications* (pp. 721–726). IEEE CS.

Chen, C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Set and Systems, 114*, 1–9.

Chen, S.-H., & Hwang, C. L. (1992). *Fuzzy multiple attribute decision making methods and applications*. Berlin/New York: Springer-Verlag.

Cook, W. D. (2006). Distance-based and ad hoc consensus models in ordinal preference ranking. *European Journal of Operational Research, 172*, 369–385.

Cook, W. D., Kress, M., & Seiford, L. M. (1997). A general framework for distance-based consensus in ordinal ranking models. *European Journal of Operational Research, 96*(2), 392–397.

Huang, C.-L., Lo, C.-C., et al. (2005a). Service discovery through multi-agent consensus. In *Proceedings of ieee international workshop on service-oriented system engineering (SOSE 2005)* (pp. 37–44).

Huang, C.-L., Chao, K.-M., & Lo, C.-C. (2005b). A moderated fuzzy matchmaking for web services. In *Proceedings of the fifth international conference on computer and information technology (CIT'05)* (pp. 1116–1122). IEEE CS.

Hwang, C.-J., & Lin, M. J. (1987). Group decision making under multiple criteria: Methods and applications. *Lectures Notes in Economics and Mathematical Systems, 281*, 36–45.

Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making: Methods and applications*. Springer-Verlag.

Jorge, C., & Amit, S. (Eds.). (2006). *Semantic web services. Processes and applications*. Springer.

Kaufmann, A., & Gupta, M. M. (1991). *Introduction to fuzzy arithmetic theory and application*. New York: Van Nostrand Reinhold.

Li, D. F., & Sun, T. (2007). Fuzzy LINMAP method for multi-attribute group decision making with linguistic variables and incomplete information. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 15*(2), 153–173.

Liu, Y., Ngu, H. H., & Zeng, L. (2004). QoS computation and policing in dynamic web service selection. In *Proceedings of 13th international conference on world wide web* (pp. 65–73).

Li, D. F., & Yang, J. B. (2004). Fuzzy linear programming technique for multiattribute group decision making in fuzzy environments. *Information Sciences, 158*, 263–275.

Ran, S. (2003). A model for web services discovery with QoS. *ACM SIGecom Exchanges, 4*, 1–10.

Sirin, E., Parsia, B., & Hendler, J. (2004). Filtering and selecting semantic web services with interactive composition techniques. *IEEE Intelligent Systems*, 42–49.

Srinivasan, V., & Shocker, A. D. (1973). Linear programming techniques for multidimensional analysis of preference. *Psychometrika, 38*, 337–369.

Wang, P., Chao, K.-M., Lo, C.-C., Huang, C.-L., & Li, Y. (2006). A fuzzy model for selection of QoS-aware web services. In *ICEBE'06* (pp. 585–593).

Zeng, L., Benatallah, B., et al. (2004). Qos-aware middleware for web service composition. *IEEE Transactions on Software Engineering, 30*(5), 311–327.

Zhou, C., Chia, L.-T., & Lee, B.-S. (2005). Semantics in service discovery and QoS measurement. *IT Professional, 7*, 29–34.

Zhou, C., Chin, L. T., & Lee, B. S. (2004). DAML-QoS ontology for web services. In *International conference on web services (ICWS 2004)* (pp. 472–479).