A group selection approach to supplier collaborative configuration problems with correlation of experts and attributes

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Received 23 April 2015

Accepted 25 August 2015

Abstract

Enterprises nowadays are often confronted with selecting supplier collaborative configuration problems in supply chain management. The aim of this paper is to develop a group selection methodology with the correlation of experts and attributes for solving supplier collaborative configuration problems. In this methodology, opinions of experts for supplier collaborative configuration on the basic attributes are integrated, respectively. The Denoeux cautious combination rules are further modified to delete the ignorance caused by relative weights in the aggregation and hereby we estimate the group evaluations of supplier collaborative configuration, which are used to rank supplier collaborative configuration schemes/alternatives through employing the minimum/maximum regret value method. A real case is used to verify and show the rationality, effectiveness and applicability.

Keywords: Supplier collaborative configuration; Group decision making; Decision analysis; Multiattribute decision making; Evidential reasoning

1. Introduction

In recent years, the increasing complexity of components and parts has raised the development costs of new products and development uncertainty. Therefore, a more emphasis on value creation has spurred substantial interest in the concept of cost control in complex environments in supply chains¹⁻⁴. In the recent survey, Su⁵ proposed a hierarchical grey decision-making trial and evaluation laboratory method to identify and analyze criteria and alternatives in incomplete information. Su's method may identify supplier prioritization. Verdouw⁶ proposed a control model for object virtualization in supply chain management to define feasible options for the virtualization of supply chain control. In the innovation-driven times, people pay more attention to collaboration and believe that enterprises should collaborate with suppliers to complete the development and manufacturing tasks of new products. The collaboration could be more efficient and create more social value. During the new product development

process, the supplier collaborative management significantly affects the quality, price and delivery date of the final products. Hence, it is necessary to study collaborative relationships between enterprises and suppliers, which may help enterprises collaboratively configure suppliers in a scientific and rational manner. Consequently, the production costs of the enterprises are further reduced and hereby the profits are enhanced. This paper will focus on developing effective and practical group selection models and method of the supplier collaborative configuration problems.

Recently, there are few of articles involved in the supplier collaborative configuration problems⁷⁻⁸. Fuzzy DEMATEL technique⁹⁻¹⁰, evidential reasoning method¹¹⁻¹² and hybrid solution¹³⁻¹⁴ were widely used. Therefore, the evidential reasoning theory with the advantages of dealing with uncertainty was more adaptive to the supply chain management. For instance, the traditional evidential reasoning method was used to solve the design and contractor selection problems of complex engineering products¹⁵⁻¹⁶. The rules and utility

of evidential reasoning were used to deal with the uncertainty problems of attributes in multi-attribute decision analysis¹⁷⁻¹⁹. The evidential reasoning method was applied to multi-attribute decision analysis with uncertain intervals, which has incomplete information or total ignorance²⁰. Ölcner²¹ explored a new fuzzy multi-attribute decision-making method, which is used to solve the aggregation problems of fuzzy qualitative attributes and the fuzzy multi-attribute group decision-making problems. Fu and Fu²²⁻²³ proposed a new system that integrates multi-agents, context-aware computing, and context-aware reasoning or case-based reasoning to improve cost collaborative management in supply chains. The preceding works were primarily based on evidential reasoning in which the aggregation problem of fuzzy attributes is a significant and difficult aspect in decision analysis.

For supplier collaborative configuration selection problems, Dickson²⁴ chose 23 fuzzy and non-fuzzy evaluation criteria. Combining the ANP with multi-objective linear programming, Demirtas²⁵ developed a method for selecting suppliers. Li²⁶ regarded outsourcing provider selection problems as a type of fuzzy inhomogenous multi-attribute group decision making problems, which are solved through developing a new fuzzy mathematical programming method. Hu²⁷ studied the supplier selection problems in green procurement under the mode of low carbon economy. Zhang²⁸ adopted a framework of a central coordination system, which is equipped with a multi-criteria genetic optimization feature, to reduce less complexity in the evaluation stage. As far as we know, although there are some researches on the supplier collaborative configuration problems, but most of them have limited application situations for mathematic constraints. Therefore, the aim of this paper is to develop new group selection models and method for solving supplier collaborative configuration problems based on the correlation of experts and attributes in which there are cognitive uncertainties of experts from the purchasing, quality, research and development (R&D), and sales departments of the enterprise. Compared with the existing related methods, the method proposed in this paper has three innovation aspects. Firstly, we loosen the constraints of the independence of expert opinions, which allow experts to share their experience and knowledge. Secondly, the selection process of the supplier

collaborative configuration problems coincides with reality. Second, the difficulty of attribute selection is reduced, and the dominant or recessive correlation between partial attributes cannot be repelled by loosening the independence requirement. As a result, the robustness of optimal selection results of the supplier collaborative configuration problems is enhanced. Thirdly, the developed method is of more extensive applications due to adequately modifying the Denoeux cautious combination rules²⁹.

2. Some concepts and notations

For convenience to understand the group selection methodology with the correlation of experts and attributes, we briefly review some relevant concepts and notations.

2.1. Belief functions and evidential reasoning

The belief function theory is a theoretical framework for evidential reasoning with partial and unreliable information^{20, 30-31}. Let a finite set Ω be the frame of discernment and S be the evidential source on Ω . Partial knowledge regarding the actual value of S taken by the variable ω is represented by a belief function, which is defined as a function m from 2^Ω to $[0, 1]$, so that:

$$\sum_{A \subseteq \Omega} m(A) = 1 \quad (1)$$

where $m(A) > 0$ and each focal set A is a set of possible values for ω . The quantity $m(A)$ can be interpreted as the measure of beliefs, which is committed exactly to $\omega \in A$ on the basis of a given evidential corpus. Complete ignorance corresponds to $m(\Omega) = 1$, whereas perfect knowledge of the value of ω is represented by the allocation of the whole mass of beliefs to a unique singleton of Ω . The belief function with nested focal elements is said to be consonant. m is said to be simple support if there exist $A \subset \Omega$ and $w \in [0, 1]$ so that $m(A) = 1 - w$ and $m(\Omega) = w$, and all other masses are equal to zero. If $m(\Phi) = 0$, where Φ is an empty set, then m is said to be normal. The belief function m can be represented by a commonality function with $q(A) = \sum_{B \supseteq A} m(B)$ for any $A \subseteq \Omega$. For decomposable

and orthodox belief function m , it can be defined as the following standard combination of several simple belief functions:

$$m = \bigoplus_{\phi \neq A \subset \Omega} A^{w(A)} \quad (2)$$

where $w(A)$ is defined as a weight function for any $A \subset \Omega$ and $A \neq \Phi$, $w(A) \in [0,1]$. The symbol $\bigoplus$ is defined as a Dempster-Shafer composition operator. Extendedly, for any unorthodox belief function m , it cannot be expressed as Eq. (3), thereof any $A \subset \Omega$ and $w(A) \in [0,+\infty)$. The extended $w(A)$ is defined as Eq. (4), thereof $2N$ is denoted as even number set and $|A|$ is denoted as the cardinality of A .

$$m = \bigoplus_{A \subset \Omega} A^{w(A)} \quad (3)$$

$$w(A) = \prod_{B \supseteq A} q(B)^{(-1)^{|B|-|A|+1}} = \begin{cases} \frac{\prod_{B \supseteq A, |B| \neq 2} q(B)}{\prod_{B \supseteq A, |B| \in 2N} q(B)}, & |A| \in 2N \\ \frac{\prod_{B \supseteq A, |B| \in 2N} q(B)}{\prod_{B \supseteq A, |B| \neq 2} q(B)}, & |A| \notin 2N \end{cases} \quad (4)$$

which can be simplified as follows:

$$w(A) = \begin{cases} \frac{m(\Omega)}{m(h_p) + m(\Omega)}, & A = h_p \\ m(\Omega) \prod_{p=1}^P \left[1 + \frac{m(h_p)}{m(\Omega)} \right], & A = \phi \\ 1 & \text{otherwise} \end{cases} \quad (5)$$

When the reliability of a source is doubtful, the mass provided by this source can be discounted through using Eq. (6):

$$\begin{cases} m^\lambda(A) = (1-\lambda)m(A) & A \neq \Omega \\ m^\lambda(\Omega) = (1-\lambda)m(\Omega) + \lambda \end{cases} \quad (6)$$

where $\lambda \in [0,1]$ is the discount rate. The discount rate is related to the confidence held by an external agent in the reliability of the source. It can be interpreted as the plausibility that the source is unreliable. When λ is equal to 1, the vacuous mass function is obtained. When $\lambda=0$, m remains unchanged.

2.2. Denoeux synthesized rules

Assume that m_1 and m_2 are two dependent belief functions which are induced by distinct items of evidences on Ω . The Denoeux synthesized rules^{29, 32} can be defined as follows:

$$m_{1 \wedge 2} = m_1 \wedge m_2 = \bigoplus_{\Phi \neq A \subset \Omega} A^{w_{1 \wedge 2}(A)} \quad (7)$$

$$w_{1 \wedge 2}(A) = \min\{w_1(A), w_2(A)\} \quad (8)$$

where $w_{1 \wedge 2}(A)$ is a conjunction weight, and the operator “ $\wedge$ ” has the characteristics of interactivity, conjunction and power.

Considering the ignorance caused by relative weight or discount and incomplete information, the modified Denoeux cautiously synthesized rules are given as follows:

$$m_{1 \wedge 2} = m_1 \wedge^* m_2 = \bigoplus_{\Phi \neq A \subset \Omega} A^{w_{1 \wedge 2}(A)} \quad (9)$$

$$w_{1 \wedge 2}(A) = \min \begin{cases} \min\{w_1(A), w_2(A)\}, & A = h_p, p=1,2,\dots,P \\ \min\{w_1(A), w_2(A)\}, & A = \phi \\ \min\{w_1(A), w_2(A)\}, & A = \bar{\Omega} \end{cases} \quad (10)$$

where $\Omega = \{h_p \mid p=1,2,\dots,P\}$, and $\bar{\Omega}$ is an ignorance set.

3. Representation of supplier collaboration configuration problems

Assume that there are M supplier collaboration configuration schemes, which are respectively denoted by A_l ($l=1,2,\dots,M$). L basic attributes are respectively denoted by e_i ($i=1,2,\dots,L$). The weight vector of the basic attributes is denoted by $w=(w_1, w_2, \dots, w_L)$, where $0 \leq w_i \leq 1$ ($i=1,2,\dots,L$) and $\sum_{i=1}^L w_i = 1$.

Meanwhile, T experts are denoted by t_k ($k=1,2,\dots,T$). The relative weight vector of T experts is denoted by $\lambda=(\lambda_1, \lambda_2, \dots, \lambda_T)$, where $0 \leq \lambda_k \leq 1$ ($k=1,2,\dots,T$) and $\sum_{k=1}^T \lambda_k = 1$.

The experts evaluate the M supplier collaboration configuration schemes on L basic attributes and hereby form the set of evaluation ratings with mutual exclusive and complete characteristics. The evaluation ratings are expressed as the set $\Omega = \{H_n \mid n=1,2,\dots,N\}$. Moreover, let $S_i^k(A_l) = \{(H_n, \beta_{n,i}^k(A_l)) \mid n=1,2,\dots,N\}$ represent the distributed evaluation set of the expert t_k ($k=1,2,\dots,T$) for the supplier collaboration configuration scheme A_l ($l=1,2,\dots,M$) on the attribute e_i ($i=1,2,\dots,L$). The belief degrees of the evaluation set on the evaluation rating H_n are $\beta_{n,i}^k(A_l)$, where $\beta_{n,i}^k(A_l) \geq 0$

and $\sum_{n=1}^N \beta_{n,i}^k(A_l) \leq 1$. When $\sum_{n=1}^N \beta_{n,i}^k(A_l) = 1$, the distributed evaluation set is complete; otherwise, it is incomplete. If the distributed evaluation set is incomplete, then the unallocated belief degree is assigned to Ω . That is,

$$\sum_{n=1}^N \beta_{n,i}^k(A_l) + \beta_{\Omega,i}^k(A_l) = 1. \quad \text{In}$$

particular, $\sum_{n=1}^N \beta_{n,i}^k(A_l) = 0$ represents complete ignorance.

Once M supplier collaboration configuration schemes are evaluated on L basic attributes, we can obtain the belief decision matrix as follows:

$$D_g^k = (S_i^k(A_l))_{L \times M} \quad (11)$$

4. Group selection models and method of supplier collaboration configuration problems

4.1. Aggregation method of expert opinions on basic attributes

4.1.1 Determination of relative weights

The relative weights of the group opinions of experts t_k ($k = 1, 2, \dots, T$) for the supplier collaboration configuration schemes A_l ($1 \leq l \leq M$) on basic attributes e_i ($1 \leq i \leq L$) can be computed by using the following formulae (i.e., Eqs. (12)-(17)):

$$m_{n,i}^k = m_i^k(H_n) = \lambda_k \beta_{n,i}^k(A_l) \quad (12)$$

$$m_{\Omega,i}^k = m_i^k(\Omega) = 1 - \lambda_k \sum_{n=1}^N \beta_{n,i}^k(A_l) \quad (13)$$

$$\bar{m}_{\Omega,i}^k = \bar{m}_i^k(\Omega) = 1 - \lambda_k \quad (14)$$

$$\tilde{m}_{\Omega,i}^k = \tilde{m}_i^k(\Omega) = \lambda_k (1 - \sum_{n=1}^N \beta_{n,i}^k(A_l)) \quad (15)$$

$$m_{\Omega,i}^k = \bar{m}_{\Omega,i}^k + \tilde{m}_{\Omega,i}^k \quad (16)$$

$$\sum_{k=1}^T \lambda_k = 1 \quad (17)$$

Thus, the opinion of the expert t_k for the supplier collaboration configuration scheme A_l on the basic attribute e_i can be expressed as $m_i^k = \{(H_1, m_{1,i}^k), (H_2, m_{2,i}^k), \dots, (H_N, m_{N,i}^k), (\Omega, m_{\Omega,i}^k)\}$.

In the aforementioned relative weight determination, the ignorance $m_{\Omega,i}^k$ is divided into $\bar{m}_{\Omega,i}^k$ and $\tilde{m}_{\Omega,i}^k$, which are respectively caused by the relative weight of the basic attribute e_i and the incompleteness that the basic attribute e_i evaluates A_l . In this paper, we use the analytical synthesis method²⁰ to deal with the two parts of ignorance differently. $\bar{m}_{\Omega,i}^k$ has no relationship with the expert opinions and is only used to deal with the conflicts between the expert opinions. Therefore, $\bar{m}_{\Omega,i}^k$ is deleted from the synthesized results and only maintains $\tilde{m}_{\Omega,i}^k$. In the following group opinion aggregation, $\bar{m}_{\Omega,i}^k$ is also deleted according to the modified Denoeux relevant belief synthesized rules.

4.1.2 Aggregation of expert opinions on the basic attributes

In this subsection, let us consider expert opinions involving ignorance caused by the relative weights. However, those opinions cannot be rationally synthesized by the Denoeux cautiously synthesized rules²⁹ because

such ignorance cannot be deleted. Therefore, the Denoeux cautiously synthesized rules should be modified to facilitate the involvement of such ignorance in the aggregation of expert opinions and subsequently delete the ignorance from the synthesized results.

We use the example of expert group opinions for the supplier collaboration configuration schemes A_l ($1 \leq l \leq M$) on the basic attributes e_i ($1 \leq i \leq L$) after processing by λ_k to elaborate the modified Denoeux cautiously synthesized rules and explain the aggregation process of expert group opinions.

(1) Weight functions of the ignorance caused by the relative weights

Denoeux²⁹ argued that an arbitrary non-dogmatic belief function can be divided into a series of simple belief functions and the corresponding weight function $w(A) \in [0, +\infty)$ can be defined as

$w(A) = \prod_{B \supseteq A} q(B)^{(-1)^{|B|-|A|+1}}$. Apparently, the function $w(A)$ does not involve the ignorance caused by the relative weights. Given that the ignorance caused by the relative weights should be deleted in the aggregation of expert opinions, the weight function should be extended to represent such ignorance. Generally, for an arbitrary expert's opinion m which is processed by the relative weights, it follows that $m(\Omega) = m(\bar{\Omega}) + m(\tilde{\Omega})$, where $m(\bar{\Omega})$ denotes the ignorance caused by the incompleteness of the expert opinion m , and the relative weight of ignorance can be computed as follows:

$$w(\bar{\Omega}) = \frac{m(\tilde{\Omega})}{m(\tilde{\Omega}) + m(\bar{\Omega})} \quad (18)$$

Based on the preceding results, for any $A \subset \Omega$ or $A = \bar{\Omega}$, the nonstandard decomposition of the expert opinion m is expanded as follows:

$$m = \bigoplus_{A \subset \Omega} A^{w(A)} \quad (19)$$

where $w(A) \in [0, +\infty)$.

According to Eq. (18), weights of the opinions m_i^k from the expert t_k on the basic attribute e_i are computed as follows:

$$w_i^k(\bar{\Omega}) = \frac{\tilde{m}_{\Omega,i}^k}{\bar{m}_{\Omega,i}^k + \tilde{m}_{\Omega,i}^k} \quad (20)$$

(2) Weight functions of expert opinions

As a result, according to Eq. (18), combining with Eq. (20), the weight functions of expert opinions m_i^k are calculated by using the following formulae (i.e., Eqs. (21)-(23)):

$$\{\emptyset\}: w_i^k(\emptyset) = m_{\Omega,i}^k \prod_{n=1}^N \left(1 + \frac{m_{n,i}^k}{m_{\Omega,i}^k} \right) \quad (21)$$

$$\{H_n\}: w_i^k(H_n) = \frac{m_{\Omega,i}^k}{m_{n,i}^k + m_{\Omega,i}^k} \quad (22)$$

$$\{\bar{\Omega}\}: w_i^k(\bar{\Omega}) = \frac{\tilde{m}_{\Omega,i}^k}{\tilde{m}_{\Omega,i}^k + \tilde{m}_{\Omega,i}^k} \quad (23)$$

(3) Synthesis of the weight functions of expert group opinions

Once the weight functions w_i^k of m_i^k are synthesized, then we can compute the weight functions of expert group opinion for the supplier collaboration configuration schemes A_l ($1 \leq l \leq M$) on the basic attributes e_i ($1 \leq i \leq L$) according to the following formulae (i.e., Eqs. (24)-(26)):

$$\{\emptyset\}: w_i(\emptyset) = \min\{w_i^k(\emptyset) | k=1,2,\dots,T\} \quad (24)$$

$$\{H_n\}: w_i(H_n) = \min\{w_i^k(H_n) | k=1,2,\dots,T\} \quad (25)$$

$$\{\bar{\Omega}\}: w_i(\bar{\Omega}) = \min\{w_i^k(\bar{\Omega}) | k=1,2,\dots,T\} \quad (26)$$

(4) Aggregation of expert group opinions for schemes on basic attributes

Using Eqs. (24)-(26), the standardized belief function can be computed as follows:

$$m_i = \theta \oplus_{\emptyset \neq A \subset \Omega} A^{w_i(A)} \quad (27)$$

where the standardized coefficient is θ and $\theta = (1 - m_i(\emptyset) - m_i(\bar{\Omega}))^{-1}$. $m_i(\bar{\Omega})$ is introduced to delete the ignorance so that it ensures the rationality of the synthesized results.

4.2. Aggregation of expert opinions on supplier collaboration configuration schemes

Aggregation of expert opinions on supplier collaboration configuration schemes is similar to that of the expert opinions on the basic attributes. First, the relative weights of basic attributes are used to conduct the relative weights between expert group opinions. The preceding aggregation method is subsequently used to synthesize expert group opinions on the basic attributes to evaluate supplier collaboration configuration schemes. Similarly, the ignorance caused by the relative weights is deleted from the synthesized results. More specifically, in a similar way to Eq. (18), weights of the opinions m_i^k of the experts t_k on the supplier collaboration configuration schemes A_l ($1 \leq l \leq M$) are computed as follows:

$$w_l^k(\bar{\Omega}) = \frac{\tilde{m}_{\Omega,i}^k}{\tilde{m}_{\Omega,i}^k + \tilde{m}_{\Omega,i}^k} \quad (28)$$

Combining with Eq. (20), the weight functions of expert opinions m_l^k can be calculated by using the following formulae (i.e., Eqs. (29)-(31)):

$$\{\emptyset\}: w_l^k(\emptyset) = m_{\Omega,l}^k \prod_{n=1}^N \left(1 + \frac{m_{n,l}^k}{m_{\Omega,l}^k} \right) \quad (29)$$

$$\{H_n\}: w_l^k(H_n) = \frac{m_{\Omega,l}^k}{m_{n,l}^k + m_{\Omega,l}^k} \quad (30)$$

$$\{\bar{\Omega}\}: w_l^k(\bar{\Omega}) = \frac{\tilde{m}_{\Omega,l}^k}{\tilde{m}_{\Omega,l}^k + \tilde{m}_{\Omega,l}^k} \quad (31)$$

Then, we can compute the weight functions of expert group opinions for the supplier collaboration configuration schemes A_l ($1 \leq l \leq M$) according to the following formulae (i.e., Eqs. (32)-(34)):

$$\{\emptyset\}: w_l(\emptyset) = \min\{w_l^k(\emptyset) | k=1,2,\dots,T\} \quad (32)$$

$$\{H_n\}: w_l(H_n) = \min\{w_l^k(H_n) | k=1,2,\dots,T\} \quad (33)$$

$$\{\bar{\Omega}\}: w_l(\bar{\Omega}) = \min\{w_l^k(\bar{\Omega}) | k=1,2,\dots,T\} \quad (34)$$

Hereby, the standardized belief function can be computed as follows:

$$m_l = \hat{\theta} \oplus_{\emptyset \neq A \subset \Omega} A^{w_l(A)} \quad (35)$$

where the standardized coefficient is $\hat{\theta} = (1 - m_l(\emptyset) - m_l(\bar{\Omega}))^{-1}$. $m_l(\bar{\Omega})$ is introduced to delete the ignorance so that it ensures the rationality of the synthesized results.

4.3. Calculation of evaluation rating utilities

The evaluation rating utilities of the experts are independently provided so that they meet the additive utility condition. Thus, using the weighted average method, we can compute the expert group evaluation ratings as follows:

$$u(H_n) = \sum_{k=1}^T \lambda_k u^k(H_n) \quad (n=1,2,\dots,N) \quad (36)$$

4.4. Determination of the optimal supplier collaboration configuration scheme

Different experts have different evaluation rating utilities because they have diverse experiences, types and amount of knowledge as well as levels of education. That is to say, $u^k(H_n)$ ($k=1,2,\dots,T$) may be different for experts t_k . The minimum/maximum regret value method²¹ can be adopted to generate group orders of the supplier collaboration configuration schemes and hereby

determine the optimal supplier collaboration configuration scheme.

5. Group selection process of supplier collaborative configuration problems

The group selection process of the supplier collaborative configuration problems can be summarized as follows.

5.1. Identify experts, attributes and schemes of supplier collaborative configuration problems

Experts from various departments (or fields) are selected by the cross-departmental comprehensive administrators of the enterprise, who recognize basic attributes under the goal of supplier collaborative configuration selection and their respective types such as benefit attributes and cost attributes. Moreover, they establish the evaluation rating set of all basic attributes. All feasible collaborative configuration schemes (or alternatives) are subsequently listed or identified. Thus, the selection problem of the supplier collaborative configuration schemes is constructed. The numbers of experts, basic attributes, and the selected schemes are denoted by T , L , and M , respectively.

5.2. Determine weights of the attributes and experts

The relative weights of the basic attributes and experts can be determined according to Eq. (12)-(17) and Eq. (21)-(26) or by the relative comparison method developed by Ölcü²¹ or the chain ordered pair-wise comparison method proposed by Li³³.

5.3. Collect evaluations and evaluation rating utilities of experts

The distributed evaluations of the basic attributes of each supplier collaborative configuration scheme from experts are initially collected. The evaluation rating utilities of experts are subsequently collected. Finally, the group selection model could be built with the values of the quantitative basic attributes through using the evaluation rating utilities.

5.4. Obtain group evaluations of supplier collaborative configuration schemes

Using the expert weights, the modified Denoeux cautiously synthesized rules are used to aggregate the evaluations of experts on the basic attributes for every

supplier collaborative configuration scheme. Hereby, using the attribute weights, the modified Denoeux cautiously synthesized rules are utilized to aggregate the group evaluations of supplier collaborative configuration schemes. Thus, the group evaluations of the supplier collaborative configuration schemes are obtained according to Eq. (27).

5.5. Estimate the aggregation utilities of evaluation ratings

The aggregation utilities of the evaluation ratings for the supplier collaborative configuration schemes are calculated.

5.6. Rank the supplier collaborative configuration schemes

Based on the aggregation utilities of the evaluation ratings for collaborative configuration schemes, we can calculate their maximum, minimum, and average utilities, which are employed to generate the ranking order of the collaborative configuration schemes through using the maximum/minimum regret value method²⁰.

6. Case study

Six types of new cars are currently designed and developed by an automobile manufacturing enterprise. Central collaboration model was adopted to establish a relationship with suppliers and manage them collaboratively. Let us consider an example of the instrument panel, in which 15 suppliers supply the six types of new cars. At a certain time point, the enterprise formulate four supplier collaboration configuration schemes on different suppliers and different types of car supply collaboration configuration schemes after negotiating with the purchasing, quality, and R&D departments according to the supplier rules and regulations of the enterprise. To identify/choose the optimal supplier collaboration configuration scheme, one representative from each department should be selected to eventually form an expert group. Each supplier collaboration configuration scheme should be evaluated on the following four aspects: production capacity, R&D capability, improvement room, and collaborative development.

Assume that the relative weight vector of the four attributes are $(w_1, w_2, w_3, w_4) = (0.1, 0.3, 0.3, 0.3)$, the relative

weight vector of the four experts are $(\lambda_1, \lambda_2, \lambda_3, \lambda_4) = (0.3, 0.2, 0.2, 0.3)$, the evaluation rating set is $\Omega = \{H_1, H_2, H_3, H_4, H_5\} = \{\text{Poor}, \text{Average}, \text{Good}, \text{Very Good}, \text{Excellent}\}$, and the evaluation rating utility sets of the four experts are $\{u^1(H_1)=0, u^1(H_2)=0.4, u^1(H_3)=0.6, u^1(H_4)=0.8, u^1(H_5)=1\}$, $\{u^2(H_1)=0, u^2(H_2)=0.3, u^2(H_3)=0.5, u^2(H_4)=0.8, u^2(H_5)=1\}$, $\{u^3(H_1)=0, u^3(H_2)=0.5, u^3(H_3)=0.7, u^3(H_4)=0.8, u^3(H_5)=1\}$, $\{u^4(H_1)=0, u^4(H_2)=0.5, u^4(H_3)=0.7, u^4(H_4)=0.9, u^4(H_5)=1\}$, respectively.

Firstly, the original evaluations of the supplier collaboration configuration schemes are independently given by the four experts, depicted as in Table 1.

In Table 1, the evaluation $(0, 0, 0.8, 0, 0, 0.2)$ of the supplier collaboration configuration scheme A_1 on the production capability given by for the expert t_1 can be represented by $\{(H_1, 0), (H_2, 0), (H_3, 0.8), (H_4, 0), (H_5, 0), (\Omega, 0.2)\}$. Others may be similarly explained.

Secondly, according to Eqs. (9) and (10), the modified Denoeux cautiously synthesized rules are used to aggregate the group evaluations of the supplier collaboration configuration schemes on the all four attributes, depicted as in Table 2. The aggregated evaluation of the expert group for the supplier collaboration configuration scheme A_1 on each basic attribute is complete. Meanwhile, for other three supplier collaboration configuration schemes, only the aggregated evaluations on special attributes are complete. According to the synthesized method on each expert opinion weight function of the modified Denoeux cautiously synthesized rules, only when all of the expert opinions are incomplete evaluation, the aggregated group opinion is incomplete evaluation. Compared with Table 1, the incomplete evaluations derived from Table 2 are all incomplete.

Table 1 Evaluations of the supplier collaboration configuration schemes given by the experts

Schemes	Experts	Production Capacity	R&D Capability	Improvement Room	Collaborative Development
A_1	t_1	(0,0,0.8,0,0,0.2)	(0,0,0.8,0,0,0.2)	(0,0,0,0.8,0,0.2)	(0,0,0.7,0,0,0.3)
	t_2	(0,0,0.7,0.1,0,0.2)	(0,0,0.7,0,0,0.3)	(0,0,0,0.8,0.1,0.1)	(0,0,0.6,0.2,0,0.2)
	t_3	(0,0,0.8,0.1,0,0.1)	(0,0,0.7,0.1,0,0.2)	(0,0,0.2,0.7,0,0.1)	(0,0,0.7,0.2,0,0.1)
	t_4	(0,0,0.7,0.1,0,0.2)	(0,0,0.8,0.1,0,0.1)	(0,0,0.2,0.7,0,0.1)	(0,0,0.7,0.2,0,0.1)
A_2	t_1	(0,0,0,0.9,0.1,0)	(0,0,0,0.3,0.7,0)	(0,0,0,0.6,0,0.4)	(0,0,0,0.9,0.1)
	t_2	(0,0,0.1,0.9,0,0)	(0,0,0.1,0.8,0,0.1)	(0,0,0.2,0.7,0,0.1)	(0,0,0.7,0.1,0,0.2)
	t_3	(0,0,0,0.7,0.2,0.1)	(0,0,0,0.9,0.1,0)	(0,0,0.6,0.3,0,0.1)	(0,0,0.8,0.2,0)
	t_4	(0,0,0,0.8,0.2,0)	(0,0,0,0.9,0.1,0)	(0,0,0.6,0.2,0,0.2)	(0,0,0.9,0.1,0)
A_3	t_1	(0,0,0,0.6,0,0.4)	(0,0,0.3,0.7,0,0)	(0,0,0,0.2,0.8,0)	(0,0,0.1,0.8,0,0.1)
	t_2	(0,0,0.1,0.6,0,0.3)	(0,0,0.1,0.7,0,0.2)	(0,0,0.3,0.5,0,0.2)	(0,0,0.2,0.6,0,0.2)
	t_3	(0,0,0.2,0.7,0,0.1)	(0,0,0.2,0.8,0,0)	(0,0,0,0.8,0,0.2)	(0,0,0.2,0.7,0,0.1)
	t_4	(0,0,0.2,0.7,0,0.1)	(0,0,0.3,0.6,0,0.1)	(0,0,0,0.8,0.1,0.1)	(0,0,0.2,0.8,0,0)
A_4	t_1	(0,0,0.4,0.6,0,0)	(0,0,0.3,0.7,0,0)	(0,0,0,0.3,0.6,0.1)	(0,0,0.4,0.4,0,0.2)
	t_2	(0,0,0.3,0.6,0,0.1)	(0,0,0.2,0.6,0,0.2)	(0,0,0.2,0.7,0,0.1)	(0,0,0.3,0.6,0,0.1)
	t_3	(0,0,0.4,0.6,0,0)	(0,0,0.3,0.7,0,0)	(0,0,0.1,0.8,0,0.1)	(0,0,0.2,0.7,0,0.1)
	t_4	(0,0,0.4,0.6,0,0)	(0,0,0.3,0.7,0,0)	(0,0,0.4,0.6,0,0)	(0,0,0.2,0.6,0,0.2)

Table 2 Aggregated evaluations of the expert group for the schemes on attributes

Schemes	Production Capacity	R&D Capability	Improvement Room	Collaborative Development
A_1	(0,0,0.8318,0.104,0.0642)	(0,0,0.8,0.1,0,0.1)	(0,0,0.184,0.7068,0.0546,0.0546)	(0,0,0.7297,0.2085,0.0619)
A_2	(0,0,0.0504,0.777,0.1726,0)	(0,0,0.0343,0.5432,0.4225,0)	(0,0,0.4927,0.4566,0.0507)	(0,0,0.1807,0.4182,0.401,0)
A_3	(0,0,0.2085,0.7297,0.0619)	(0,0,0.3,0.7,0,0)	(0,0,0.0961,0.4425,0.4614,0)	(0,0,0.2,0.8,0,0)
A_4	(0,0,0.4,0.6,0,0)	(0,0,0.3,0.7,0,0)	(0,0,0.2539,0.3809,0.3652,0)	(0,0,0.3767,0.5651,0.0582)

The modified Denoeux cautiously synthesized rules are used to aggregate the expert group opinions on the supplier collaboration configuration schemes between different attributes and hereby obtain the expert group aggregated evaluations, depicted as in Table 3.

Table 3 Aggregated evaluations of the expert group for the supplier collaboration configuration schemes

Schemes	H_1	H_2	H_3	H_4	H_5	Ω
A_1	0	0	0.5021	0.4521	0.0349	0.0109
A_2	0	0	0.333	0.3752	0.2918	0
A_3	0	0	0.1921	0.5124	0.2955	0
A_4	0	0	0.2565	0.4886	0.2549	0

Thirdly, according to Eq. (17), the expert group aggregated utilities of the four supplier collaboration configuration schemes are obtained as $\{u(H_1)=0, u(H_2)=0.43, u(H_3)=0.63, u(H_4)=0.83, u(H_5)=1\}$. Thus, we obtain the expert group aggregated evaluation expecting utilities, depicted as in Table 4.

Table 4 Expecting utility and order of the supplier collaboration configuration schemes

Expecting Utilities	A_1	A_2	A_3	A_4
Minimum Values	0.7265	0.813	0.8418	0.822
Maximum Values	0.7373	0.813	0.8418	0.822
Average Vales	0.7319	0.813	0.8418	0.822
Ranking Order	4	3	1	2

Lastly, according to Table 4, using the minimum/maximum regret value method, we can calculate the maximum regret values of the expecting utilities of the four supplier collaboration configuration schemes as follows:

$$R(A_1)=\max\{\max\{0.813,0.8418,0.822\}-0.7265,0\}=0.115,$$

$$R(A_2)=\max\{\max\{0.7373,0.8418,0.822\}-0.813,0\}=0.0288,$$

$$R(A_3)=\max\{\max\{0.7373,0.813,0.822\}-0.8418,0\}=0,$$

$$R(A_4)=\max\{\max\{0.7373,0.813,0.8418\}-0.822,0\}=0.0198$$

It is easy to see that the supplier collaboration configuration scheme A_3 has both the minimum and maximum regret values. Hence, A_3 is the optimal supplier collaboration configuration scheme among the four supplier collaboration configuration schemes. A_4 is optimal among the rest of the three supplier collaboration configuration schemes by deleting A_3 and then repeating the preceding calculation. Similarly, the optimal supplier collaboration configuration scheme A_2 can be obtained by deleting scheme A_4 and then calculating the maximum regret values of the rest of the two schemes. The ranking order of the four supplier collaboration configuration schemes is $A_3 \succ A_4 \succ A_2 \succ A_1$. Therefore, we can determine A_3 is the optimal supplier collaboration configuration scheme.

If the selection purpose is to only determine the optimal supplier collaboration configuration scheme, then the minimum and maximum regret values can be obtained after calculating the maximum regret value of the expecting utility of each supplier collaboration configuration scheme. Generally, to enhance the reliability of the selection results and thus ensure the prompt provision of the secondary-optimal selection if

the optimal selection fails to work, providing the ranking order of all supplier collaboration configuration schemes is highly recommended.

Additionally, if the aggregated evaluations of the supplier collaboration configuration schemes on the experts are complete, then the minimum, maximum and average values of the expecting utilities for supplier collaboration configuration schemes are identical. The ranking order of the supplier collaboration configuration schemes is the same as that of the average values based on the expecting utility.

7. Conclusion

The supplier collaborative configuration problems involve many aspects and factors such as suppliers, experts and their importance (i.e., weights), attributes and their importance (i.e., weights), and evaluation ratings and their utility. In the above, we propose the group selection model and method for solving such supplier collaborative configuration problems. The main conclusions or contributions can be summarized as follows:

(1) Determining the group optimal selection of the supplier collaborative configuration schemes based on evidential theory is rational and feasible. The distributed evaluations and utilities with incomplete information are used to accurately describe the basic attribute information. Furthermore, the developed model has several advantages/benefits. On the one hand, the developed method loosens the constraints of the independence of expert opinions, which allow experts to share their experience and knowledge so that the optimal selection process of the supplier collaborative configuration schemes may coincide more with reality. On the other hand, the difficulty of attribute selection is reduced and the dominant or recessive correlation between partial attributes cannot be repelled by loosening the independence requirement. Thus, the robustness of the optimal selection results of the supplier collaborative configuration schemes are enhanced.

(2) The traditional Denoeux cautious combination rules are inapplicable due to the ignorance caused by the relative weights. However, the modified Denoeux cautious combination rules can be used to solve the above problem by expelling such ignorance from the aggregation process of expert opinions and hereby deleting the ignorance from the combination results.

(3) The results of the case study indicate that the developed group selection method for supplier collaborative configuration problems with correlation of experts and attributes is rational, feasible and applicable.

8 References

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