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A hybrid ANP model in fuzzy environments for strategic alliance partner selection in the airline industry

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ABSTRACT

Strategic airline alliances are an increasingly common strategy for enhancing airline competitiveness and satisfying customer needs, especially in an era characterized by blurring industry boundaries, fast-changing technologies, and global integration. Airlines have been very active in utilizing this form of strategic development. However, the selection of a suitable partner for a strategic alliance is not an easy decision, involving a host of complex considerations by different departments. Furthermore the decision-makers may hold diverse opinions and preferences arising due to incomplete information and knowledge or inherent conflict between various departments. In this study fuzzy preference programming and the analytic network process (ANP) are combined to form a model for the selection of partners for strategic alliances. The effects of uncertainty and disagreement between decision-makers as well as the interdependency and feedback that arise from the use of different criteria and alternatives are also addressed. This generic model can be easily extended to fulfill the specific needs of a variety of companies.

1. Introduction

Strategic alliances between airlines are now common in the aviation industry. They are frequently made in response to changing economic and regulatory conditions [1]. Three major alliances established within the last 10 years—Star Alliance, One-world and Sky Team—now account for nearly 70% of passengers and turnover in the global market [2]. Strategic alliance strategies allow airlines to expand networks, attract more passengers, and take advantage of product complementarities, as well as providing cost-reduction opportunities in passenger service related areas (such as code-sharing, joint baggage handling, joint use of lounges, gates and check-in counters, and exchange of flight attendants) [3]. A good strategic partner can further enhance the quality of their connecting services by adjusting arrival and departure flights so as to minimize waiting time between flights while providing sufficient time to make connections. On the other hand, ineffective strategic alliances can lead to the loss of core competencies and capabilities, exposure to unexpected risk and even business failure. Take for example—the fall of Swissair. Financial statements show that its airline alliance policy and investment strategy were responsible for the majority of its losses from 1997 to 2001 [4].

Prior research suggests that the choice of alliance partner is an important variable with significant influence on the performance of the strategic alliance partners [5,6]. An appropriate partner is one that can contribute resources and capabilities that the focal firm lacks. This ultimately determines the viability of the strategic alliance. Partner-related selection criteria require consideration to determine whether the corporate cultures of the partners are compatible, and whether trust exists between the partners' management teams. This ensures that the selected partner and focal firm achieve organizational interdependence. Although the importance of selecting the right partner for forming strategic alliances has been recognized in literature, there have been few empirical studies on how to choose that partner which stress the interrelationship between the partners and the focal firm at the same time. The analytic network process (ANP) was proposed by Saaty [7] to overcome the problem of interrelation among criteria or alternatives. The ANP is a general form of the analytic hierarchy process (AHP), which releases the restrictions of the hierarchical structure. It has been successfully applied in many multi-criteria decision making (MCDM) problems [8–11]. However, due to problems such as incomplete information and subjective uncertainty, even experts find it difficult to quantify the precise ratio of weights for the different criteria. The concept of fuzzy sets has been incorporated into

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AHP to deal with the problem of uncertainty, although ANP has not often been used to address this type of problem in fuzzy environments. A way to cope with uncertain judgments and to incorporate the vagueness that typifies human thinking is to express the preferences as fuzzy sets or fuzzy numbers [12]. Therefore, the objective of this study is to combine fuzzy preference programming and ANP to make a model capable of helping airlines select the best partner for strategic alliances.

The rest of this paper is structured as follows: In Section 2, we summarize some of the important previous studies regarding the strategic alliance strategy, and the problem characteristics are described. In Section 3, the basic concepts of fuzzy preference programming and ANP are reviewed. In Section 4, a strategic alliance model is developed. The implementation using the proposed fuzzy ANP is presented in Section 5. Section 6 includes discussions and some conclusions.

2. The strategic alliance

While merger activities have slowed significantly since 2000, strategic alliances are increasingly and widely used by airlines. International alliances give airlines access to parts of the world than would otherwise be economical, or where there may lack the authority to operate their own flights [3]. Through alliances, partners are able to compete more successfully. Yoshino and Rangan [13] and Gomes-Cassers [14] define the alliance as a cooperative venture between firms situated on the continuum between markets and hierarchies. The alliance is distinguished by several characteristics: independent firms; horizontal or vertical relationships; relationships which are not solely transactional; partners share resources, risks and benefits but have limited control and incomplete contracts. The types of airline alliance may include reciprocal frequent-flyer program recognition, shared lounges and check-in facilities, code-sharing agreements, marketing arrangements, procurement policies, system commonality, and even the interchangers of flight-crew personnel and aircraft [2].

There have been a number of empirical studies on the effectiveness of alliances, including those by Gellman Research Associates [15], Park and Cho [16], Oum et al. [17], Park et al. [18], and Zhang et al. [3]. Results show that alliances improve a carrier's performance on a number of economic measures, including productivity, pricing, profitability, and share price. Other studies, such as Dev et al. [19] discussed strategic alliances from a number of theoretical perspectives, including transaction cost economics, network relationships, game theory, developmental processes, ethics and firm internationalization. Brueckner [20] analyzed the effects of international airline code-sharing on traffic levels and welfare using specific demand and cost functions. He showed that the beneficial effects of code-sharing outweigh its harmful effects for most parameter values in his theoretical model. Fan et al. [21] examined the forces influencing the consolidation and structure of the airline alliance. They highlighted the following five forces: (i) increased globalization in trade and air transportation; (ii) increased intra-regional interaction, (iii) economic incentives for airline consolidation; (iv) pace of liberalization of international air transport industry, and (v) anti-trust concerns. Holtbrugge et al. [2] investigated human resource management (HRM) after strategic alliance. The main focus in all of these alliance studies has been the importance of the strategic alliance or the performance measures after the alliance. Discussion of the issue of strategic partner selection has been relatively rare. The selection of a suitable partner for a strategic alliance is not an easy decision, involving many complex considerations. It is essentially a group-decision involving many dimensions and inherent risks, such as inter-partner conflicts, and potential structural and cultural incompatibilities. The proposed hybrid fuzzy preference programming and ANP model is able to consider decision-makers' uncertainty and provides insights into the interrelationship between alliance motivations and partner selection criteria in the airline industry, which to the best of our knowledge, has largely been neglected.

3. Proposed hybrid fuzzy preference programming and ANP model

In this section, the concepts of fuzzy preference programming for coping with the uncertain judgments in a group-decision process are first introduced. The ANP method for determining the best partner for the strategic alliance is then discussed, including consideration of the dependence and feedback effects. The combined model can help companies to evaluate a suitable partner and fulfill their specified needs.

3.1. Fuzzy preference programming

Fuzzy preference programming was first proposed by Mikhailov and Singh [22]. It is mainly used to derive priority vectors from a set of comparison judgments or interval comparisons. Let $A = \{l_{ij}, u_{ij}\}$ represent an interval comparison matrix with n components, where l_{ij} and u_{ij} are the lower and upper bounds of the corresponding uncertain judgments. Interval judgments are considered consistent if there exists a priority vector $\boldsymbol{w}$ that satisfies the following inequalities:

$$l_{ij} \le \frac{w_i}{w_j} \le u_{ij}. \tag{1}$$

Inconsistency in the judgments indicates that no priority vector satisfies all the interval judgments simultaneously. Thus, a sufficient solution vector has to satisfy all the interval judgments as much as possible, that is

$$l_{ij} \tilde{\le} \frac{w_i}{w_j} \tilde{\le} u_{ij}, \quad i = 1, 2, \ldots, n-1; \quad j = 2, 3, \ldots, n; \quad j > i, \tag{2}$$

where $\tilde{\le}$ denotes the statement "fuzzy less or equal to".

In order to handle the above inequalities we can represent them as a set of single-sided fuzzy constraints:

$$\begin{aligned} &w_i - w_j u_{ij} \tilde{\le} 0, \\ &-w_i + w_j l_{ij} \tilde{\le} 0. \end{aligned} \tag{3}$$

The above m fuzzy constrains can be represented in the following matrix form:

$$\boldsymbol{Rw} \tilde{\le} 0, \tag{4}$$

where the matrix $\boldsymbol{R} \in \Re^{m \times n}$; $m = n(n-1)$.

The kth row of Eq. (4) is a fuzzy linear constraint, which can be defined as a linear membership function of the type:

$$\mu_{\tilde{A}_k}(\boldsymbol{R}_k\boldsymbol{w}) = \begin{cases} 1 - \dfrac{\boldsymbol{R}_k\boldsymbol{w}}{d_k}, & 0 < \boldsymbol{R}_k\boldsymbol{w} \le d_k, \\ 0, & \boldsymbol{R}_k\boldsymbol{w} \ge d_k, \\ 1, & \boldsymbol{R}_k\boldsymbol{w} \le 0 \end{cases} \tag{5}$$

where d_k is tolerance parameter for the kth row, representing the admissible interval of approximate satisfaction of crisp inequality $\boldsymbol{R}_k\boldsymbol{w} \le 0$. The membership function of $\boldsymbol{R}_k\boldsymbol{w}$ can be represented as in Fig. 1.

The membership function (5) is equal to zero when the corresponding crisp constraint $\boldsymbol{R}_k\boldsymbol{w} \le 0$ is strongly violated; it is between zero and one when the crisp constraint is approximately satisfied; and it is equal to one when the constraint is fully satisfied.

To solve the fuzzy preference programming, two assumptions are needed. First let $\mu_{\tilde{A}_k}(\boldsymbol{R}_k\boldsymbol{w})$, $k = 1, 2, \ldots, m$ be the membership functions of the fuzzy constraints $\boldsymbol{Rw} \tilde{\le} 0$ on the $n-1$ dimensional simplex, where $\widetilde{A}_k$ is a fuzzy number of the kth pair-wise comparison:

$$Q^{n-1} = \{\boldsymbol{w} = (w_1, w_2, \ldots, w_n) | w_i > 0, \quad w_1 + w_2 + \ldots + w_n = 1\}. \tag{6}$$

The feasible fuzzy $\tilde{P}$ area on the simplex Q^{n-1} is a fuzzy set, described by the membership function:

$$\mu_{\tilde{P}}(\boldsymbol{w}) = [\min\left\{\mu_1(\boldsymbol{R}_1\boldsymbol{w}), \ldots, \mu_m(\boldsymbol{R}_m\boldsymbol{w}\right\} | w_1 + \ldots + w_n = 1], \tag{7}$$

The feasible fuzzy area is defined as the intersection of all fuzzy constraints on the simplex. The second assumption of the fuzzy preference programming selects a priority vector with the highest degree of membership as follows:

$$\beta = \max[\min\{\mu_{\tilde{A}_1}(\boldsymbol{R}_1\boldsymbol{w}), \ldots, \mu_{\tilde{A}_m}(\boldsymbol{R}_m\boldsymbol{w})\} | w_1 + \ldots + w_n = 1], \tag{8}$$

where $m = \frac{1}{2}n(n-1)$.

Bellman and Zadeh [23] proposed a max-min operator for deriving a maximizing solution for general decision-making problems with fuzzy goals and fuzzy constraints. Zimmermann [24] employed Bellman and Zadeh's idea to show that the max-min fuzzy linear problem can be transferred into a conventional linear programming:

Maximize β

Subject to $d_k\beta + R_k w \le d_k$,

$$w_1 + w_2 + \ldots + w_n = 1, \quad w_i > 0, i = 1, 2, \ldots, n, \quad k = 1, 2, \ldots, m. \tag{9}$$

where $\beta \le 1 - (\boldsymbol{R}_k\boldsymbol{w}/d_k)$ can now be written as $d_k\beta + \boldsymbol{R}_k\boldsymbol{w} \le d_k$. The details of the max-min operator and its relationship between fuzzy preference programming are illustrated in Appendix A. For comparison, we also added the compromise solutions with multiple objectives obtained using the min-max operator, as shown in Appendix B.

The optimal solution for the above linear program is a vector $(\boldsymbol{w}^*, \beta^*)$, whose first component represents a priority vector which has the maximum degree of membership in the feasible fuzzy area, and the second component gives us the value of that maximum degree, the so-called consistency index [12]. Please note that for the max-min operator, the maximum β represents the highest degree of membership in the decision set:

$$\mu_D(x_{\max}) = \max_{x\ge0}\min_{ij}\{\mu_{G_i}(x), \mu_{C_j}(x)\}. \tag{10}$$

However, in our proposed fuzzy preference programming method, we only apply the fuzzy constraints μ_{C_j} and do not use the membership function of fuzzy goals μ_{G_i} (see Appendix A). Furthermore, the β value is equal to 1, representing the highest consistent level (which is similar to 0 in the AHP consistency ratio λ); 0 indicates when the constraints are completely violated.

3.2. Analytic network process

ANP is the generic form of AHP, allowing for more complex interdependent relations among elements/criteria [7]. Saaty [25] first developed AHP in 1971, to help establish decision models through a process that contains both qualitative and quantitative components. Qualitatively, it decomposes a decision problem from the top overall goal to a set of manageable clusters, sub-clusters, and so on, down to the bottom level, which usually contains scenarios or alternatives [26]. Although both the AHP and the ANP derive ratio scale priorities by making paired comparisons of elements on a criterion, there are some differences between them. The first difference is that the AHP is a special case of the ANP, because the ANP handles dependence within a cluster (inner dependence) and among different clusters (outer dependence). Second, the ANP is a nonlinear structure, while the AHP is hierarchical and linear, with a goal at the top level and the alternatives on the bottom level [27].

The first step in the ANP is to develop the structure of the designed model. The AHP decision model is always restricted to being hierarchical, containing several levels assumed to have independent criteria. Only adjusted levels of the ANP are assumed to have dependence/correlation with each other. Therefore, the ANP is a network structure, where the hierarchical restriction is relaxed so that dependence/correlation can be stipulated in any part of the decision model to form the sub-matrices for the so-called supermatrix [7,26]. The second step is to compare the criteria for the whole system to form a supermatrix. This is done through pair-wise comparisons by asking "How much importance does a criterion have compared to another criterion with respect to our interests or preferences?" The relative importance value is determined using a scale of 1–9, representing equal importance to extreme importance, respectively [7,28]. The general form of the supermatrix can be described as follows:

$$\boldsymbol{W} = \begin{array}{cc|cccc|} & & C_1 & C_2 & \cdots & C_m \\ & & e_{11}\cdots\; e_{1n_1} & e_{21}\cdots\; e_{2n_2} & \cdots & e_{m1}\cdots e_{mn_m} \\ \hline C_1 & \begin{matrix} e_{11} \\ e_{12} \\ \vdots \\ e_{1n_1} \end{matrix} & \boldsymbol{W}_{11} & \boldsymbol{W}_{12} & \cdots & \boldsymbol{W}_{1m} \\ C_2 & \begin{matrix} e_{21} \\ e_{22} \\ \vdots \\ e_{2n_2} \end{matrix} & \boldsymbol{W}_{21} & \boldsymbol{W}_{22} & \cdots & \boldsymbol{W}_{2m} \\ \vdots & \vdots & \vdots & \vdots & & \vdots \\ C_m & \begin{matrix} e_{m1} \\ e_{m2} \\ \vdots \\ e_{mn_m} \end{matrix} & \boldsymbol{W}_{m1} & \boldsymbol{W}_{m2} & \cdots & \boldsymbol{W}_{mm} \\ \hline \end{array}, \tag{11}$$

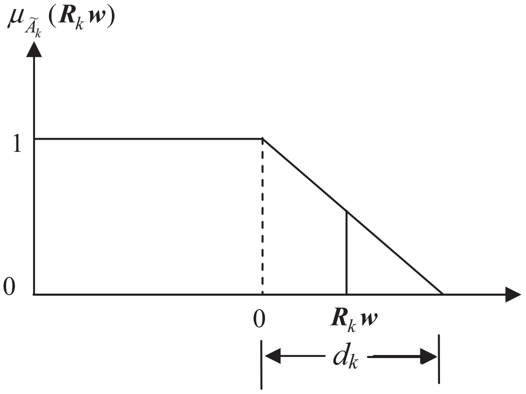

Fig. 1. Illustrated membership function.

where C_m denotes the mth cluster; e_{mn} denotes the nth element in the mth cluster; and matrix $\boldsymbol{W}_{ij}$ is compose of a serial principal eigenvector of the influence of the elements compared in the jth cluster to the ith cluster. The form of the supermatrix depends on the variety of the structure. For example, if the structure of the system is shown as in Fig. 2, the unweighted supermatrix $\boldsymbol{W}$, containing the local priorities derived from the pair-wise comparisons throughout the network can be illustrated as follows:

$$\boldsymbol{W} = \begin{array}{cc} & \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{array}{c} C_1 \\ C_2 \\ C_3 \end{array} & \begin{bmatrix} 0 & 0 & W_{13} \\ W_{21} & 0 & 0 \\ 0 & W_{32} & W_{33} \end{bmatrix} \end{array}. \tag{12}$$

$\boldsymbol{W}_{21}$ is a matrix that represents the weights of cluster 2 with respect to cluster 1; matrix $\boldsymbol{W}_{32}$ denotes the weights of cluster 3 with respect to cluster 2; and matrix $\boldsymbol{W}_{13}$ shows the weights of cluster 1 with respect to cluster 3. In addition, matrix $\boldsymbol{W}_{33}$ is denoted as the inner dependence and feedback within cluster 3. After forming the supermatrix, the weighted supermatrix is derived by transforming the sum of all columns to exactly unity. This step is very similar in concept to the Markov chain for ensuring that the sum of the probabilities of all states equals 1 [28]. The weighted supermatrix can then be raised to limiting powers, to calculate the overall priorities that are represented on each row in the converged matrix.

4. Constructing a strategic partnering model for analysis

The model was developed and validated using input from an international airline operating in Taiwan. This airline currently flies to more than 40 destinations around the world, although most are within the Asia Pacific region. The company has sought to join strategic alliances in order to develop a far-reaching service network and increase competitive power, to enhance the effectiveness of its global logistics and to provide better service for satisfying customer needs. The decision is a strategic one, in that the success of the development would have great impact on the competitiveness of the company.

Since partner selection is crucial to success, it is imperative for decision-makers to devise, identify and recognize effective partner selection factors as well as to evaluate questions of compatibility and feasibility prior to joining or developing any strategic alliance. The conceptual model of the strategic partner selection process is first developed based on previous work [10,16,18,26,29]. Then, through the Delphi method we consulted with some senior managers of the airline in order to modify the original model. After adding/deleting some elements and modifying the flow graph, the final strategic model used in this study is illustrated in Fig. 3. Of course, the present network was mainly based on the managers' opinions of the case company; other companies may end up with different networks based on their own operation environment.

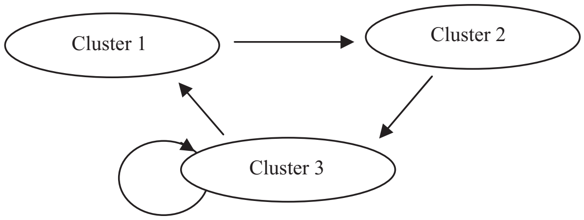

Fig. 2. Illustrated structure of the system (example).

The relative factors and alternatives are structured in the form of a hierarchy. The model requires the development of attributes at each level and a definition of their relationship. The ultimate goal is to select the best partner. To do this, it is first necessary to strategically analyze the internal organizational and external environmental driving forces, which act as the underlying motivation and reasons for alliance formation. Based on the considered driving forces, the alliances' scope and structure are provided for evaluation. There are five major ways to implement strategic alliances, including market, product/service, computer systems, equipment and equipment servicing, and logistics. After the types of strategic alliance are investigated, some choices of appropriate partners for strategic alliance formation are considered. Finally, the evaluation of the alliance is fed back into the analytical phase, to incorporate any changes based upon experience. We are seeking to determine which of several alternatives would best support the realization of the ultimate goal while feedback effects are considered. Details of the procedure are described as follows:

(1) *Strategic analysis*: The first step is the strategic analysis phase where internal and external driving forces for a strategic alliance are analyzed. The internal drivers include "risk sharing," "economies of scale," "access to assets, resources and competencies," and "shaping competition." Strategic alliances are seen as an attractive mechanism for hedging risk, because neither partner has to bear the full risk or cost of the alliance activities [30]. The economies of scale advantage can be achieved when alliance partners link up their existing networks so that they can provide connecting services for new markets. Marketing costs can be shared between alliance partners, which may have strongly entrenched positions in certain markets [31]. The regulatory framework for "bilateral agreements", landing rights and congestion at certain airports means that airlines already possessing licenses to operate a route or have slots at congested airports have important and marketable assets that are attractive to alliance partners [29]. Strategic alliances can also be used as a defensive ploy to reduce competition, since an obvious benefit of strategic alliances is converting a competitor into a partner [32]. Alternatively, alliance formation may form part of an offensive strategy, for example by linking with a rival in order to put pressure on the profits and market share of a common competitor [33].

The external drivers include "information revolution," "economic restructuring," and "global competition." Computer reservations systems (CRS) allow airlines to monitor, manage and control their capacity through yield management and their clients through frequent flyer programs. Undoubtedly, the airlines that own the CRS will favor their own flights. Joint airline ownership may reduce the chances of CRS being biased in favor of a particular airline, but the dominance of CRS companies gives them considerable market power [31]. Also, consumers often favor their own national airline or its partners to an

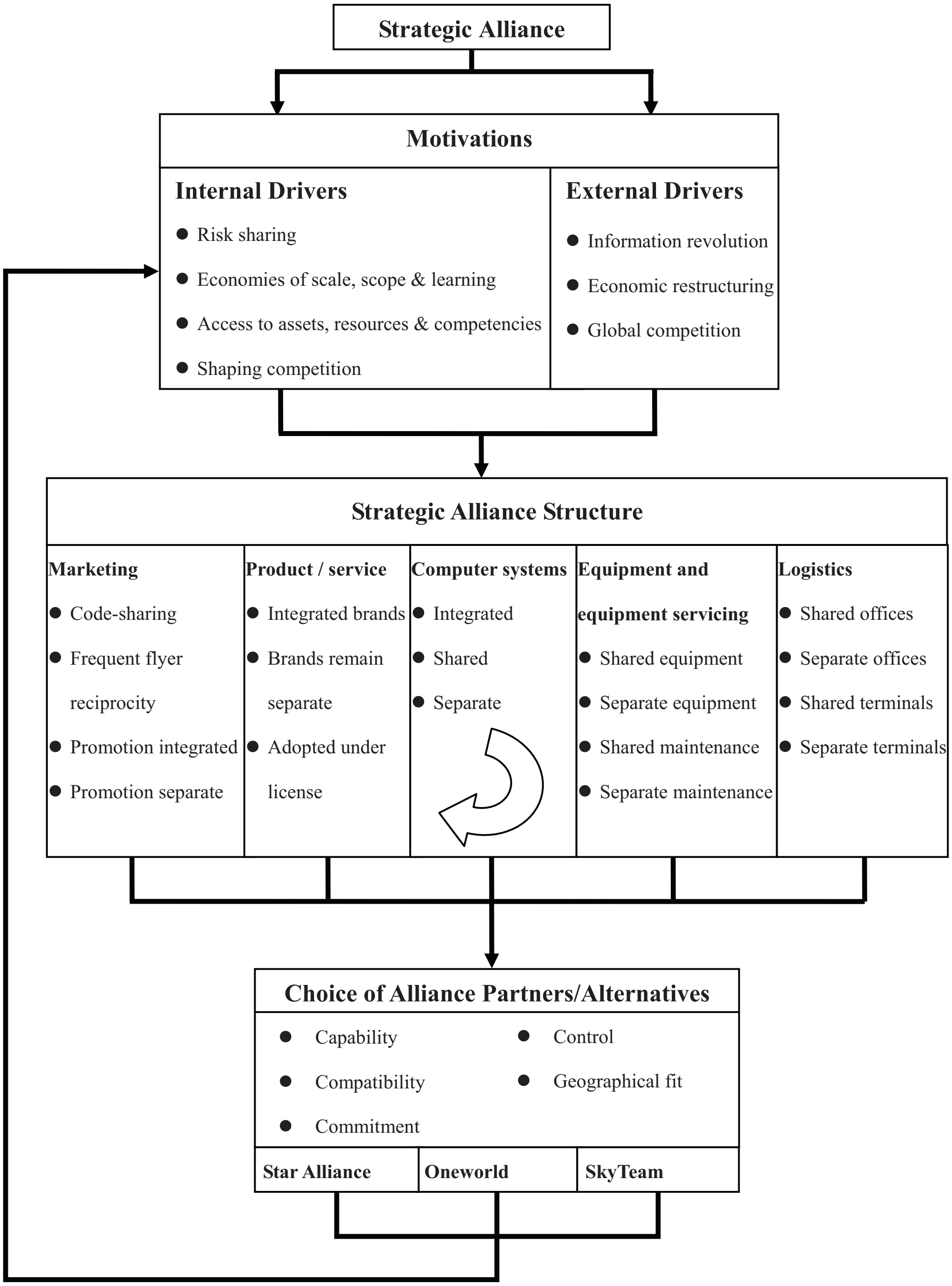

Fig. 3. Network structure of project partnering.

extraordinary degree. Such a patriotic attitude to purchasing, rarely replicated in other industries, drives airlines to form alliances as the only effective means of market entry [29]. Economic restructuring through the philosophy of economic disengagement by governments, as is currently occurring in many parts of the world, has also had a major impact on airline industry structure. In addition, liberalization, privatization, foreign ownership and transnational mergers may also have a major impact upon the future structure of the airline industry, even though many regulatory and ownership barriers remain in force worldwide. Since this means that mergers and acquisitions are often precluded as viable growth strategies for international airlines. Consequently the formation of strategic alliances is, in many cases, the only available form of market entry. Airlines seek to maximize their global reach, in the belief that those that offer a global service will be in the strongest competitive position. In other words, globalization is an important external drive for alliance formation in today's highly competitive environment.

(2) *Strategic development*: In determining the methods by which strategic development will take place, organizational management is faced with making a choice between a variety of different alliance structures and scopes, as indicated in Fig. 3. The airline will prioritize its strategic development based on previous strategic analysis and its current operational situation. There are many ways to implement a strategic alliance, such as shared airport facilities, synchronized scheduling, reciprocity in frequent flyer programs, freight coordination and joint marketing activities. There are usually inner dependence and feedback effects between these different strategic alliance strategies. Also, due to resource constraints, it may be possible to pursue only some of these options. Once the preference

Table 1
Fuzzy weight comparisons of external drivers.

	Market	Service/product	Computer	Equipment	Logistic	Weights
Market	1	(1, 3)	(2, 5)	(3, 5)	(1, 3)	0.41
Service/Product	(1/3, 1)	1	(1/5, 1/3)	(3, 7)	(1, 3)	0.16
Computer System	(1/5, 1/2)	(3, 5)	1	(4, 7)	(3, 5)	0.24
Equipment	(1/5, 1/2)	(1/3, 1)	(1/7, 1/4)	1	(1/2, 3)	0.08
Logistic	(1/3, 1)	(1/3, 1)	(1/5, 1/3)	(1/3, 2)	1	0.11

Consistency index = 0.92.

is made, the airline is committed to pursuing these courses of action.

(3) *Strategic partner selection*: There are several reasons for the successful implementation of strategic alliances but the importance of partner selection has been emphasized by several writers [34,35]. There are some important factors that need to be considered when choosing appropriate partners. The selected partner should have the capability to carry out its role within the alliance. Partners should also be able to demonstrate equal commitment to an alliance through experiencing commensurate levels of risk. The compatibility of the partner and the focal firm, both in cultural and operational terms, is another significant factor. For example, the failure of the "Alcazar" alliance in the early 1990s was due to misunderstandings between the various American partners and differently affiliated CRS systems. The success of the strategic alliance also depends on an effective control system and whether partners are likely to contribute to the alliance. Sometimes, a strong focused leadership can be viewed as opportunistic, and a power imbalance lends potential for conflict among the partners. A key question that needs to be addressed in the assessment of alliance control is the extent to which each partner is able to achieve whatever strategic objectives they have set themselves when entering into the alliance relationship [29]. The geographical fit also needs to be considered when selecting strategic partners. Airlines are careful to avoid forming partnerships with airlines that have overlapping markets. For example, in the Northwest/KLM alliance, partners have distinctive geographical strengths in the USA and Europe.

(4) *Feedback evaluation*: After the partners are decided, the selected partners will have some degree of impact or effect on the focal firm, both internal and external. Whether an alliance can improve a carrier's performance and fulfill the objectives that drove the alliance is an essential factor for long-lasting strategic alliances. If the interdependence within the alliance is not strong enough and performance improvement is limited, the alliance will easily collapse. Therefore, the evaluation and feedback for selected partners as related to the driving forces is included in this model.

5. Implementation of the proposed hybrid model

In this study, the general manager of the airline under study designated a team to develop a strategic partner selection plan. Twenty-five managers from different departments, including planning, operation, maintenance, human resources, information systems, and safety, with at least 15 years experience in the airline and expertise in their own particular fields filled out a survey.

5.1. Pair-wise comparisons and fuzzy preference programming

In ANP, like AHP, managers are asked to make pair-wise comparisons of the elements in each level with respect to their relative importance toward their upper/control criterion. To ensure that no extreme cases exist, the Delphi method is applied to collect the data. Since different experts come from different departments they propound a variety of viewpoints, and his or her judgment will be different. After circulating the questionnaire several times, each pair-wise comparison converges to an acceptable range, without extreme cases. As mentioned in Section 3.2, a scale of 1–9 is used to compare the two components, with a score of 1 representing no difference between the two components and 9 representing overwhelming dominance of the component under consideration (row component) over the comparison component (column component). When scoring is conducted for a pair, a reciprocal value is automatically assigned to the reverse comparison within the matrix (i.e., $a_{ji} = 1/a_{ij}$). Since many of these values are strategic and subjective, the comparison ratios are represented as an interval (l_{ij}, u_{ij}), with upper and lower bounds. Two separate pair-wise comparison matrices (internal and external drivers) have to be developed in this step. An example of the pair-wise comparison matrix of external drivers for the strategic alliance is shown in Table 1. Please note that the intervals shown in Table 1 indicate a range of answers from 25 managers.

Using the fuzzy preference programming introduced in Section 3.1, the interval of the comparison ratios (Table 1) can be transferred into a linear programming problem as follows (the tolerance parameter $d_k = 1$):

maximize β

$$\begin{aligned}
\text{Subject to}\quad & \beta + w_1 - 3w_2 \le 1,\\
& \beta - w_1 + w_2 \le 1,\\
& \cdots\\
& \beta + w_4 - 3w_5 \le 1,\\
& \beta - w_4 + 0.5w_5 \le 1,\\
& w_1 + w_2 \cdots + w_5 = 1.
\end{aligned}$$

The above linear programming problem is solved in order to derive the consistency index and the weighted priorities for this matrix, as indicated in the last column of Table 1. The weighted internal drive priorities can be used for similar procedures to obtain the sub-matrix showing motivation, as illustrated in Table 2. It is obvious that the market (0.41) has the highest priority with respect to external drives, while the computer system (0.43) is considered the most important of internal drives.

The second step in our pair-wise comparison of different alliance structures is to compare the relative importance of three proposed alliances. The three proposed alliances have been arrived

Table 2
Weight priorities for motivation.

	Weights				
	Market	Service/product	Computer system	Equipment	Logistic
Internal drives	0.21	0.13	0.43	0.16	0.07
External drives	0.41	0.16	0.24	0.08	0.11

Table 3
Fuzzy weight comparisons for marketing.

	Star Alliance	One-world	Sky Team	Weights
Star Alliance	1	(1, 5)	(3, 7)	0.57
One-world	(1/5, 1)	1	(1, 3)	0.29
Sky Team	(1/7, 1/3)	(1/3, 1)	1	0.14

Table 4
Weight priorities under different alliance structures.

	Weights		
	Star Alliance	One-world	Sky Team
Marketing	0.57	0.29	0.14
Service/product	0.46	0.42	0.12
Computer system	0.16	0.62	0.22
Equipment	0.41	0.36	0.23
Logistics	0.21	0.34	0.45

at through discussion with 25 airline managers through the Delphi method. Five separate pair-wise comparison matrices (market, service/product, computer system, equipment, and logistics) are required to fully describe the relative importance of different alliances with respect to alliance structure. An example of one of these matrices is shown in Table 3. The weight priorities (last column of Table 3) can be derived by fuzzy preference programming similar to step one. In this case, the "Star Alliance" would have the greatest importance with respect to marketing consideration. The other weight priorities (under different alliance structures) are shown in Table 4. The results indicate that "One-world" is better for their computer system while the "Sky Team" leads on logistics.

As described in our model (Fig. 3), the motivations for strategic alliances include both external and internal drivers. Any formulated strategic alliance should fulfill its original motivations. Therefore, we must consider the feed-back effect that will occur if the selected alliance can satisfy its internal and external drives. Using similar procedures to steps one and two, we obtain the weight priorities with respect to different alliances as shown in Table 5. In the "Star Alliance" there is probably more emphasis placed on external drives, "One-world" places greater importance on internal drives, while in "Sky Team" internal and external drives are found to be fairly close in importance to each other.

5.2. Sensitive analysis

In our fuzzy preference programming, the tolerance d_k was set as 1. That is the membership function of pair-wise comparison will decrease monotonically from 1 to 0 over the tolerance interval $d_k = 1$ (Fig. 1). To investigate the influence of the tolerance on the obtained weights, we conducted a sensitivity analysis by setting different d_k values. We tried values ranging from 0.1 to 9, which represented the maximum pair-wise comparison value to the minimum value. These results indicate that the obtained weights were all the same for all the different tolerance setting values, except that the β value increased from 0.189 to 0.991 as the tolerance d_k increased from 0.1 to 9. Since our main purpose is to derive the weights of the criteria, the proposed model is robust with the various tolerances of the membership functions.

Table 5
Weights of internal and external drives under different alliances.

	Weights	
	Internal drives	External drives
Star Alliance	0.19	0.81
One-world	0.85	0.15
Sky Team	0.54	0.46

$$\begin{array}{lc}
 & \begin{array}{ccc} \text{Motivations} & \begin{array}{c}\text{Strategic}\\ \text{Alliance}\\ \text{Structure}\end{array} & \begin{array}{c}\text{Choice of}\\ \text{Alliance}\\ \text{Partner}\end{array} \end{array} \\
\begin{array}{l} \text{Motivations} \\ \text{Strategic Alliance Structure} \\ \text{Choice of Alliance Partner} \end{array} & \begin{bmatrix} 0 & 0 & \boldsymbol{W}_{13} \\ \boldsymbol{W}_{21} & \boldsymbol{W}_{22} & 0 \\ 0 & \boldsymbol{W}_{32} & 0 \end{bmatrix}
\end{array}$$

Fig. 4. Structure of strategic alliance in the ANP model.

5.3. Super-matrix and limit matrix

Given the interdependent influences, a system that consists of process steps and feedback effects needs to be transformed into a super-matrix. This can be achieved by entering the local priority vectors into the super-matrix, to in turn obtain global priorities. The inner dependence and feedback effects between levels/clusters for the model developed for strategic alliance selection are shown in Fig. 3. Inner dependence exists within the alliance structure and feedback effects are related to motivation. A general view of the super-matrix for this study is also shown (Fig. 4), where the pair-wise comparison matrices of the three steps are entered into the correct locations. In a super matrix, these individual matrices are called sub-matrices. For example, $\boldsymbol{W}_{21}$ is the sub-matrix of motivation, while $\boldsymbol{W}_{22}$ is the sub-matrix of inner dependence within the "alliance structures" cluster. The complete un-weighted supermatrix for the ANP model is show in Table 6. Please note that due to inner dependence $\boldsymbol{W}_{22}$, the diagonal elements of $\boldsymbol{W}_{22}$ are first set to 0.5 while the other elements are set to 0, then the column vectors (under the alliance structure) are normalized to sum up to one [28]. The un-weighted super-matrix is then raised to a sufficiently large power until convergence occurs. In this study, convergence occurs at 36 times. Table 7 provides the final limit matrix. This limit matrix is a column stochastic and represents the final eigenvector. The alternative with the largest value should be the one selected. As shown in Table 7, the results of the alliance-partner alternatives in the case study point to the selection of "One-world" as the best choice, due to a weight of 0.108, which is larger than that of the other two alternatives.

5.4. Result analyses and discussion

Although ANP has been widely used in various applications, it is hard for decision-makers to quantify precise judgments about criteria under conditions of incomplete information and subjective uncertainty. In this paper, we propose a hybrid model combining fuzzy preference programming and ANP, which extends the original ANP by using fuzzy judgments to compare the ratios of weights between criteria. This model can avoid the convergence problems encountered using standard fuzzy arithmetic operations in fuzzy ANP. Since standard fuzzy arithmetic operations are used to multiply and divide fuzzy numbers, the method may result in the convergence and rational problems of fuzzy global weights. We use linear programming to derive the steady-state priority vectors, and then use ANP to consider clusters/criteria dependence. The model should be more practical for actual application than ANP, which ignores the uncertain judgments often made in the real world, and conventional fuzzy ANP, which causes convergent problems. Table 8 shows a comparison of the results obtained between our proposed model and the original ANP method. Our model indicates that One-world is the best selection while the original ANP method points to Star Alliance (with a higher weight 0.100 than 0.098 of One-world) as being optimal. However, in our

Table 6
Un-weighted supermatrix.

	Motivations		Alliance structure					Partners		
	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}
C_{11}	0	0	0	0	0	0	0	0.19	0.85	0.54
C_{12}	0	0	0	0	0	0	0	0.81	0.15	0.46
C_{21}	0.21	0.41	0.50	0	0	0	0	0	0	0
C_{22}	0.13	0.16	0	0.50	0	0	0	0	0	0
C_{23}	0.43	0.24	0	0	0.50	0	0	0	0	0
C_{24}	0.16	0.08	0	0	0	0.50	0	0	0	0
C_{25}	0.07	0.11	0	0	0	0	0.50	0	0	0
C_{31}	0	0	0.28	0.23	0.08	0.20	0.10	0	0	0
C_{32}	0	0	0.14	0.21	0.31	0.18	0.17	0	0	0
C_{33}	0	0	0.08	0.06	0.11	0.12	0.23	0	0	0

Note: C_{11} = internal drive; C_{12} = external drive; C_{21} = marketing; C_{22} = service/product; C_{23} = computer system; C_{24} = equipments; C_{25} = logistic; C_{31} = Star Alliance; C_{32} = One-world; C_{33} = Sky Team.

Table 7
Limit supermatrix.

	Motivations		Alliance structure					Partners		
	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}
C_{11}	0.137	0.137	0.137	0.137	0.137	0.137	0.137	0.137	0.137	0.137
C_{12}	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113
C_{21}	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
C_{22}	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
C_{23}	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172
C_{24}	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
C_{25}	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044
C_{31}	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089	0.089
C_{32}	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108	0.108
C_{33}	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053	0.053

proposed model, we considered decision-maker uncertainty when they make a decision, which could make this model more realistic than the original method. Furthermore, we divided the experts into two groups, technical (operational, maintenance and safety departments) and non-technical (financial, marketing and service departments). The opinion of the technical group was that One-world was the best alliance, but the result for the non-technical group gave Star Alliance the highest weight. These results might be because Star Alliance has a higher marketing share, and non-technical groups deemed marketing and service to be the important criteria. On the other hand, One-World was chosen by technical groups due to the experts thinking that One-world offered more reliable technical operation. Again, this is the advantage of our model that it can integrate different opinions to come up with an optimal solution.

The empirical results indicate that "One-world" is the best selection from the airline's viewpoint. However whether to join an alliance or not is not only dependent on the company's "willingness", but also on "acceptance" of the alliance. Here we provide a tool to help airlines select an optimized strategic alliance given their own requirements. It is also worth noting that different airlines may end up with different results, based on their own specific needs. Although the present model has proven valuable, there are still some areas that need further discussion. It is acknowledged that the decision levels and criteria involved in any particular implementation may differ depending on the airlines/enterprises involved. In fact, this is one of the strengths of ANP, which can be used to construct various structures considering inner dependence and feedback effects. A set of criteria should be designed for each application, depending upon what is deemed important for that application. Decision criteria or dependence within/between clusters that a company considers to be crucial can be easily added to the generic model. Also, the weighting given each component in the model is dependent on the decision-makers evaluation of the component. This helps facilitate tailoring of the model to the company in question. For example, an airline that stresses enlarging markets would likely select criteria and weightings different from an airline seeking to provide better services/products.

On the other hand, not all possible criteria and interactions are considered. Again, decision factors could be added, depending on the decision environment. Possible extensions in this area currently being explored include risk analysis of strategic alliances and different interactions between clusters. For instance, currently, only a one-way influence between motivations, alliance structures and partners is included in the model. The interactions could be modeled as two-way interactions. Perhaps a more interesting and useful extension of the model would be to include interactions within alliance structures and alternatives (partners).

One of the limitations of the original ANP is its dependency on the decision-makers. The weightings obtained are based on the decision makers' subjective opinions and many of these values are strategic, therefore, additional strategic group decision-making tools are needed. Although we can use scenario planning or the Delphi approach, these are still time-consuming and it is sometimes

Table 8
Comparison between fuzzy preference programming with ANP and original ANP.

	Motivations		Alliance structure					Partners		
	C_{11}	C_{12}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{31}	C_{32}	C_{33}
FPP + ANP	0.137	0.113	0.150	0.072	0.172	0.060	0.044	0.089	0.108	0.053
ANP	0.140	0.113	0.136	0.065	0.197	0.059	0.040	0.100	0.098	0.053

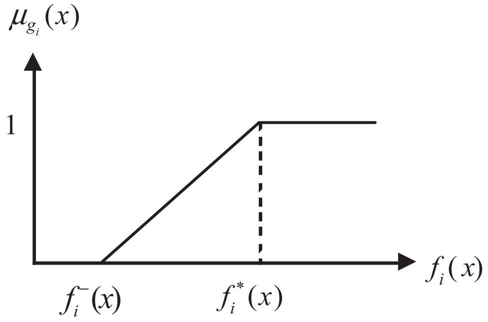

Fig. A1. Membership function of fuzzy goals.

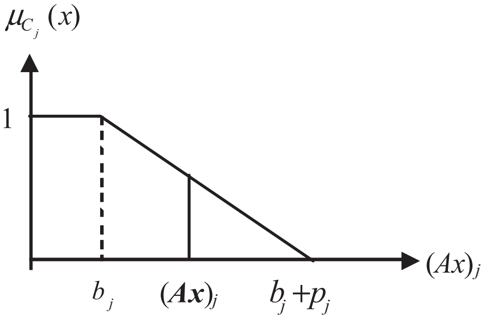

Fig. A2. Membership function of fuzzy constraints.

hard to reach a consensus. In this study, the uncertainty of judgment is removed by expressing the comparison ratios as an interval, to incorporate the vagueness inherent in human thinking. The proposed model has some further advantages. It provides opportunity for solving prioritization problems with mixed types of comparison judgments, such as intervals or crisp numbers. Also, the prioritization problem is treated as a linear program, which can easily be solved.

6. Concluding remarks

The purpose of this paper is to describe a method for strategic alliance selection that allows for consideration of important interactions among decision levels and criteria. We use a hybrid model combining fuzzy preference programming and ANP methodology that considers uncertainty in group decisions, and both inner dependence and feedback effects for this evaluation. We develop a model for the strategic alliance partner selection process based on the literature and adapted for an airline in Taiwan. The airline acts as a case study for validation of the model approach. This work should be valuable to practitioners because it provides a generic model for partner selection. This strategic decision-making tool can assist an airline in comparing proposed alliance partners with respect to different process stages and alliance structures. The model suggests that the "One-world" alliance is the best option for this particular airline. The case study helps to verify that the proposed model is an effective and efficient decision-making tool which can be easily extended.

Appendix A. The max-min operator

A.1. Fuzzy goal and fuzzy constraint programming

In fuzzy goal and fuzzy constraint programming problems, it can mathematically be represented as

$$\begin{array}{ll} \max & [\tilde{f}_1(\boldsymbol{x}), \tilde{f}_2(\boldsymbol{x}), \cdots, \tilde{f}_k(\boldsymbol{x})] \\ s.t. & \tilde{\boldsymbol{A}}\boldsymbol{x} \le \tilde{\boldsymbol{b}} \\ & \boldsymbol{x} \ge 0 \end{array} \tag{A1}$$

where $\boldsymbol{x}$ is the vector of variables and $\tilde{\boldsymbol{b}}$ is the vector for the fuzzy right hand side.

First, we can define the membership function of fuzzy goals and fuzzy constraints as follows (see Figs. A1 and A2):

$$\mu_{g_i}(\boldsymbol{x}) = \begin{cases} 1, & f_i(\boldsymbol{x}) > f_i^*(\boldsymbol{x}) \\ 1 - \dfrac{f_i^*(\boldsymbol{x}) - f_i(\boldsymbol{x})}{f_i^*(\boldsymbol{x}) - f_i^-(\boldsymbol{x})}, & f_i^-(\boldsymbol{x}) \le f_i(\boldsymbol{x}) \le f_i^*(\boldsymbol{x}) \\ 0, & f_i(\boldsymbol{x}) < f_i^-(\boldsymbol{x}) \end{cases} \tag{A2}$$

$$\mu_{C_j}(\boldsymbol{x}) = \begin{cases} 1, & (\boldsymbol{Ax})_j < b_j \\ 1 - \dfrac{(\boldsymbol{Ax})_j - b_j}{p_j}, & b_j \le (\boldsymbol{Ax})_j \le b_j + p_j \\ 0, & (\boldsymbol{Ax})_j > b_j + p_j \end{cases} \tag{A3}$$

The membership function (A2) of the fuzzy objective function i should be 0 for $f_i(x)$ levels equal to less than lower bound, 1 for $f_i(x)$ equal to or greater than the upper bounds, and monotonically increasing from 0 to 1. The membership function (3) of the fuzzy set representing constraint j should be 0 if the constraint is strongly violated (if it exceeds $b_j + p_j$), 1 if it is satisfied in the crisp sense (if equal to or less than b_j), and should decrease monotonically from 1 to 0 over the tolerance interval $(b_j, b_j + p_j)$.

The membership function of the decision set, $\mu_D(x)$, is given by

$$\mu_D(x) = \min_{ij}\{\mu_{G_i}(x), \mu_{C_j}(x)\}. \tag{A4}$$

The min-operator is used to model the intersection of the fuzzy sets of objectives and constraints. Since the decision maker wants to have a crisp decision proposal, the maximizing decision will correspond to the value of x, $x_{\max}$, that has the highest degree of membership in the decision set:

$$\mu_D(x_{\max}) = \max_{x \ge 0}\min_{ij}\{\mu_{G_i}(x), \mu_{C_j}(x)\}. \tag{A5}$$

In this case, we can transfer Eq. (A1) to β expression method as follows:

$$\begin{array}{ll} \max\limits_{x} & \beta \\ s.t. & \beta \le 1 - \dfrac{f_i^*(\boldsymbol{x}) - f_i(\boldsymbol{x})}{f_i^*(\boldsymbol{x}) - f_i^-(\boldsymbol{x})}, \quad i = 1, 2, \ldots, k \\ & \beta \le 1 - \dfrac{(\boldsymbol{Ax})_j - b_j}{p_j}, \quad j = 1, 2, \ldots, m \\ & \boldsymbol{x} \ge 0 \end{array} . \tag{A6}$$

In our proposed fuzzy preference programming, we only apply the fuzzy constraint programming (μ_{C_j}) (Eq. (A3)) with the $\boldsymbol{b_j}$ equal to 0, $(\boldsymbol{Ax})_j$ equal to $(\boldsymbol{Rw})_k$ or $\boldsymbol{R}_k\boldsymbol{w}$ and p_j equal to d_k (Figs. 1 and A2).

Appendix B. The min-max operator

A multi-objective programming (MOP) problem can be mathematically represented as follows:

$$\begin{array}{ll} \max & [f_1(\boldsymbol{x}), f_2(\boldsymbol{x}), \ldots f_k(\boldsymbol{x})] \\ s.t. & \boldsymbol{Ax} \le \boldsymbol{b} \\ & \boldsymbol{x} \le 0 \end{array} . \tag{B1}$$

The compromise solution method was originally proposed by Yu [36] in 1973. The basic idea is to find the minimum distance

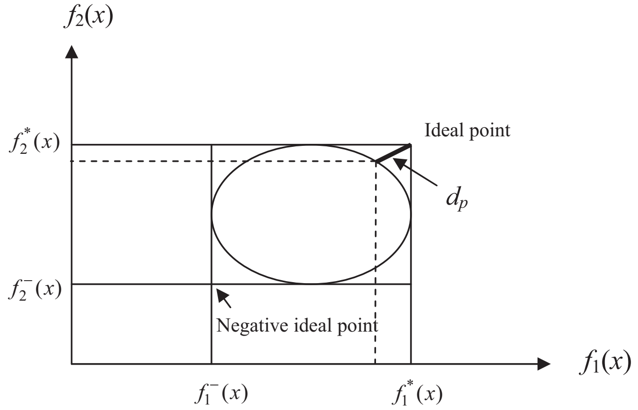

Fig. B1. Euclidean distances to the ideal solution (aspired levels) and negative-ideal solutions (worst values) in two dimensions.

(d_p) between feasible solutions and ideal point (Fig. B1). The d_p is defined as in Eq. (B2).

$$d_p = \left[\sum_{i}^{k} w_i^p \left(\frac{f_i^*(x) - f_i(x)}{f_i^*(x) - f_i^-(x)} \right)^p \right]^{1/p}. \tag{B2}$$

When the $p = \infty$, Eq. (B2) can be expressed as follows:

$$d_{p=1} = \sum_{i=1}^{k} w_i^p \left(\frac{f_i^*(\boldsymbol{x}) - f_i(\boldsymbol{x})}{f_i^*(\boldsymbol{x}) - f_i^-(\boldsymbol{x})} \right), \tag{B3}$$

$$d_{p=\infty} = \max \left[w_i \left(\frac{f_i^*(x) - f_i(x)}{f_i^*(x) - f_i^-(x)} \right) \middle| i = 1, 2, \ldots, k \right]. \tag{B4}$$

Using the definition for d_p distance as Eqs. (B3) and (B4), the multi-objective programming Eq. (B1) can be transferred as follows:

$$\begin{array}{ll} \min\limits_{x} & d \\ s.t. & \boldsymbol{Ax} \le \boldsymbol{b} \\ & \dfrac{f_1^*(\boldsymbol{x}) - f_1(\boldsymbol{x})}{f_1^*(\boldsymbol{x}) - f_1^-(\boldsymbol{x})} \le d,\ i = 1, 2, \ldots, k \\ & \boldsymbol{x} \ge 0 \end{array} \quad \text{or} \quad \begin{array}{ll} \min\limits_{x} \max\limits_{i} & d \\ s.t. & \boldsymbol{Ax} \le \boldsymbol{b} \\ & \boldsymbol{x} \ge 0 \end{array} \tag{B5}$$

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