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A fuzzy e-negotiation support system for inter-firm collaborative product development

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Significant advances in manufacturing technology and the rapid intensification of the Internet and electronic commerce diffusion have given rise to competitive differentiation and rapid adaptability to competitive change. New product development is a complex and collaborative process that requires negotiation and joint decision-making. We propose a fuzzy electronic negotiation (e-negotiation) support system based on cooperative multi-criteria game theory. The proposed system comprises three major processes: initialisation, e-negotiation and joint agreement. The Internet is used to facilitate the e-negotiation process and to minimise the response time in the decision-making process. The fuzzy sets are used to overcome issues related to the imprecise or vague judgments and incomplete information in the negotiation process. The proposed system enables the manufacturing parties involved in the negotiation process to determine the optimal coalition form for new product development and choose a common strategy to improve the payoffs of the members of the coalition group. Finally, a case study is used to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and algorithms in the mobile telecommunications industry.

Keywords: collaborative product development; multi-criteria decision-making; cooperative multi-criteria game theory; e-negotiation support system; fuzzy sets

1. Introduction

The rapid evolution of manufacturing technology and global connectivity has drastically increased organisational awareness and responsiveness to the interactions between the cooperating parties in the manufacturing sector of the economy. Cooperation requires negotiation. Negotiation is a process of social interaction and communication whereby the parties involved in the negotiation process communicate to reach a joint agreement (Thompson and Nadler 2002). The main steps of negotiation are: (1) exchange of information; (2) each party evaluates this information from its own perspective; (3) joint agreement is reached by mutual selection (Thompson 1998). Cooperation has become prevalent in manufacturing, and the possibility to cooperate offers a promising solution for manufacturers to the problem of identifying appropriate trading partners (Choy *et al*. 2004). Numerous operating modes based on cooperative relations between the manufacturing parties have been widely adopted in practice (Zhao *et al*. 2010, Renna and Argoneto 2011).

The ability to cooperate and perform negotiation activities over the Internet has greatly increased the ability of the manufacturing partners to reduce costs and shorten cycle times (Chiu *et al*. 2005). Carmel *et al*. (1993) have argued that electronic negotiation (e-negotiation) is not only quick and direct but also helps the parties involved in the negotiation process separate the negotiated issues from the personality issues due to the effect of anonymity. The decision-making aspect of the negotiation process requires that parties use information to evaluate alternatives and to formulate offers and arguments. The communication aspect of the negotiation process requires parties exchange information to make offers and influence and motivate opposing parties to make counter offers. In spite of the importance of negotiation, achieving higher quality, lower cost and shorter cycle time has been the primary goal of collaborative product development (Noori and Lee 2004, Li *et al*. 2005, Molina *et al*. 2005, Ouzizi *et al*. 2006, Harmancioglu *et al*. 2007, Pol *et al*. 2007, Hu *et al*. 2010). The literature on collaborative product development generally does not effectively support group decision-making and negotiation among potential manufacturing partners (Jing and Lu 2010).

In game theory, there are two different approaches to the multilateral cooperation problem, cooperative and non-cooperative approaches (McCain 2008). In other words, the type of solution in game theory largely depends on the behaviour of the decision makers and their relationship. If the decision makers

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do not cooperate with each other, that is, each of them cares only about its own benefit, then the game is non-cooperative. Non-cooperative game theory deals with situations where a decision maker treats the others as competitors. The Nash equilibrium is the most widely used non-cooperative game-theoretic solution (von Neumann and Morgenstern 1944, Nash 1950a). In contrast, if the decision makers are willing to cooperate with each other and to compromise, then the game is cooperative. The cooperative game theory deals with situations in which a group of decision makers work together as collaborators in order to achieve a joint business objective (e.g. to increase total revenue, maximise total profit, increase total market shares, decrease total costs or minimise total costs) (Song and Panayides 2002). In the game theory literature, there are many methods to solve cooperative games. The von Neumann stable set, the core, the kernel, the Shapley value, the nucleolus and the Nash bargaining solution are the most widely used cooperative game-theoretic methods (Nash 1950b, Shapely 1953).

Most of the game theory literature deals with cooperative games in characteristic function form where the characteristic function of a game is a mapping that assigns a precise number, called the worth of the coalition or payoff of the coalition, to each coalition of the players' set. However, the payoff to the coalition in real-world problems is sometimes imprecise or vague. Imprecise payoff may be the result of unquantifiable, incomplete or non-obtainable information. The fuzzy sets theory is ideally suited to handle the ambiguity and impreciseness encountered in game theory (Mares 2000, Wu 2010). When a new product is being developed, it is not normally possible to elicit explicit data because of the implicit nature of early-stage product conceptualisation (Yan *et al.* 2006). Since Zadeh (1965) introduced fuzzy set theory, and Bellman and Zadeh (1970) described the decision-making method in fuzzy environments, an increasing number of manufacturing studies have dealt with fuzzy-logic-based decision-making models for new product development (Büyüközkan and Feyzioğlu 2004, Mikhailov and Tsvetinov 2004, Feyzioğlu and Büyüközkan 2008, Zhang and Chu 2009, Chiang and Che 2010) and cooperative games where the knowledge about the worth of coalitions is described by fuzzy intervals (Nishizaki and Sakawa 2000, Mares 2001, Tsurumi *et al.* 2001, Espin *et al.* 2007, Al-Ahmari 2008, Jing and Lu 2010, Mallozzi *et al.* 2011). According to Zadeh (1975), it is very difficult for conventional quantification to reasonably express complex situations and it is necessary to use linguistic variables whose values are words or sentences in a natural or artificial language.

New product development is an inter- or intra-firm activity that transforms market opportunities and a set of assumptions about product technology into a product available for sale (Davila 2000, Haque *et al.* 2000, Krishnan and Ulrich 2001). Schmidt *et al.* (2001) compared the new product development decision-making effectiveness of individuals, face-to-face teams and virtual teams. A virtual team was a geographically and temporally dispersed work group that communicated asynchronously via the Internet. They found that teams made more effective decisions than individuals, and virtual teams made the most effective decisions. Manufacturing alliances are inter-firm co-operative agreements to combine complementary resources between manufacturing firms in an effort to create a more competitive product than either firm could develop independently.

Among the existing technologies to support collaborative product development, the focus has been in sharing product data and providing collaborative tools to bring the multidisciplinary teams together. Huang *et al.* (2000) proposed a remote web-based decision support system to facilitate the teamwork in a collaborative product development environment where the team members are geographically distributed. Rodriguez and Al-Ashaab (2005) introduced a knowledge-driven decision support system to facilitate knowledge sharing in collaborative product development. Hung *et al.* (2007) proposed a decision support system for assessing design alternatives for production of modular products in a collaborative product development environment based on the tradeoffs between quality, time and cost. Tseng *et al.* (2007) studied collaborative product development from technological standpoint and proposed a decision support system that encompassed a marketing information system, a human resources management system, a supply-chain management system, a communication media, an integrated product design studio, a user interface and databases. Li and Qin (2006) summarised the collaborative product development technologies from three aspects: visualisation-based collaborative systems, co-design collaborative systems and concurrent engineering-based collaborative systems. Hu *et al.* (2010) discussed internet-based intelligent system architecture for collaborative product development built upon service-oriented architecture for handling distributed heterogeneous resource sharing. They proposed a decision support technology to provide efficient and effective knowledge-sharing functionality on demand. Büyüközkan and Arsenyan (2012) present a thorough and comprehensive review of the collaborative product development literature.

The research on optimal coalition formation among manufacturing parties is very limited. Li *et al.*

(2005) proposed a partner formation model based on a pre-defined attributes set, called attributes of potential partner. Apart from the basic information such as the name, location, contacts, etc., they considered attributes of a potential partner including the Standard International Trade Classification, the relevant certification situations such as the International Organization for Standardization certifications and the quality assurance measures such as sampling and quality control methods. Yoshimura *et al.* (2005) argued that the optimal collaboration partners should be selected from a group of candidates, so that production of new products can be achieved at a minimum cost, both financial and in terms of effort and expended resources. Although they acknowledged the importance of financial considerations, their proposed decision support model solely considered technological factors when selecting an optimum collaborative product development partner. Hacklin *et al.* (2006) showed that optimal coalition assessment approaches in the literature traditionally have aimed at supporting the decision through optimising quantitative measures such as minimised net costs, net rejections and net late deliveries (Kumar *et al.*, 2004). They suggested that the coalition formation decisions must also consider rather soft and qualitative factors such as innovation strength and creativity.

This research is based on the premise that (i) a business process in collaborative product development consists of several decentralised manufacturing partners and (ii) operational decisions of these different partners impact each other's profit. To effectively model and analyse decision-making in such multi-firm situation where the outcome depends on the choice made by every manufacturing partner, game theory is a natural choice. We use cooperative game theory and consider the issue of coalition formation among manufacturing partners in collaborative product development (Nagarajan and Sosic 2008). We also recognise that a central feature of any new product alliances is that they are often marked by two distinct phases of potential contribution: product development and market development. We emphasise the alliance for the product development phase and consider the case in which firms continue to jointly develop a product but compete individually in the market (Amaldoss and Rapoport 2005). The modelling framework in this study differs from the conventional inter-firm collaborative product development studies focusing on technology assessment (Li and Qin 2006, Tseng *et al.* 2007), design alternative selection (Shen *et al.* 2008, Zhang and Chu 2009), knowledge sharing and knowledge integration considerations (Hung *et al.* 2008, Chen 2010) or tactical decisions (prices and quantities) (Hung *et al.* 2007, Yeh *et al.* 2009). This study is, in sum, concerned with game-theoretic interactions within new product development alliances whose purpose is to substantially create value through collaborative partner formation strategies. In particular, we develop a set of detailed metrics and a comprehensive framework that unravels the optimal new product development for the collaborating manufacturing partners.

Several studies on negotiation support systems have focused on the quantitative modelling aspects of the negotiation process and showed the usefulness and applicability of the multiple criteria decision-theoretic models in the negotiation process (Munier 1993, Espinasse *et al.* 1997, Bui *et al.* 2001, Pekec 2001, Baek and Kim 2007, Kebriaei and Johari Majd 2009). A thorough understanding of the product structure and the tasks to be developed is important in the collaborative product development between manufacturing parties as the products' lifecycles become shorter (Fagerström and Jackson 2002). The traditional product lifecycle management solutions have focused primarily on product design and data management (Trappey and Hsiao 2008). Several systems have been developed to support the collaboration in the early stages of the product lifecycle, like the CyberCO (Huang and Mak 2002), WebBlow (Wang *et al.* 2003), P_PROCE (Qian and Shenseng 2002) and KdCPD (Rodriguez and Al-Ashaab 2005). Ming *et al.* (2008) have discussed the need for a new collaborative product development protocol that can promote negotiation and optimal selection of manufacturing partners to speed product development, manage programs effectively and enable strategic sourcing in the early stages of the collaborative product development lifecycle. They argued that this collaboration protocol should include different layers of alignment, such as goal, process, method, message and information.

We propose a fuzzy e-negotiation support system based on cooperative multi-criteria game theory. The proposed system enables the parties involved in the negotiation process to determine the optimal coalition form for new product development and choose a common strategy to improve the payoffs of the members of the coalition group. The Internet is used to facilitate the negotiation process and to minimise the response time in the group decision-making process. The fuzzy sets are used to overcome issues related to the imprecise or vague judgments and incomplete information in the negotiation process. A case study in telecommunication industry is used to exhibit the applicability of the proposed framework. The product lifecycle of the mobile phone in telecommunication industry is shortened and the manufacturing cost is reduced due to stiff competition.

Most mobile phone manufacturers and integrators have chosen a collaborative product development strategy based on the considerations of cost and delivery time (Chiang and Trappey 2007).

The proposed e-negotiation system offers a potential solution to the organisational problems over the Internet by using asynchronous meetings, which involves working together without being in the same place or at the same time. The technology is used to overcome space and time constraints that burden face-to-face meetings in conventional negotiation. Asynchronous meetings, powered by the Internet increase the range and depth of information access and improve group task performance effectiveness by overcoming process losses (Maruca 2000, Cil *et al.* 2005, Galin *et al.* 2007).

As depicted in Figure 1, the proposed e-negotiation support system comprises three processes: initialisation, e-negotiation and joint agreement. The e-negotiation process is embedded in the e-negotiation system bridging the initialisation and joint agreement phases. The system is initialised and the negotiators exchanging their payoff values. The e-negotiation process then determines the optimal coalition form. Next, the negotiators review the outcome and they either reach an agreement or the e-negotiation phase is repeated until all the negotiators involved reach a joint agreement. The Internet provides the basis for the interaction between the parties involved in the e-negotiation system. The system utilises a coalitional game to model situations in which negotiators can beneficially form decision-making groups, rather than acting individually. Additionally, an outcome of a coalitional game could consist of a partition of the set of negotiators into groups, together with an action for each group in the partition.

This article is organised into five sections. The next section presents the mathematical notations and definitions used in our model. In section 3, we illustrate the details of the proposed framework. In section 4, we present a case study to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and algorithms in the mobile telecommunications industry. In section 5, we conclude with our conclusions and future research directions.

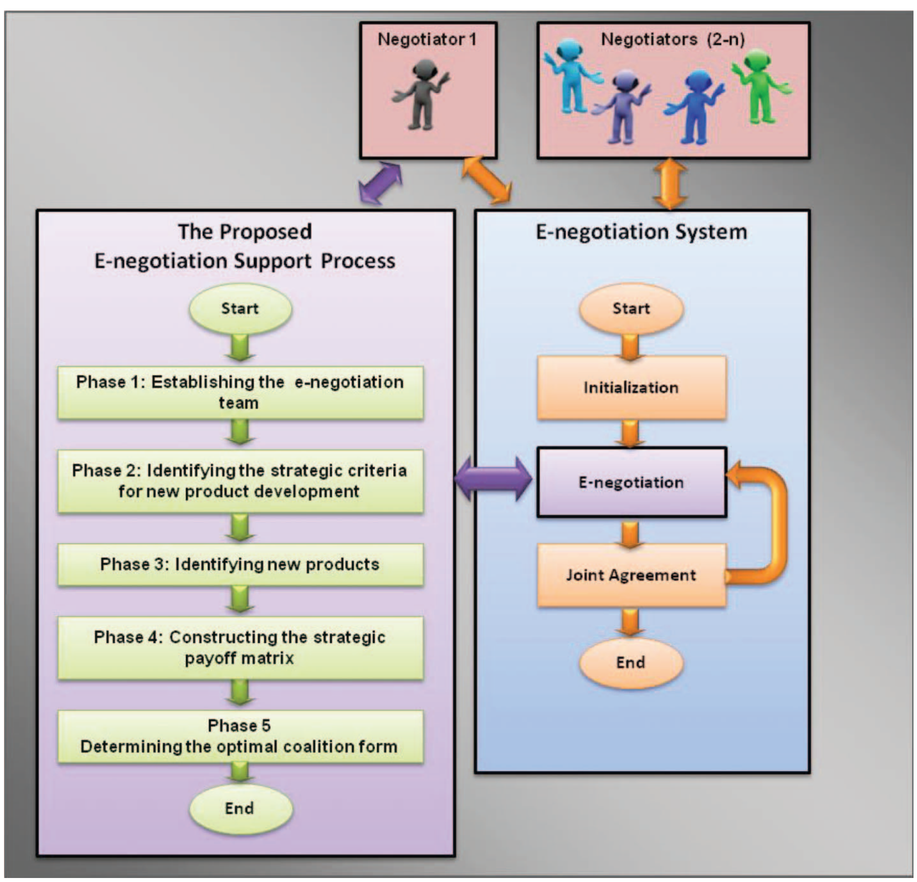

Figure 1. The proposed e-negotiation support system.

2. The mathematical notations

Let us introduce the following mathematical notations and definitions used throughout this article:

m	The number of new products
n	The number of e-negotiation team members
$vot(A)$	The voting power of the enterprise in the e-negotiation team member $T(e-negotiation)$
$vot(y_j)$	The voting power of the e-negotiation team member $T(e-negotiation)$
N	The set of the e-negotiation team
S	A coalition that defines a subset of the e-negotiation team as one negotiator
$\overline{S}$	A complementary coalition of $S(\overline{S}=N-S)$
$v_h(A)$	The value of the company's characteristic function of the hth criterion
$v_h(y_j)$	The value of the jth negotiator's characteristic function of the hth criterion
$v'_h(A)$	The normalised value of the company's characteristic function of the hth criterion
$v'_h(y_j)$	The normalised value of the jth negotiator's characteristic function of the hth criterion
$I(A)$	The value of the company's imputation evaluated
$I(y_j)$	The value of the jth negotiator's imputation
$\tilde{u}_h(A(i))$	The fuzzy weighted collective value of the payoff of the hth criterion evaluated by the enterprise for the ith new product
$\tilde{u}_h(y_j(i))$	The fuzzy weighted collective value of the payoff of the hth criterion evaluated by the jth e-negotiation team member for the ith new product
$\tilde{u}_h^k(A(i))$	The individual fuzzy value of the payoff of the hth criterion evaluated by the enterprise for the ith new product
$\tilde{u}_h^k(y_j(i))$	The individual fuzzy value of the payoff of the hth criterion evaluated by the jth e-negotiation team member for the ith new product

3. The proposed framework

The modular model depicted in Figure 2 is proposed to determine the optimal coalition form:

This proposed framework in embedded in the e-negotiation system described earlier. Figure 3 shows the interface between the local process and the web-based process in the proposed e-negotiation system. The local process is initiated by the negotiator using the local interface and establishing an e-negotiation team for the new product development. Next, the negotiators use the web-based interface to identify the strategic criteria for the new product development, identify new products and construct the strategic payoff matrix. The optimal coalition form is then determined using the local process. Finally, the coalition form obtained in the local process is used to support the negotiators in reaching a joint agreement.

3.1. *Phase 1: establishing the e-negotiation team*

In this phase, we establish the e-negotiation team as follows:

$$T(e-negotiation) = (A, y_1, \dots, y_n) \tag{1}$$

Next, we determine a voting power weight to each member of the e-negotiation team as follows:

$$VOT = (vot(A), vot(y_1), \dots, vot(y_n)) \tag{2}$$

3.2. *Phase 2: identifying the strategic criteria for new product development*

In this phase, the e-negotiation team determines a list of the strategic criteria relevant to the new product development. Let us consider $c_1, c_2, \dots, c_p$ as the strategic criteria.

3.3. *Phase 3: identifying new products*

In this phase, the e-negotiation team determines a list of new products. Let us assume that they have identified m new products as follows:

$$N(P) = [n(p_1), n(p_2), \dots, n(p_m)] \tag{3}$$

3.4. *Phase 4: constructing the strategic payoff matrix*

In this phase, the cooperative game theory approach is used to construct a strategic payoffs matrix for each strategic e-negotiation. This phase is divided into the following two steps.

3.4.1. *Step 4-1: calculating the individual fuzzy payoff matrix*

In this step, the individual fuzzy expected payoffs of each new product are evaluated by the e-negotiation team member $T(e-negotiation)$ using the matrix shown in Table 1.

The following trapezoidal fuzzy numbers are used to find the individual fuzzy present values of the expected payoffs for each e-negotiation evaluated by the e-negotiation team member $T(e-negotiation)$:

$$\tilde{u}_h^k(A(i)) = \Big(\big(u_h^k(A(i))\big)^c,\ \big(u_h^k(A(i))\big)^d,\ \big(u_h^k(A(i))\big)^\alpha,\ \big(u_h^k(A(i))\big)^\beta \Big) \tag{4}$$

$$\tilde{u}_h^k(y_j(i)) = \Big(\big(u_h^k(y_j(i))\big)^c,\ \big(u_h^k(y_j(i))\big)^d,\ \big(u_h^k(y_j(i))\big)^\alpha,\ \big(u_h^k(y_j(i))\big)^\beta \Big) \tag{5}$$

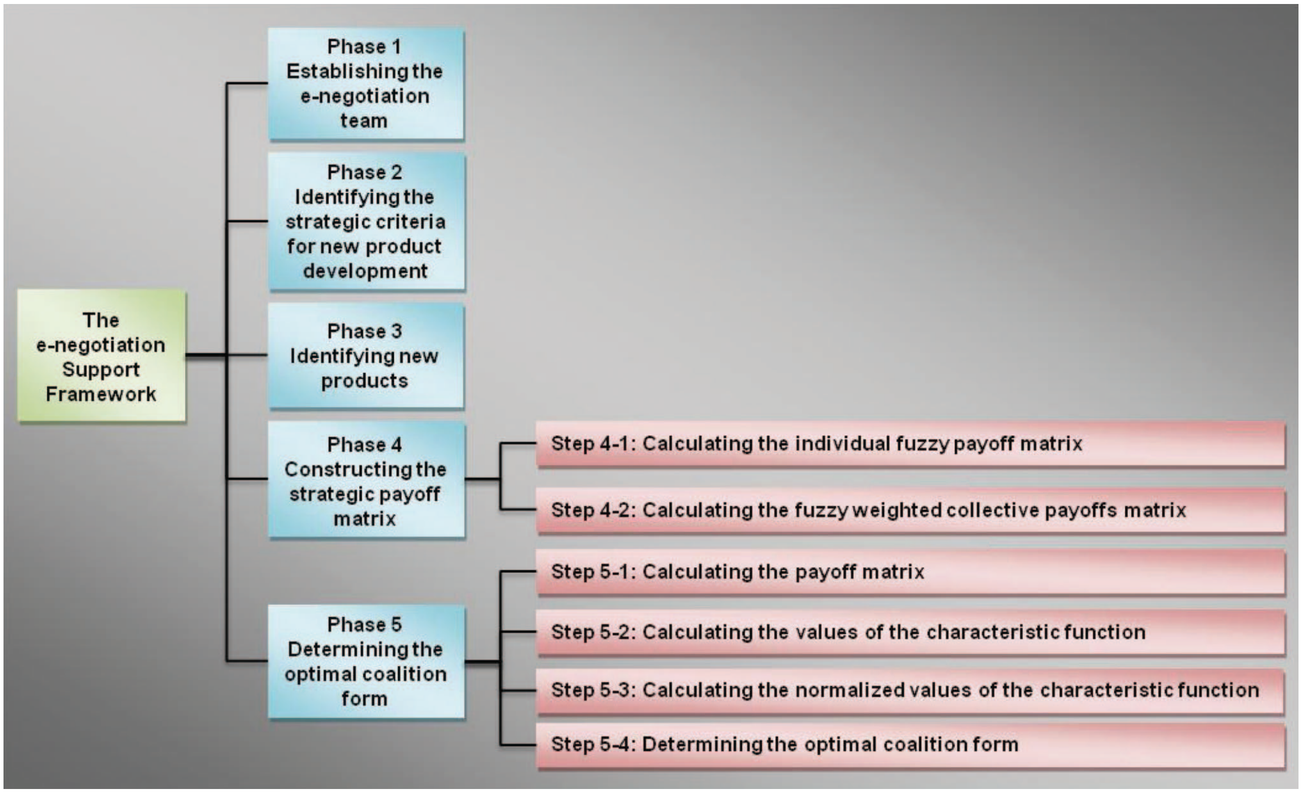

Figure 2. The proposed e-negotiation support framework.

3.4.2. Step 4-2: calculating the fuzzy weighted collective payoffs matrix

With regard to step 4-1, the individual fuzzy present value of the expected payoffs for each e-negotiation is aggregated using the voting powers to form a fuzzy weighted collective expected payoffs matrix as shown in Table 2.

$$\tilde{u}_h(A(i)) = \Big((u_h(A(i)))^c,\ (u_h(A(i)))^d,\ (u_h(A(i)))^\alpha,\ (u_h(A(i)))^\beta \Big) \quad (6)$$

$$\tilde{u}_h(y_j(i)) = \Big((u_h(y_j(i)))^c,\ (u_h(y_j(i)))^d,\ (u_h(y_j(i)))^\alpha,\ (u_h(y_j(i)))^\beta \Big) \quad (7)$$

$$[\tilde{u}_h(A(i))] = \frac{\sum_{k=1}^{n} (vot(k))\left([\tilde{u}_h^k(A(i))]\right)}{\sum_{k=1}^{n} vot(k)}; \quad h = 1,2,\ldots,p;\ i = 1,2,\ldots,m. \quad (8)$$

$$[\tilde{u}_h(y_j(i))] = \frac{\sum_{k=1}^{n} (vot(k))\left([\tilde{u}_h^k(y_j(i))]\right)}{\sum_{k=1}^{n} vot(k)}; \quad h = 1,2,\ldots,p;\ i = 1,2,\ldots,m \quad (9)$$

3.5. *Phase 5: Determining the optimal coalition form*

This phase is divided into the following four steps:

3.5.1. Step 5-1: calculating the payoff matrix

In this step, all coalitions are identified. Then, the payoff matrices are depicted in coalitional form as shown in Tables 3–6.

3.5.2. Step 5-2: calculating the values of the characteristic function

In this step, the values of the characteristic functions are calculated for all coalitions using the following models:

$Max\ v_h(A)$

Subject to (Strategic Game Model F_1):

$$\sum_r p_r.\, \tilde{u}_h(s = \{A(i)\}, \bar{s} = \{y_1(r), y_2(r), \ldots, y_n(r)\}) \geq v_h(A);\ i = 1,2,\ldots,m\ ;\ h = 1,2,\ldots,p$$

$$\sum_r p_r = 1$$

$p_r \geq 0,\ v_h(A)$: Free variable

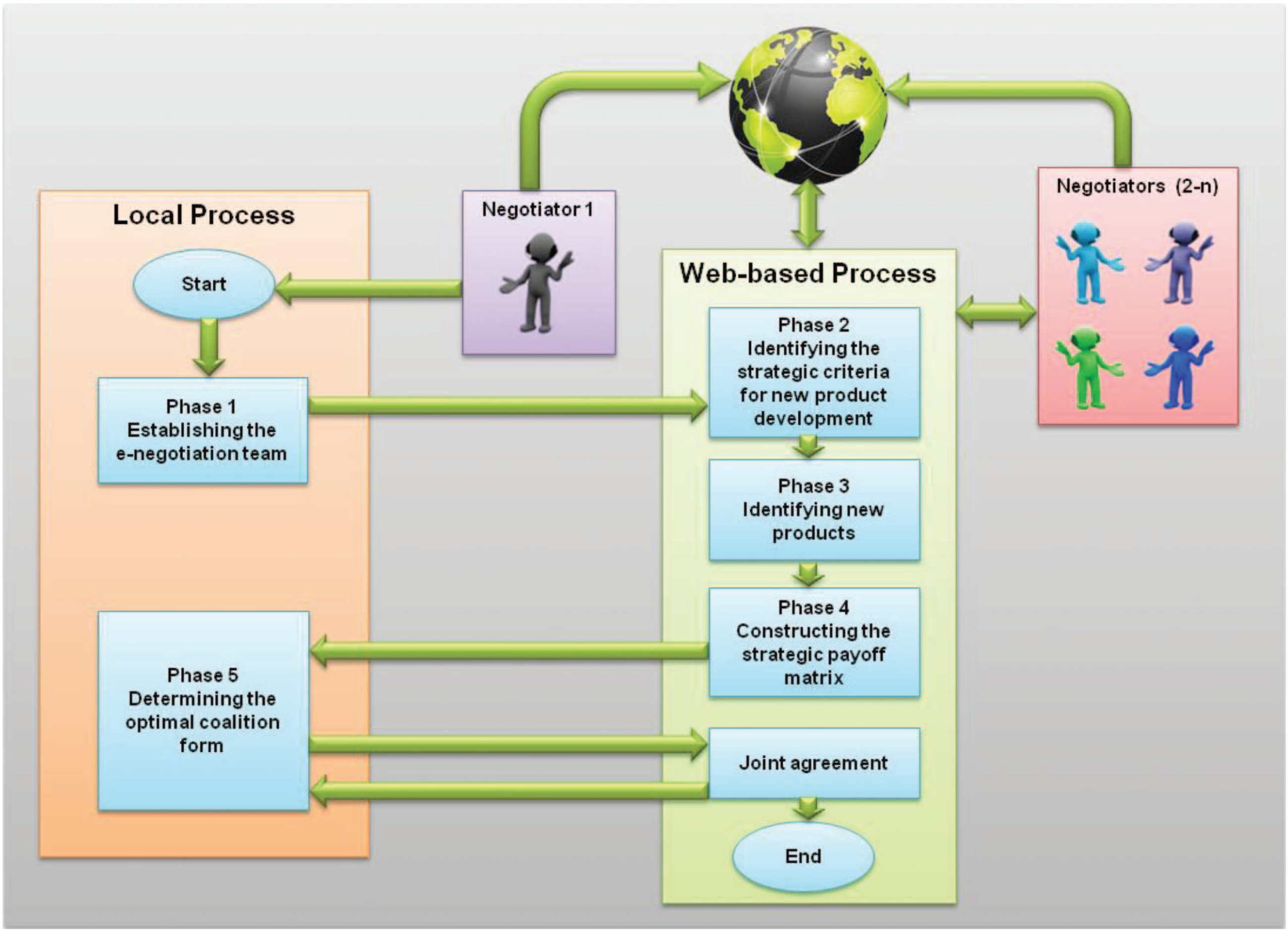

Figure 3. The interface between the local processes and the web-based processes.

Table 1. The fuzzy individual payoffs matrix for the $i$ith member of the e-negotiation team.

	Criteria								
	c_1				…	c_p			
Strategy combinations	A	y_1	…	y_n	…	A	y_1	…	y_n
$(A(1), y_1(1), \ldots, y_n(1))$	$\tilde{u}_1^k(A(1))$	$\tilde{u}_1^k(y_1(1))$	…	$\tilde{u}_1^k(y_n(1))$	…	$\tilde{u}_p^k(A(1))$	$\tilde{u}_p^k(y_1(1))$	…	$\tilde{u}_p^k(y_n(1))$
⋮	⋮	⋮	⋮	⋮	…	⋮	⋮	⋮	⋮
$(A(m), y_1(m), \ldots, y_n(m))$	$\tilde{u}_1^k(A(m))$	$\tilde{u}_1^k(y_1(m))$	…	$\tilde{u}_1^k(y_n(m))$	…	$\tilde{u}_p^k(A(m))$	$\tilde{u}_p^k(y_1(m))$	…	$\tilde{u}_p^k(y_n(m))$

Table 2. The fuzzy weighted collective payoffs matrix of the e-negotiation team.

	Criteria								
	c_1				…	c_p			
Strategy combinations	A	y_1	…	y_n	…	A	y_1	…	y_n
$(A(1), y_1(1), \ldots, y_n(1))$	$\tilde{u}_1(A(1))$	$\tilde{u}_1(y_1(1))$	…	$\tilde{u}_1(y_n(1))$	…	$\tilde{u}_p(A(1))$	$\tilde{u}_p(y_1(1))$	…	$\tilde{u}_p(y_n(1))$
⋮	⋮	⋮	⋮	⋮	…	⋮	⋮	⋮	⋮
$(A(m), y_1(m), \ldots, y_n(m))$	$\tilde{u}_1(A(m))$	$\tilde{u}_1(y_1(m))$	…	$\tilde{u}_1(y_n(m))$	…	$\tilde{u}_p(A(m))$	$\tilde{u}_p(y_1(m))$	…	$\tilde{u}_p(y_n(m))$

Table 3. The payoffs matrix of the singleton coalition strategies.

	Criteria						
	c_1			$\cdots$	c_p		
Coalition	$(y_1(1)y_2(1)\ldots y_n(1))$	$\cdots$	$(y_1(m)y_2(m)\ldots y_n(m))$	$\cdots$	$(y_1(1)y_2(1)\ldots y_n(1))$	$\cdots$	$(y_1(m)y_2(m)\ldots y_n(m))$
$(A(1))$	$\tilde{u}_1\begin{pmatrix} s=\{A(1)\}, \\ \bar{s}=\{y_1(1),y_2(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_1\begin{pmatrix} s=\{A(1)\}, \\ \bar{s}=\{y_1(1),y_2(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_p\begin{pmatrix} s=\{A(1)\}, \\ \bar{s}=\{y_1(1),y_2(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_p\begin{pmatrix} s=\{A(1)\}, \\ \bar{s}=\{y_1(m),y_2(m),\ldots,y_n(m)\}\end{pmatrix}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$(A(m))$	$\tilde{u}_1\begin{pmatrix} s=\{A(m)\}, \\ \bar{s}=\{y_1(1),y_2(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_1\begin{pmatrix} s=\{A(m)\}, \\ \bar{s}=\{y_1(m),y_2(m),\ldots,y_n(m)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_p\begin{pmatrix} s=\{A(m)\}, \\ \bar{s}=\{y_1(1),y_2(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_p\begin{pmatrix} s=\{A(m)\}, \\ \bar{s}=\{y_1(m),y_2(m),\ldots,y_n(m)\}\end{pmatrix}$

Table 4. The payoffs matrix for the coalition strategies and the jth negotiator.

	Criteria						
	c_1			$\cdots$	c_p		
Coalition	$A(1)y_1(1)\ldots y_{j-1}(1)y_{j+1}(1)\ldots y_n(1)$	$\cdots$	$A(m)y_1(m)\ldots y_{j-1}(m)y_{j+1}(m)\ldots y_n(m)$	$\cdots$	$A(1)y_1(1)\ldots y_{j-1}(1)y_{j+1}(1)\ldots y_n(1)$	$\cdots$	$A(m)y_1(m)\ldots y_{j-1}(m)y_{j+1}(m)\ldots y_n(m)$
$(y_j(1))$	$\tilde{u}_1\begin{pmatrix} s=\{y_j(1)\}, \\ \bar{s}=\{A(1),y_1(1),\ldots y_{j-1}(1), \\ y_{j+1}(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_1\begin{pmatrix} s=\{y_j(1)\}, \\ \bar{s}=\{A(m),y_1(m),\ldots y_{j-1}(m), \\ y_{j+1}(m),\ldots,y_n(m)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_p\begin{pmatrix} s=\{y_j(1)\}, \\ \bar{s}=\{A(1),y_1(1),\ldots y_{j-1}(1), \\ y_{j+1}(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_p\begin{pmatrix} s=\{y_j(1)\}, \\ \bar{s}=\{A(m),y_1(m),\ldots y_{j-1}(m), \\ y_{j+1}(m),\ldots,y_n(m)\}\end{pmatrix}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$(A(m))$	$\tilde{u}_1\begin{pmatrix} s=\{y_j(m)\}, \\ \bar{s}=\{A(1),y_1(1),\ldots y_{j-1}(1), \\ y_{j+1}(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_1\begin{pmatrix} s=\{y_j(m)\}, \\ \bar{s}=\{A(m),y_1(m),\ldots y_{j-1}(m), \\ y_{j+1}(m),\ldots,y_n(m)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_p\begin{pmatrix} s=\{y_j(m)\}, \\ \bar{s}=\{A(1),y_1(1),\ldots y_{j-1}(1), \\ y_{j+1}(1),\ldots,y_n(1)\}\end{pmatrix}$	$\cdots$	$\tilde{u}_p\begin{pmatrix} s=\{y_j(m)\}, \\ \bar{s}=\{A(m),y_1(m),\ldots y_{j-1}(m), \\ y_{j+1}(m),\ldots,y_n(m)\}\end{pmatrix}$

Table 5. The payoffs matrix for coalition between (A, y_j).

Coalition	Criteria c_1: $A(1)y_1(1)\ldots y_{j-1}(1)y_{j+1}(1)\ldots y_n(1)$	$\cdots$	$A(m)y_1(m)\ldots y_{j-1}(m)y_{j+1}(m)\ldots y_n(m)$	$\cdots$	c_p: $A(1)y_1(1)\ldots y_{j-1}(1)y_{j+1}(1)\ldots y_n(1)$	$\cdots$	$A(m)y_1(m)\ldots y_{j-1}(m)y_{j+1}(m)\ldots y_n(m)$
$(A(1), y_j(1))$	$\tilde{u}_1\left(\begin{array}{l} s=\{A(1),y_j(1)\},\\ \bar{s}=\{y_1(1),\ldots y_{j-1}(1),\\ y_{j+1}(1),\ldots,y_n(1)\}\end{array}\right)$	$\vdots$	$\tilde{u}_1\left(\begin{array}{l} s=\{A(m),y_j(1)\},\\ \bar{s}=\{y_1(m),\ldots y_{j-1}(m),\\ y_{j+1}(m),\ldots,y_n(m)\}\end{array}\right)$	$\vdots$	$\tilde{u}_p\left(\begin{array}{l} s=\{A(1),y_j(1)\},\\ \bar{s}=\{y_1(1),\ldots y_{j-1}(1),\\ y_{j+1}(1),\ldots,y_n(1)\}\end{array}\right)$	$\vdots$	$\tilde{u}_p\left(\begin{array}{l} s=\{A(m),y_j(1)\},\\ \bar{s}=\{y_1(m),\ldots y_{j-1}(m),\\ y_{j+1}(m),\ldots,y_n(m)\}\end{array}\right)$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
$(A(1), y_j(m))$	$\tilde{u}_1\left(\begin{array}{l} s=\{A(1),y_j(m)\},\\ \bar{s}=\{y_1(1),\ldots y_{j-1}(1),\\ y_{j+1}(1),\ldots,y_n(1)\}\end{array}\right)$	$\vdots$	$\tilde{u}_1\left(\begin{array}{l} s=\{A(m),y_j(m)\},\\ \bar{s}=\{y_1(m),\ldots y_{j-1}(m),\\ y_{j+1}(m),\ldots,y_n(m)\}\end{array}\right)$	$\vdots$	$\tilde{u}_p\left(\begin{array}{l} s=\{A(1),y_j(m)\},\\ \bar{s}=\{y_1(1),\ldots y_{j-1}(1),\\ y_{j+1}(1),\ldots,y_n(1)\}\end{array}\right)$	$\vdots$	$\tilde{u}_p\left(\begin{array}{l} s=\{A(m),y_j(m)\},\\ \bar{s}=\{y_1(m),\ldots y_{j-1}(m),\\ y_{j+1}(m),\ldots,y_n(m)\}\end{array}\right)$

and

$Max\ v_h(y_j)$
Subject to (Strategic Game Model F_2) :

$$\sum_r p_r.\,\tilde{u}_h\big(s=\{y_j(i)\},\bar{s}=\{A(r),y_1(r),\ldots,y_{j-1}(r),\ y_{j+1}(r),\ldots,y_n(r)\}\big)\geq v_h(y_j);\ i=1,2,\ldots,m;\ h=1,2,\ldots,p$$

$$\sum_r p_r=1$$

$p_r\geq 0,\ v_h(y_j)$: Free variable.

and

$Max\ v_h(A, y_j)$
Subject to (Strategic Game Model F_3):

$$\sum_r p_r.\,\tilde{u}_h\big(s=\{A(i),y_j(i')\},\bar{s}=\{y_1(r),\ldots,y_{j-1}(r),\ y_{j+1}(r),\ldots,y_n(r)\}\big)\geq v_h(A,y_j);\ \ i,i'=1,2,\ldots,m;\ h=1,2,\ldots,p$$

$$\sum_r p_r=1$$

$p_r\geq 0,\ v_h(A,y_j)$: Free variable

and

$Max\ v_h(A, y_1,\ldots,y_n)$
Subject to (Strategic Game Model F_q)

$$\sum_r p_r.\,\tilde{u}_h\big(s=\{A(r),y_1(r),\ldots,y_n(r)\}\big)\geq v_h(A,y_1,\ldots,y_n)\,;\ i=1,2,\ldots,m;\ \ h=1,2,\ldots,p$$

$$\sum_r p_r=1$$

$p_r\geq 0,\ v_h(A,y_1,\ldots,y_n)$: Free variable

The optimal solutions for these models form the values of the characteristic functions as shown in Table 7.

3.5.3. Step 5-3: calculating the normalised values of the characteristic function

In this step, the normalised values of the characteristic function are calculated for all coalitions as shown in Table 8.

$$v'_h(a)=\frac{v_h(a)-\sum_{i\in a}v_h(i)}{v_h(N)-\sum_{i\in N}v_h(i)}\tag{10}$$

Table 6. The payoffs matrix of the grand coalition.

Coalition	Criteria		
	c_1	...	c_p
$A(1)y_1(1)\dots y_n(1)$	$\tilde{u}_1(s=\{A(1),y_1(1),\dots,y_n(1)\})$	...	$\tilde{u}_p(s=\{A(1),y_1(1),\dots,y_n(1)\})$
$\vdots$	$\vdots$	...	$\vdots$
$A(m)y_1(m)\dots y_n(m)$	$\tilde{u}_1(s=\{A(m),y_1(m),\dots,y_n(m)\})$	...	$\tilde{u}_p(s=\{A(m),y_1(m),\dots,y_n(m)\})$

Table 7. The values of the characteristic functions.

Criteria								
c_1				...	c_p			
Singleton coalitions	2-coalitions	...	Grand coalition	...	Singleton coalitions	2-coalitions	...	Grand coalition
$v_1(A)$	$v_1(A,y_1)$	...	$v_1(A,y_1,\dots,y_n)$	...	$v_p(A)$	$v_p(A,y_1)$	...	$v_p(A,y_1,\dots,y_n)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	...	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$v_1(y_n)$	$v_1(y_{n-1},y_n)$	...	–	...	$v_p(y_n)$	$v_p(y_{n-1},y_n)$	...	–

Table 8. The normalised values of the characteristic functions.

Criteria								
c_1				...	c_p			
Singleton coalitions	2-coalitions	...	Grand coalition	...	Singleton coalitions	2-coalitions	...	Grand coalition
$v'_1(A)$	$v'_1(A,y_1)$	...	$v'_1(A,y_1,\dots,y_n)$	...	$v'_p(A)$	$v'_p(A,y_1)$	...	$v'_p(A,y_1,\dots,y_n)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	...	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$v'_1(y_n)$	$v'_1(y_{n-1},y_n)$	...	–	...	$v'_p(y_n)$	$v'_p(y_{n-1},y_n)$	...	–

3.5.4. Step 5-4: determining the optimal coalition form

In this step, the optimal coalition form is determined using the model G given below:

$$Max\ \phi$$

$$\text{Subject to (ModelG)}:$$

$$\varphi \le I(A) + I(y_1) - Min\left\{v'_1(A,y_1),\dots,v'_p(A,y_1)\right\}$$

$$\varphi \le I(A) + I(y_2) - Min\left\{v'_1(A,y_2),\dots,v'_p(A,y_2)\right\}$$

$$\vdots$$

$$I(A) + I(y_1) + \cdots + I(y_n) = 1$$

$$I(A), I(y_1),\dots,I(y_n) \ge 0$$

$$\phi:\ \text{Free variable}$$

The optimal solution for model (G), $I^*(A)$, $I^*(y_1),\dots,I^*(y_n)$, represents the optimal values of the imputations and points of the core. Finally, ranked values $I^*(y_1),\dots,I^*(y_n)$ represent the optimal coalition form for the new product development.

In the next section, we present a case study to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and algorithms in the mobile telecommunications industry.

4. Case study

The mobile telecommunications business, driven by innovative technologies and globalisation, is undergoing a critical revolution. Recent advances in technology and globalisation are changing business functions and practices. Cellular technology generations, from Global System for Mobile Communication (GSM) to 3G Universal Mobile Telecommunication Systems (UMTS) and 4G Worldwide Interoperability for Microwave Access (WiMax), are continuously enhancing the qualities and capabilities of mobile services and providing new opportunities for telecommunication industry. The Appllet company[1] is an American multinational corporation that designs and markets consumer electronics. The company is planning to launch a new line of mobile phones called iTel.[2] While Appllet had extensive experience in the design and development of mobile phones, they lacked semiconductor experience and needed to form a coalition with a semiconductor company to produce the new iTel mobile phones. The management at Appllet agreed to use the proposed e-negotiation support system in this study to determine an optimal coalition form for their new product development.

4.1. Phase 1: establishing the e-negotiation team

In this phase, we established an e-negotiation team as follows:

$$T(e - negotiation) = (A, y_1, y_2)$$

Next, we determined a voting power weight to each member of the e-negotiation team as follows:

$$V = (v(A), v(y_1), v(y_2))$$

4.2. Phase 2: identifying the strategic criteria for new product development

In this phase, the e-negotiation team determined the following five strategic criteria (Porter 1980, 7–33) relevant to the new product development:

- c_1: *Threat of entry* – New players to a market most likely bring in new capacity and additional resources. As a result, the prices might drop and the costs for the existing players might increase.
- c_2: *Intensity of rivalry among existing players* – The existing players most likely compete using tactics like price competition, advertising and enhanced customer service.
- c_3: *Pressure from substitute products* – The mobile telecommunications industry is also competing in a sense with substitute products. Substitute products most likely limit the prices by setting a ceiling.
- c_4: *Bargaining power of buyers* – The buyers' goal is to negotiate the prices down and quality up. This most likely results in a competition among the players in the market.
- c_5: *Bargaining power of suppliers* – The suppliers usually try to squeeze higher price for products with lesser quality.

Table 9. The collective fuzzy weighted payoffs matrix of the e-negotiation team for the new product development.

			Strategy combinations							
			$(A(1), y_1(1), y_2(1))$	$(A(2), y_1(1), y_2(1))$	$(A(1), y_1(2), y_2(1))$	$(A(1), y_1(1), y_2(2))$	$(A(2), y_1(2), y_2(1))$	$(A(2), y_1(1), y_2(2))$	$(A(1), y_1(2), y_2(2))$	$(A(2), y_1(2), y_2(2))$
Criteria	c_1	A	(4.5,5.5,0.5,0.5)	(0.5,1.5,0.5,0.5)	(2.5,3.5,0.5,0.5)	(0.5,1.5,0.5,0.5)	(1.5,2.5,0.5,0.5)	(1.5,2.5,0.5,0.5)	(4.5,5.5,0.5,0.5)	(0.5,1.5,0.5,0.5)
		y_1	(0.5,1.5,0.5,0.5)	(0.5,1.5,0.5,0.5)	(0.5,1.5,0.5,0.5)	(0.5,1.5,0.5,0.5)	(2.5,3.5,0.5,0.5)	(2.5,3.5,0.5,0.5)	(3.5,4.5,0.5,0.5)	(0.5,1.5,0.5,0.5)
		y_2	(1.5,2.5,0.5,0.5)	(1.5,2.5,0.5,0.5)	(3.5,4.5,0.5,0.5)	(2.5,3.5,0.5,0.5)	(4.5,5.5,0.5,0.5)	(4.5,5.5,0.5,0.5)	(0.5,1.5,0.5,0.5)	(4.5,5.5,0.5,0.5)
	c_2	A	(3.75,4.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(4.75,5.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
		y_1	(0.75,1.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(3.75,4.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
		y_2	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(3.75,4.25,0.25,0.25)	(3.75,4.25,0.25,0.25)	(0.75,1.25,0.25,0.25)	(4.75,5.25,0.25,0.25)
	c_3	A	(3.8,4.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(2.8,3.2,0.2,0.2)	(3.8,4.2,0.2,0.2)
		y_1	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(2.8,3.2,0.2,0.2)	(3.8,4.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
		y_2	(0.8,1.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(3.8,4.2,0.2,0.2)	(3.8,4.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(3.8,4.2,0.2,0.2)
	c_4	A	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(4.75,5.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
		y_1	(0.75,1.25,0.25,0.25)	(0.75,1.25,0.25,0.25)	(0.75,1.25,0.25,0.25)	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
		y_2	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)	(3.75,4.25,0.25,0.25)	(3.75,4.25,0.25,0.25)	(3.75,4.25,0.25,0.25)	(0.75,1.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
	c_5	A	(4.8,5.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(2.8,3.2,0.2,0.2)	(2.8,3.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
		y_1	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(1.8,2.2,0.2,0.2)	(2.8,3.2,0.2,0.2)	(2.8,3.2,0.2,0.2)	(2.8,3.2,0.2,0.2)
		y_2	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(2.8,3.2,0.2,0.2)	(2.8,3.2,0.2,0.2)	(3.8,4.2,0.2,0.2)	(4.8,5.2,0.2,0.2)	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)

4.3. Phase 3: identifying new products

In phase 3, the e-negotiation team was advised by the management team to consider the following two new iTel products:

$$N(P) = [n(p_1), n(p_2)] = [5G_1, 5G_2]$$

4.4. Phase 4: constructing the strategic payoff matrix

In step 4-1, the e-negotiation team used Equations (4) and (5) to determine an individual fuzzy expected payoffs matrix for each of the two new products evaluated by each e-negotiation team member. In step 4-2, the e-negotiation team used Equations (6) and (9) to determine the individual fuzzy present value of the expected payoffs. Next, the individual fuzzy present value of the expected payoffs was aggregated by the voting powers to form a collective fuzzy weighted expected payoffs matrix as shown in Table 9.

4.5. Phase 5: determining the optimal coalition form

In step 5-1, all coalitions were identified and the payoff matrices were depicted in coalitional form as shown in Tables 10–16.

In step 5-2, the values of the characteristic functions were calculated for all coalitions using the following models:

$$\begin{aligned}
&Max\ v_1(A)\\
&\text{Subject to (Strategic Game Model } F_1):\\
&v_1(A) - (4.5, 5.5, 0.5, 0.5)p_1 - (0.5, 1.5, 0.5, 0.5)p_2 \le 0\\
&v_1(A) - (2.5, 3.5, 0.5, 0.5)p_1 - (1.5, 2.5, 0.5, 0.5)p_2 \le 0\\
&v_1(A) - (0.5, 1.5, 0.5, 0.5)p_1 - (1.5, 2.5, 0.5, 0.5)p_2 \le 0\\
&v_1(A) - (4.5, 5.5, 0.5, 0.5)p_1 - (0.5, 1.5, 0.5, 0.5)p_2 \le 0\\
&p_1 + p_2 = 1\\
&p_1, p_2 \ge 0,\ v_1(A):\ \text{Free variable}
\end{aligned}$$

and

Table 10. The payoffs matrix of the singleton coalition strategies for Appllet.

Criteria	Strategy combinations	The singleton coalition	
		$A(1)$	$A(2)$
c_1	$y_1(1), y_2(1)$	(4.5,5.5,0.5,0.5)	(0.5,1.5,0.5,0.5)
	$y_1(2), y_2(1)$	(2.5,3.5,0.5,0.5)	(1.5,2.5,0.5,0.5)
	$y_1(1), y_2(2)$	(0.5,1.5,0.5,0.5)	(1.5,2.5,0.5,0.5)
	$y_1(2), y_2(2)$	(4.5,5.5,0.5,0.5)	(0.5,1.5,0.5,0.5)
c_2	$y_1(1), y_2(1)$	(3.75,4.25,0.25,0.25)	(1.75,2.25,0.25,0.25)
	$y_1(2), y_2(1)$	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)
	$y_1(1), y_2(2)$	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)
	$y_1(2), y_2(2)$	(4.75,5.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
c_3	$y_1(1), y_2(1)$	(3.8,4.2,0.2,0.2)	(1.8,2.2,0.2,0.2)
	$y_1(2), y_2(1)$	(1.8,2.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
	$y_1(1), y_2(2)$	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
	$y_1(2), y_2(2)$	(2.8,3.2,0.2,0.2)	(3.8,4.2,0.2,0.2)
c_4	$y_1(1), y_2(1)$	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)
	$y_1(2), y_2(1)$	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)
	$y_1(1), y_2(2)$	(1.75,2.25,0.25,0.25)	(4.75,5.25,0.25,0.25)
	$y_1(2), y_2(2)$	(2.75,3.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
c_5	$y_1(1), y_2(1)$	(4.8,5.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
	$y_1(2), y_2(1)$	(0.8,1.2,0.2,0.2)	(1.8,2.2,0.2,0.2)
	$y_1(1), y_2(2)$	(0.8,1.2,0.2,0.2)	(2.8,3.2,0.2,0.2)
	$y_1(2), y_2(2)$	(2.8,3.2,0.2,0.2)	(0.8,1.2,0.2,0.2)

Table 11. The payoffs matrix of the singleton coalition strategies for negotiator y_1.

Criteria	Strategy combinations	The singleton coalition	
		$y_1(1)$	$y_1(2)$
c_1	$A(1), y_2(1)$	(0.5,1.5,0.5,0.5)	(0.5,1.5,0.5,0.5)
	$A(2), y_2(1)$	(0.5,1.5,0.5,0.5)	(2.5,3.5,0.5,0.5)
	$A(1), y_2(2)$	(0.5,1.5,0.5,0.5)	(3.5,4.5,0.5,0.5)
	$A(2), y_2(2)$	(2.5,3.5,0.5,0.5)	(0.5,1.5,0.5,0.5)
c_2	$A(1), y_2(1)$	(3.75,4.25,0.25,0.25)	(1.75,2.25,0.25,0.25)
	$A(2), y_2(1)$	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)
	$A(1), y_2(2)$	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)
	$A(2), y_2(2)$	(2.75,3.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
c_3	$A(1), y_2(1)$	(4.8,5.2,0.2,0.2)	(1.8,2.2,0.2,0.2)
	$A(2), y_2(1)$	(1.8,2.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
	$A(1), y_2(2)$	(0.8,1.2,0.2,0.2)	(2.75,3.25,0.25,0.25)
	$A(2), y_2(2)$	(0.8,1.2,0.2,0.2)	(3.8,4.2,0.2,0.2)
c_4	$A(1), y_2(1)$	(2.75,3.25,0.25,0.25)	(1.75,2.25,0.25,0.25)
	$A(2), y_2(1)$	(2.75,3.25,0.25,0.25)	(2.75,3.25,0.25,0.25)
	$A(1), y_2(2)$	(1.75,2.25,0.25,0.25)	(2.75,3.25,0.25,0.25)
	$A(2), y_2(2)$	(4.75,5.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
c_5	$A(1), y_2(1)$	(4.8,5.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
	$A(2), y_2(1)$	(0.8,1.2,0.2,0.2)	(1.8,2.2,0.2,0.2)
	$A(1), y_2(2)$	(0.8,1.2,0.2,0.2)	(2.8,3.2,0.2,0.2)
	$A(2), y_2(2)$	(2.8,3.2,0.2,0.2)	(0.8,1.2,0.2,0.2)

Table 12. The payoffs matrix of the singleton coalition strategies for negotiator y_2.

Criteria	Strategy combinations	The singleton coalition	
		$y_2(1)$	$y_2(2)$
c_1	$A(1), y_1(1)$	(1.5,2.5,0.5,0.5)	(2.5,3.5,0.5,0.5)
	$A(2), y_1(1)$	(1.5,2.5,0.5,0.5)	(4.5,5.5,0.5,0.5)
	$A(1), y_1(2)$	(3.5,4.5,0.5,0.5)	(0.5,4.5,0.5,0.5)
	$A(2), y_1(2)$	(4.5,5.5,0.5,0.5)	(4.5,5.5,0.5,0.5)
c_2	$A(1), y_1(1)$	(2.75,3.25,0.25,0.25)	(1.75,2.25,0.25,0.25)
	$A(2), y_1(1)$	(2.75,3.25,0.25,0.25)	(3.75,4.25,0.25,0.25)
	$A(1), y_1(2)$	(3.75,4.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
	$A(2), y_1(2)$	(3.75,4.25,0.25,0.25)	(4.75,5.25,0.25,0.25)
c_3	$A(1), y_1(1)$	(0.8,1.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
	$A(2), y_1(1)$	(1.8,2.2,0.2,0.2)	(3.8,4.2,0.2,0.2)
	$A(1), y_1(2)$	(1.8,2.2,0.2,0.2)	(1.8,2.2,0.2,0.2)
	$A(2), y_1(2)$	(3.8,4.2,0.2,0.2)	(3.8,4.2,0.2,0.2)
c_4	$A(1), y_1(1)$	(2.75,3.25,0.25,0.25)	(3.75,4.25,0.25,0.25)
	$A(2), y_1(1)$	(2.75,3.25,0.25,0.25)	(3.75,4.25,0.25,0.25)
	$A(1), y_1(2)$	(1.75,2.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
	$A(2), y_1(2)$	(3.75,4.25,0.25,0.25)	(0.75,1.25,0.25,0.25)
c_5	$A(1), y_1(1)$	(0.8,1.2,0.2,0.2)	(2.8,3.2,0.2,0.2)
	$A(2), y_1(1)$	(0.8,1.2,0.2,0.2)	(4.8,5.2,0.2,0.2)
	$A(1), y_1(2)$	(2.8,3.2,0.2,0.2)	(0.8,1.2,0.2,0.2)
	$A(2), y_1(2)$	(3.8,4.2,0.2,0.2)	(0.8,1.2,0.2,0.2)

Table 13. The payoffs matrix of the coalition strategies between Appllet and negotiator y_1.

Criteria	Strategy combinations	The coalition strategies between A and y_1			
		$A(1), y_1(1)$	$A(2), y_1(1)$	$A(1), y_1(2)$	$A(2), y_1(2)$
c_1	$y_2(1)$	(5,7,1,1)	(1,3,1,1)	(3,5,1,1)	(4,6,1,1)
	$y_2(2)$	(1,3,1,1)	(4,6,1,1)	(8,10,1,1)	(1,3,1,1)
c_2	$y_2(1)$	(4.5,5.5,0.5,0.5)	(3.5,4.5,0.5,0.5)	(3.5,4.5,0.5,0.5)	(6.5,7.5,0.5,0.5)
	$y_2(2)$	(3.5,4.5,0.5,0.5)	(5.5,6.5,0.5,0.5)	(7.5,8.5,0.5,0.5)	(1.5,2.5,0.5,0.5)
c_3	$y_2(1)$	(4.6,5.4,0.4,0.4)	(2.6,3.4,0.4,0.4)	(2.6,3.4,0.4,0.4)	(1.6,2.4,0.4,0.4)
	$y_2(2)$	(1.6,2.4,0.4,0.4)	(3.6,4.4,0.4,0.4)	(6.6,7.4,0.4,0.4)	(4.6,5.4,0.4,0.4)
c_4	$y_2(1)$	(3.5,4.5,0.5,0.5)	(3. 5,4. 5,0.5,0.5)	(2. 5,3.5,0.5,0.5)	(5.5,6.5,0.5,0.5)
	$y_2(2)$	(3.5,4. 5,0.5,0.5)	(7.5,8.5,0.5,0.5)	(5.5,6.5,0.5,0.5)	(1.5,2.5,0.5,0.5)
c_5	$y_2(1)$	(5.6,6.4,0.4,0.4)	(1.6,2.4,0.4,0.4)	(2.6,3.4,0.4,0.4)	(3.6,4.4,0.4,0.4)
	$y_2(2)$	(3.6,4.4,0.4,0.4)	(5.6,6.4,0.4,0.4)	(5.6,6.4,0.4,0.4)	(3.6,4.4,0.4,0.4)

Table 14. The payoffs matrix of the coalition strategies between Appllet and negotiator y_2.

Criteria	Strategy combinations	The coalition strategies between A and y_2			
		$A(1), y_2(1)$	$A(2), y_2(1)$	$A(1), y_2(2)$	$A(2), y_2(2)$
c_1	$y_1(1)$	(6,8,1,1)	(2,4,1,1)	(3,5,1,1)	(6,8,1,1)
	$y_1(2)$	(6,8,1,1)	(6,8,1,1)	(5,7,1,1)	(5,7,1,1)
c_2	$y_1(1)$	(6.5,7.5,0.5,0.5)	(4.5,5. 5,0.5,0.5)	(3.5,4. 5,0.5,0.5)	(6.5,7. 5,0.5,0.5)
	$y_1(2)$	(4.5,5. 5,0.5,0.5)	(6.5,7. 5,0.5,0.5)	(5.5,6. 5,0.5,0.5)	(5.5,6. 5,0.5,0.5)
c_3	$y_1(1)$	(4.6,5.4,0.4,0.4)	(3.6,4.4,0.4,0.4)	(1.6,2.4,0.4,0.4)	(4.6,5.4,0.4,0.4)
	$y_1(2)$	(3.6,4.4,0.4,0.4)	(4.6,5.4,0.4,0.4)	(4.6,5.4,0.4,0.4)	(7.6,8.4,0.4,0.4)
c_4	$y_1(1)$	(3.5,4. 5,0.5,0.5)	(5.5,6.5,0.5,0.5)	(4.5,5. 5,0.5,0.5)	(8.5,9. 5,0.5,0.5)
	$y_1(2)$	(4.5,5. 5,0.5,0.5)	(6.5,7.5,0.5,0.5)	(3.5,4. 5,0.5,0.5)	(1.5,2.5,0.5,0.5)
c_5	$y_1(1)$	(5.6,6.4,0.4,0.4)	(1.6,2.4,0.4,0.4)	(4.6,5.4,0.4,0.4)	(7.6,8.4,0.4,0.4)
	$y_1(2)$	(3.6,4.4,0.4,0.4)	(4.6,5.4,0.4,0.4)	(3.6,4.4,0.4,0.4)	(1.6,2.4,0.4,0.4)

Table 15. The payoffs matrix of the coalition strategies between negotiator y_1 and negotiator y_2.

Criteria	Strategy combinations	The coalition strategies between y_1 and y_2			
		$y_1(1), y_2(1)$	$y_1(2), y_2(1)$	$y_1(1), y_2(2)$	$y_1(2), y_2(2)$
c_1	$A(1)$	(2,4,1,1)	(4,6,1,1)	(3,5,1,1)	(4,6,1,1)
	$A(2)$	(2,4,1,1)	(7,9,1,1)	(7,9,1,1)	(5,7,1,1)
c_2	$A(1)$	(3.5,4. 5,0.5,0.5)	(4.5,5. 5,0.5,0.5)	(3.5,4. 5,0.5,0.5)	(3.5,4. 5,0.5,0.5)
	$A(2)$	(4.5,5. 5,0.5,0.5)	(7.5,8. 5,0.5,0.5)	(6.5,7. 5,0.5,0.5)	(5.5,6. 5,0.5,0.5)
c_3	$A(1)$	(1.6,2.4,0.4,0.4)	(2.6,3.4,0.4,0.4)	(1.6,2.4,0.4,0.4)	(5.6,6.4,0.4,0.4)
	$A(2)$	(2.6,3.4,0.4,0.4)	(4.6,5.4,0.4,0.4)	(5.6,6.4,0.4,0.4)	(4.6,5.4,0.4,0.4)
c_4	$A(1)$	(3.5,4. 5,0.5,0.5)	(3.5,4. 5,0.5,0.5)	(4.5,5. 5,0.5,0.5)	(3.5,4. 5,0.5,0.5)
	$A(2)$	(3.5,4. 5,0.5,0.5)	(6.5,7.5,0.5,0.5)	(6.5,7.5,0.5,0.5)	(1.5,2.5,0.5,0.5)
c_5	$A(1)$	(1.6,2.4,0.4,0.4)	(4.6,5.4,0.4,0.4)	(4.6,5.4,0.4,0.4)	(3.6,4.4,0.4,0.4)
	$A(2)$	(1.6,2.4,0.4,0.4)	(5.6,6.4,0.4,0.4)	(7.6,8.4,0.4,0.4)	(3.6,4.4,0.4,0.4)

$Max\ v_1(y_1)$

Subject to (Strategic Game Model F_2):

$v_1(y_1) - (0.5, 1.5, 0.5, 0.5)p_1 - (0.5, 1.5, 0.5, 0.5)p_2 \leq 0$

$v_1(y_1) - (0.5, 1.5, 0.5, 0.5)p_1 - (2.5, 3.5, 0.5, 0.5)p_2 \leq 0$

$v_1(y_1) - (0.5, 1.5, 0.5, 0.5)p_1 - (3.5, 4.5, 0.5, 0.5)p_2 \leq 0$

$v_1(y_1) - (2.5, 3.5, 0.5, 0.5)p_1 - (0.5, 1.5, 0.5, 0.5)p_2 \leq 0$

$p_1 + p_2 = 1$

$p_1, p_2 \geq 0,\ v_1(y_1)$: Free variable

and

$Max\ v_1(y_2)$

Subject to (Strategic Game Model F_3):

$v_1(y_2) - (1.5, 2.5, 0.5, 0.5)p_1 - (2.5, 3.5, 0.5, 0.5)p_2 \leq 0$

$v_1(y_2) - (1.5, 2.5, 0.5, 0.5)p_1 - (2.5, 3.5, 0.5, 0.5)p_2 \leq 0$

$v_1(y_2) - (3.5, 4.5, 0.5, 0.5)p_1 - (0.5, 1.5, 0.5, 0.5)p_2 \leq 0$

$v_1(y_2) - (4.5, 5.5, 0.5, 0.5)p_1 - (4.5, 5.5, 0.5, 0.5)p_2 \leq 0$

$p_1 + p_2 = 1$

$p_1, p_2 \geq 0,\ v_1(y_2)$: Free variable

and

Table 16. The payoffs matrix of the grand coalition for Applet and negotiators y_1 and y_2.

Criteria	Strategy combinations							
	$(A(1), y_1(1), y_2(1))$	$(A(2), y_1(1), y_2(1))$	$(A(1), y_1(2), y_2(1))$	$(A(1), y_1(1), y_2(2))$	$(A(2), y_1(2), y_2(1))$	$(A(2), y_1(1), y_2(2))$	$(A(1), y_1(2), y_2(2))$	$(A(2), y_1(2), y_2(2))$
c_1	(6.5,9.5,1.5,1.5)	(2.5,5.5,1.5,1.5)	(6.5,9.5,1.5,1.5)	(3.5,6.5,1.5,1.5)	(8.5,11.5,1.5,1.5)	(8.5,11.5,1.5,1.5)	(8.5,11.5,1.5,1.5)	(5.5,8.5,1.5,1.5)
c_2	(7.25,10.25,0.75,0.75)	(6.25,9.25,0.75,0.75)	(6.25,9.25,0.75,0.75)	(5.25,8.25,0.75,0.75)	(10.25,13.25,0.75,0.75)	(9.25,12.25,0.75,0.75)	(8.25,11.25,0.75,0.75)	(6.25,9.25,0.75,0.75)
c_3	(5.4,6.6,0.6,0.6)	(4.4,5.6,0.6,0.6)	(4.4,5.6,0.6,0.6)	(2.4,6.6,0.6,0.6)	(5.4,6.6,0.6,0.6)	(7.4,8.6,0.6,0.6)	(8.4,9.6,0.6,0.6)	(8.4,9.6,0.6,0.6)
c_4	(6.25,9.25,0.75,0.75)	(6.25,9.25,0.75,0.75)	(5.25,8.25,0.75,0.75)	(7.25,10.25,0.75,0.75)	(9.25,12.25,0.75,0.75)	(11.25,14.25,0.75,0.75)	(6.25,9.25,0.75,0.75)	(2.25,5.25,0.75,0.75)
c_5	(6.4,7.6,0.6,0.6)	(2.4,6.6,0.6,0.6)	(5.4,6.6,0.6,0.6)	(6.4,7.6,0.6,0.6)	(7.4,8.6,0.6,0.6)	(10.4,11.6,0.6,0.6)	(6.4,7.6,0.6,0.6)	(4.4,5.6,0.6,0.6)

$$
\begin{aligned}
&Max\ v_1(A, y_1)\\
&\text{Subject to (Strategic Game Model } F_4\text{):}\\
&v_1(A, y_1) - (5, 7, 1, 1)p_1 - (1, 3, 1, 1)p_2 - (3, 5, 1, 1)p_3\\
&\quad - (4, 6, 1, 1)p_4 \leq 0\\
&v_1(A, y_1) - (1, 3, 1, 1)p_1 - (4, 6, 1, 1)p_2 - (8, 10, 1, 1)p_3\\
&\quad - (1, 3, 1, 1)p_4 \leq 0\\
&p_1 + p_2 + p_3 + p_4 = 1\\
&p_1, p_2, p_3, p_4 \geq 0,\ v_1(A, y_1)\text{: Free variable}
\end{aligned}
$$

and

$$
\begin{aligned}
&Max\ v_1(A, y_2)\\
&\text{Subject to (Strategic Game Model } F_5\text{):}\\
&v_1(A, y_2) - (6, 8, 1, 1)p_1 - (2, 4, 1, 1)p_2 - (3, 5, 1, 1)p_3\\
&\quad - (6, 8, 1, 1)p_4 \leq 0\\
&v_1(A, y_2) - (6, 8, 1, 1)p_1 - (6, 8, 1, 1)p_2 - (5, 7, 1, 1)p_3\\
&\quad - (5, 7, 1, 1)p_4 \leq 0\\
&p_1 + p_2 + p_3 + p_4 = 1\\
&p_1, p_2, p_3, p_4 \geq 0,\ v_1(A, y_2)\text{: Free variable}
\end{aligned}
$$

and

$$
\begin{aligned}
&Max\ v_1(y_1, y_2)\\
&\text{Subject to (Strategic Game Model } F_6\text{):}\\
&v_1(y_1, y_2) - (2, 4, 1, 1)p_1 - (4, 6, 1, 1)p_2 - (3, 5, 1, 1)p_3\\
&\quad - (4, 6, 1, 1)p_4 \leq 0\\
&v_1(y_1, y_2) - (2, 4, 1, 1)p_1 - (7, 9, 1, 1)p_2 - (7, 9, 1, 1)p_3\\
&\quad - (5, 7, 1, 1)p_4 \leq 0\\
&p_1 + p_2 + p_3 + p_4 = 1\\
&p_1, p_2, p_3, p_4 \geq 0,\ v_1(A, y_2)\text{: Free variable}
\end{aligned}
$$

and

$$
\begin{aligned}
&Max\ v_1(A, y_1, y_2)\\
&\text{Subject to (Strategic Game Model } F_7\text{):}\\
&v_1(A, y_1, y_2) - (6.5, 9.5, 1.5, 1.5)p_1 - (2.5, 5.5, 1.5, 1.5)p_2\\
&\quad - (6.5, 9.5, 1.5, 1.5)p_3\\
&\quad - (3.5, 6.5, 1.5, 1.5)p_4 - (8.5, 11.5, 1.5, 1.5)p_5\\
&\quad - (8.5, 11.5, 1.5, 1.5)p_6 - (8.5, 11.5, 1.5, 1.5)p_7\\
&\quad - (5.5, 8.5, 1.5, 1.5)p_8 \leq 0\\
&p_1 + p_2 + p_3 + p_4 + p_5 + p_6 + p_7 + p_8 = 1\\
&p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8 \geq 0, v_1(A, y_1, y_2)\text{: Free variable}
\end{aligned}
$$

Using the Lindo software, the optimal solutions for these models were the values of the characteristic functions as shown in Table 17.

In step 5-3, using Equation (10), the normalised values of the characteristic function was calculated for all coalitions as shown in Table 18.

Table 17. The values of the characteristic functions for Appllet and negotiators y_1 and y_2.

Criteria	Coalitions	The values of the characteristic functions		
c_1	Singleton coalitions	$v_1(A) = 1.8$	$v_1(y_1) = 1$	$v_1(y_2) = 3$
	2-coalitions	$v_1(A, y_1) = 5.11$	$v_1(A, y_2) = 7$	$v_1(y_1, y_2) = 5$
	Grand coalition	$v_1(A, y_1, y_2) = 10$	–	–
c_2	Singleton coalitions	$v_2(A) = 2.6$	$v_2(y_1) = 2.33$	$v_2(y_2) = 3$
	2-coalitions	$v_2(A, y_1) = 5.33$	$v_2(A, y_2) = 6.33$	$v_2(y_1, y_2) = 5$
	Grand coalition	$v_2(A, y_1, y_2) = 12$	–	–
c_3	Singleton coalitions	$v_3(A) = 1$	$v_3(y_1) = 1.67$	$v_3(y_2) = 1$
	2-coalitions	$v_3(A, y_1) = 4.14$	$v_3(A, y_2) = 5$	$v_3(y_1, y_2) = 5.2$
	Grand coalition	$v_3(A, y_1, y_2) = 16$	–	–
c_4	Singleton coalitions	$v_4(A) = 1$	$v_4(y_1) = 2.5$	$v_4(y_2) = 2$
	2-coalitions	$v_4(A, y_1) = 5$	$v_4(A, y_2) = 6.37$	$v_4(y_1, y_2) = 5$
	Grand coalition	$v_4(A, y_1, y_2) = 13$	–	–
c_5	Singleton coalitions	$v_5(A) = 1.67$	$v_5(y_1) = 1.67$	$v_5(y_2) = 2$
	2-coalitions	$v_5(A, y_1) = 4.8$	$v_5(A, y_2) = 4.4$	$v_5(y_1, y_2) = 5$
	Grand coalition	$v_5(A, y_1, y_2) = 11$	–	–

Table 18. The normalised values of the characteristic functions for Appllet and negotiators y_1 and y_1.

Criteria	Coalitions	The normalised values of the characteristic functions		
c_1	Singleton coalitions	$v'_1(A) = 0$	$v'_1(y_1) = 0$	$v'_1(y_2) = 0$
	2-coalitions	$v'_1(A, y_1) = .55$	$v'_1(A, y_2) = .52$	$v'_1(y_1, y_2) = .24$
	Grand coalition	$v'_1(A, y_1, y_2) = 1$	–	–
c_2	Singleton coalitions	$v'_2(A) = 0$	$v'_2(y_1) = 0$	$v'_2(y_2) = 0$
	2-coalitions	–	$v'_2(A, y_2) = .18$	$v'_2(y_1, y_2) = 0$
	Grand coalition	$v'_2(A, y_1, y_2) = 1$	–	–
c_3	Singleton coalitions	$v'_3(A) = 0$	$v'_3(y_1) = 0$	$v'_3(y_2) = 0$
	2-coalitions	–	$v'_3(A, y_2) = .24$	$v'_3(y_1, y_2) = .2$
	Grand coalition	$v'_3(A, y_1, y_2) = 1$	–	–
c_4	Singleton coalitions	$v'_4(A) = 4$	$v'_4(y_1) = 0$	$v'_4(y_2) = 0$
	2-coalitions	$v'_4(A, y_1) = .2$	$v'_4(A, y_2) = .45$	$v'_4(y_1, y_2) = .07$
	Grand coalition	$v'_4(A, y_1, y_2) = 1$	–	–
c_5	Singleton coalitions	$v'_5(A) = 0$	$v'_5(y_1) = 0$	$v'_5(y_2) = 0$
	2-coalitions	–	$v'_5(A, y_2) = .13$	$v'_5(y_1, y_2) = .23$
	Grand coalition	$v'_5(A, y_1, y_2) = 1$	–	–

Next, theses normalised values were used as the right hand side values of the constraints in model (G) to find the Appllet Company's optimal cooperative strategy for the two new products $5G_1$,$5G_2$ by considering all possible combinations of the two semiconductor companies.

In step 5-4, the imputations and points of the core were determined using the following model (G):

$$Max\ \phi$$

$$\text{Subject to (Model G)}:$$

$$\varphi \le I(A) + I(y_1) - Min\{v'_1(A, y_1), v'_2(A, y_1), v'_3(A, y_1), v'_4(A, y_1), v'_5(A, y_1)\}$$

$$\varphi \le I(A) + I(y_2) - Min\{v'_1(A, y_2), v'_2(A, y_2), v'_3(A, y_2), v'_4(A, y_2), v'_5(A, y_2)\}$$

$$\varphi \le I(y_1) + I(y_2) - Min\{v'_1(y_1, y_2), v'_2(y_1, y_2), v'_3(y_1, y_2), v'_4(y_1, y_2), v'_5(y_1, y_2)\}$$

$$I(A) + I(y_1) + I(y_2) = 1$$

$$I(A), I(y_1), I(y_2) \ge 0$$

$$\phi: \text{ Free variable}$$

or

$$Max\ \phi$$

$$\text{Subject to (Model G)}:$$

$$\varphi \le I(A) + I(y_1) - 0.1$$

$$\varphi \le I(A) + I(y_2) - 0.13$$

$$\varphi \le I(y_1) + I(y_2)$$

$$I(A) + I(y_1) + I(y_2) = 1$$

$$I(A), I(y_1), I(y_2) \ge 0$$

$$\phi: \text{ Free variable}$$

The optimal solution for model (G) was: $I^*(A) = 0.41$, $I^*(y_1) = 0.28$, $I^*(y_2) = 0.31$ and based on the ranked values $I^*(y_1), \ldots, I^*(y_n)$, Appllet selected the second negotiator to form the coalition for new product development. Finally, the negotiators reviewed the obtained coalition form and confirmed this joint agreement.

5. Conclusions and future research directions

New product development is a complex and collaborative process that requires negotiation and joint decision-making. In principle, each individual treats the new product development problem differently and thus sees it from a distinct perspective. The objective of this study was to integrate a fuzzy cooperative multi-criteria game theory and Internet technologies within a collaborative e-negotiation support system for new product development. The study provided a framework for representing multiple viewpoints of a problem, aggregating the preferences of multiple negotiating parties according to various group norms and organising the decision process on the Web.

Future research paths will be fourfold: (1) to explore how similarities and differences among the negotiating interests influence the effectiveness of the e-negotiation support process; (2) to explore the effect of different cooperation strategies (i.e. face-to-face versus web-based) on choosing a common strategy to improve the payoffs of the members of the coalition group; (3) to explore the effect of multi-bilateral e-negotiations with multiple negotiating parties on the decision-making process because the result of each bilateral negotiation need to be coordinated with those of the other bilateral negotiations; and (4) to explore the role e-negotiations play in organisational longevity because joint agreements that appeared successful in a given problem at first might no longer work out to be effective in the long run.

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Notes

1. The name of the company is changed to protect its anonymity.
2. The name of the product is changed to protect its anonymity.

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