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Green Supply Chain Coordination Mechanism with Intuitionistic Fuzzy Information

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Abstract

The development of supply chain always is the focus in the theory and practical study. Coordination mechanism which can improve competition of whole supply chain has become new management mind and strategy. This paper introduces coordination mechanism in green supply chain to adapt rapidly changing of technology and environment. Because of the difficulty of expressing the decision maker's preferences accurately, intuitionistic fuzzy set is introduced to help us construct coordination mechanism of green supply chain. With attribute weights, we propose an operator and score function to evaluate the performance of this coordination mechanism, which is a critical step of the development of green supply chain. Finally, a case study is demonstrated to verify the reliability and applicability of the proposed method.

Keywords: *coordination mechanism; green supply chain; intuitionistic fuzzy set; attribute weights*

1. Introduction

A supply chain consists of many organizations acting together, with each organization dependent on the performance of other organizations in the chain. Coordination within a supply chain is a strategic response to the problems that arise from inter-organizational dependencies within the chain [1]. Johnston (1995) has defined supply chain management as: the process of strategically managing the movement and storage of materials, parts and finished inventory from suppliers, through the firm and to customers [2]. Meanwhile, supply chain management also is the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole [3]. Thus a supply chain manages information, product, service, financial and knowledge flows from the supplier network to the integrated enterprise down to the distribution network and finally to the end customers [4]. The concept of supply chain coordination, as the important aspect of supply chain management, is proposed as far as 1990s. Although this time is not long, it has been caused widespread interest of the theoretic and practical field [5-6].

With the rapid development of economy and technology, environmental sustainable development has become a new key point all over the world. It is imperative for a supply chain to obtain environmental sustainability [7]. Green supply chain which combines environmental protection with economic development is a critical stage to improve sustainable development of supply chain. Academic and corporate has focused on green supply chain in recent years [8-10]. One important aspect of green supply chain is how to save costs and increase profitability to promote business more sustainable. Integrated supply chain management is a tendency to save costs and increase profitability. Fruitful researchers are interesting in proposing measures to develop a greener and more sustainable approach into supply chains [11-12]. The main concern is how to improve the implementation of a green supply chain. Based on the ideal of integrated supply chain

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management, coordination mechanism of green supply chain is proposed in this paper.

Because there are subjective and objective assessments given by decision maker, uncertain and imprecise are the basic characteristics of decision maker's preferences. In other words, to express the decision maker's preferences accurately is difficult. In this paper, we propose a new green supply chain coordination mechanism to promote the sustainable development of supply chain management. The evaluation of coordination performance of this green supply chain coordination mechanism is the key step to accomplish and verify this coordination mechanism. This assessment problem can be considered as a multiple attribute decision making (MADM) problem. The first step of multiple attribute decision making is to provide assessments by the decision maker. Then, as mentioned above, based on the uncertain of decision maker's preferences, intuitionistic fuzzy set is introduced in this paper, which has been widely used in copying with this imperfect problem [13-15]. An operator combining with attribute weights is proposed to obtain scientific and reasonable aggregated results of attributes. Score function is also introduced to acquire the decision making result. Finally, a numerical example is demonstrated to verify applicable and reasonable of this evaluation method in intuitionistic fuzzy environment.

The main contributions of this paper include the following: (1) the construction of the coordination mechanism of green supply chain; (2) the design of IFWA for attribute combination to evaluate coordination performance of this coordination mechanism; (3) the design of a new score function with variance; (4) the application of coordination evaluation based on the proposed method.

The rest of this paper is organized as follows. In Section 2, we review some concepts of green supply chain management and propose the definition of coordination of green supply chain. Section 3 constructs a new coordination mechanism of green supply chain. Section 4 introduces some methods to evaluate coordination performance of this coordination mechanism. A case study is demonstrated in Section 5. Finally, Section 6 concludes this paper.

2. The Relevant Concepts of Coordination Development

Because of the significance of green supply chain in sustainable development, the concepts of green supply chain and its coordination are introduced in this section.

2.1 Green Supply Chain Management

Now, the new challenge is to develop ways in which industrial development and environmental protection can symbiotically coexist. The concept of green supply chain is developed under this environment. The aim of green supply chain is how to improve the overall optimization of information which flows along the value chain, especially coordination between industry and environment.

As discussed in Section 1, green supply chain management is proposed based on supply chain management. Supply chain management has widely used by companies to improve their ability level with the objective of being flexible and responsive to meet changing marker requirement demonstrated in Figure 1 [16-17]. It demonstrates the simple process of general supply chain management and its strategy, which can help industry to obtain proper performance in supply chain management.

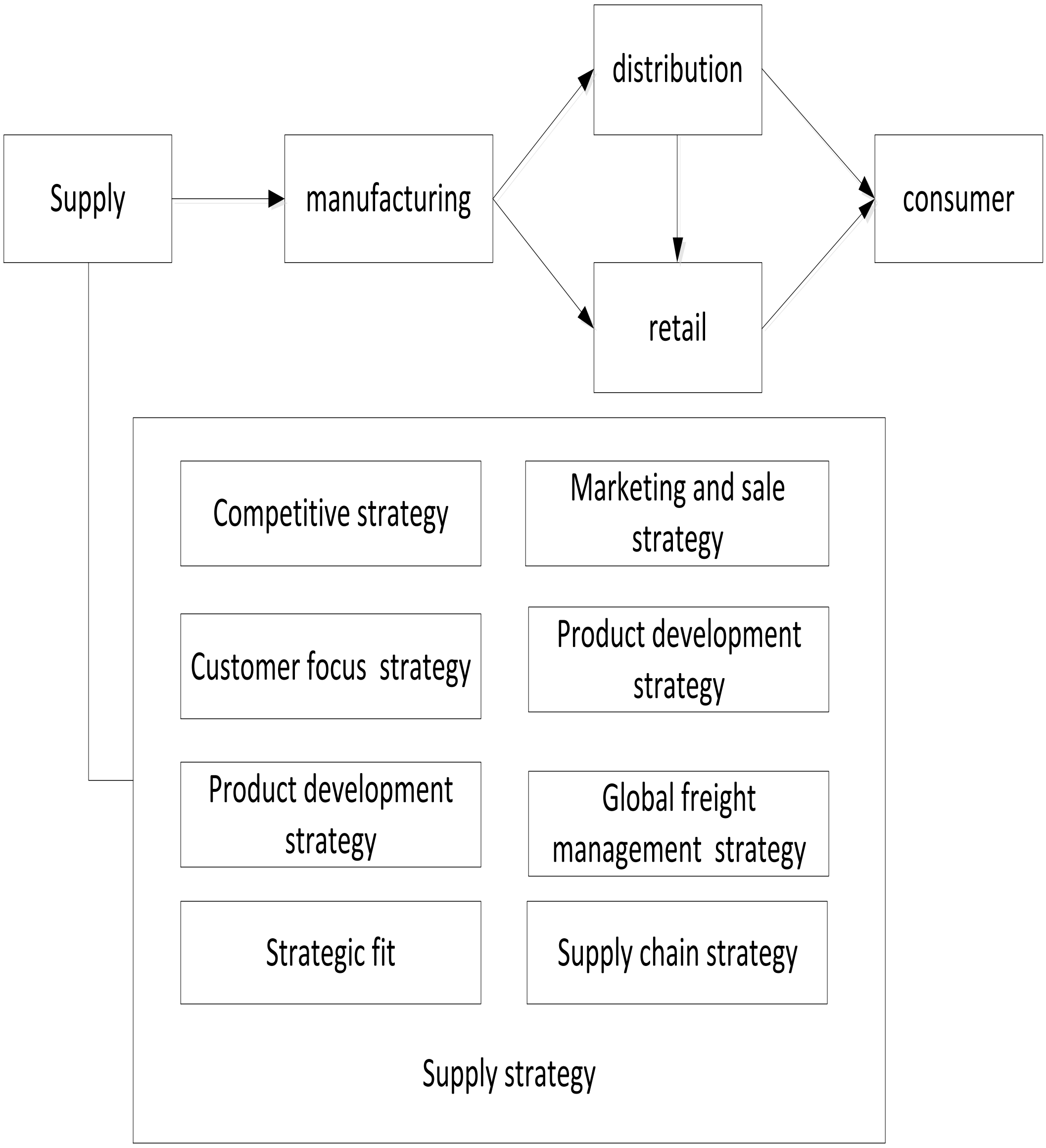

Figure 1. Supply Chain Management and its Strategy

Therefore, according to combine with environmental sustainable development, green supply chain management is proposed by Zhu and Sarkis(2004), Srivastava (2007)[18-19].Green supply chain management is defined as integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life.

Different from traditional supply chain, the important characteristic of green supply chain is to take recycling and re-use considering with environmental protection and sustainable development. Recycling is the process of collection used products, components, and/or materials from the field, disassembling them, separating them into categories of like materials, and processing into recycled products, components, and/or materials. Re-use is the process of collecting used materials, products or components from the field, and distributing or selling them as used. Coordination is an important factor to promote recycle and re-use in green supply chain.

2.2. The Definition of Green Supply Chain Coordination

As mentioned above, green supply chain coordination is based on supply chain coordination combining with recycling, re-use and other environmental factors. In other words, if companies want to reap the greatest benefits from green supply chain, they have to integrate each member of supply chain into this value chain. Therefore, the key point of this green supply chain is how to coordinate each member to obtain their prefect profits. The concept of green supply chain has not been unified. Then, firstly, we introduce the concept of supply chain coordination.

Malone and Crowston (1994) defined coordination as the process of managing dependencies among activities, and suggested different kinds of dependencies associated with such aspects as shared resources, task assignments, producer or consumer relationships, design for manufacturability and so force [20]. Simatupang and Sridharan (2002) recongnized a collaborative supply chain involves two or more independent companies that work jointly to plan and execute supply chain operations with greater success than when acting in isolation. Retail trades and vehicle manufacturing industries are the main recipients of the supply chain coordination [21]. Fugate *et al.* (2006) think a supply chain is composed of trading partners that are interconnected with financial, information, and product or service flows. Effective management of these flows requires creating synergistic relationships between the supply and distribution partners with the objective of maximizing customer value and providing a profit for each supply chain member [22]. In brief, coordination of supply chain makes each supply chain member achieve maximum of common profit.

The fundamental rationale behind coordination is that a single company cannot successfully compete by itself. Therefore, the coordination of green supply chain can be defined as a scientific process that this supply chain can obtain maximum profits. In other words, the collaborative green supply chain takes this supply chain as a system. The benefit of it is bigger than that of simple sun of each stakeholder which represents each supply chain member. The aim of coordination of green supply chain is to obtain a balance between economic society and environment. In this context, companies should rethink the way they want to develop in the future to stay profitable. Coordination of green supply chain offers companies opportunities to save costs, increase efficiency and gain new development way. It also affects all areas of an enterprise to incorporate the potential to gain a competitive advantage and to generate profits. Because of global warming, international regulation, brand reputation, stakeholders' increasing awareness, and potential value creation in green supply chain, coordination is a key way to achieve sustainable development of green supply chain.

The drivers for companies to implement coordination of green supply chain are divided into internal and external drivers. Internal drivers stem mostly from top manager's insight of long-term development, supply chain stakeholders and competition with others enterprises. External drivers for the implementation of collaborative green supply chain mainly result from economic society and government. This is particularly due to stricter environmental regulations, increased community and consumer pressures and manufacturers' need to effectively integrate environmental concerns into their supply chain strategy. Therefore, we will construct a coordination mechanism to obtain a balance between internal and external drives.

3. Construction of Green Supply Chain Coordination Mechanism

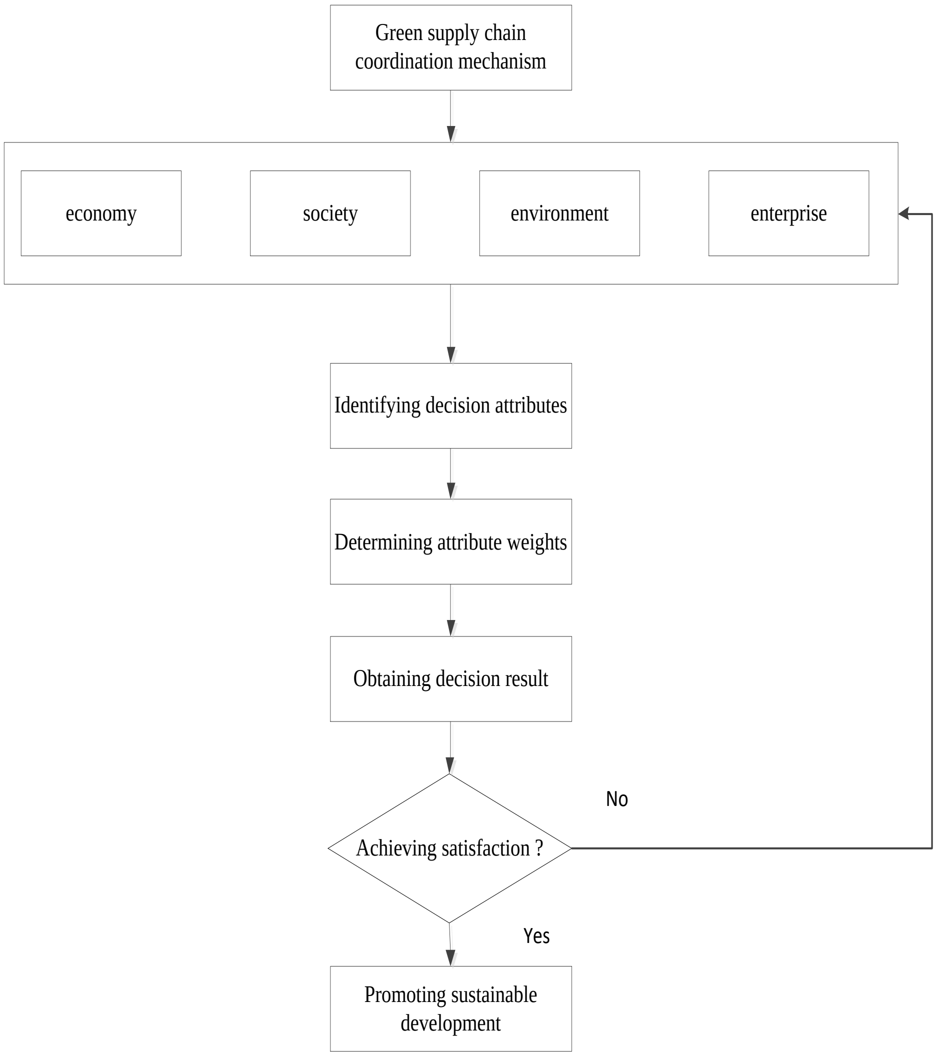

Figure 2. The Framework of Green Supply Chain Coordination Mechanism

The decision to adopt one of these alternatives will be necessary for an effective green supply chain, but will be dependent on a number of factors and elements. Based on the drivers of collaborative green supply chain, we realize that internal and external drivers can influent coordination performance. Therefore, by analyzing these drivers, it can be obtained four basic factors including economy, society, environment and enterprise. The former three are related to macroscopic level, the last one points to microcosmic level. Because of different level and perspective, different factors may result in different and even contradictory influence. So, it is important to establish a framework of green supply chain coordination mechanism. It can not only balance different factors, but also promote maximum benefits. However, this is the first step that construction of green supply chain coordination mechanism. The crucial step is to evaluate the collaborative performance of green supply chain as discussed in Section 1. Then, we introduce intuitionistic fuzzy multiple decision making method to deal with this assessment problem including three basic steps such as indentifying decision attributes, determining attribute weights, obtaining decision result. The framework of green supply chain coordination mechanism is demonstrated in Figure 2.

4. An Evaluation Model of Collaborative Performance Based on Intuitionistic Fuzzy Sets

In this section, we introduce intuitionistic fuzzy multiple decision making methods to evaluate performance of green supply chain coordination mechanism. The basic concepts of intuitionistic fuzzy aggregated operator and score function are introduced in constructing this model.

4.1. Some Concepts

Definition 1.[13] Let a finite set X = {x_1, x_2, ... , x_n} be fixed, an intuitionistic fuzzy set A in X can be defined as follows:

$$A = \{(x_i, u_A(x_i), v_A(x_i)) | x_i \in X\} \tag{1}$$

where the function $u_A: X \to [0,1]$ and $v_A: X \to [0,1]$ determine the membership degree and non-membership degree of the element $x_i \in X$,respectively, and for every $x_i \in X$:

$$0 \le u_A + v_A \le 1 \tag{2}$$

For each intuitionistic fuzzy set A in X, it can be obtained that $\pi_A(x_i) = 1 - u_A(x_i) - v_A(x_i)$ for every $x_i \in X$. $\pi_A(x_i)$ is called uncertainty or hesitancy degree. In particularly, if $\pi_A(x_i)$ =0, then the intuitionisitc fuzzy set A reduced to a conventional fuzzy set.

For convenience, we call $a = (u_a, v_a)$ an intuitionistic fuzzy number, where u_a, $v_a \in$ [0, 1], $0 \le u_a + v_a \le 1$.

Based on the definition of intuitionistic fuzzy set, some operations are introduced to express the rule of it [14].

Theorem 1. Let $a_1 = (u_1, v_1)$, $a_2 = (u_2, v_2)$, and $a_3 = (u_3, v_3)$ be three intuitionistic fuzzy numbers, then, the following operations are satisfied:

(1) $\alpha_1 \oplus \alpha_2 = \alpha_2 \oplus \alpha_1$;

(2) $\alpha_1 \otimes \alpha_2 = \alpha_2 \otimes \alpha_1$;

(3) $(\alpha_1 \oplus \alpha_2)^c = \alpha_1^c \otimes \alpha_2^c$;

(4) $(\alpha_1 \otimes \alpha_2)^c = \alpha_1^c \oplus \alpha_2^c$;

(5) $\lambda(\alpha_1)^c = (\alpha_1^\lambda)^c$;

(6) $(\alpha_1^c)^\lambda = (\lambda\alpha_1)^c$.

Here, α_1^c represents the complement of the intuitionistic fuzzy number α_1.

Theorem. 2 [14] Let $a = (u_a, v_a)$ and $b = (u_b, v_b)$ be two intuitionistic fuzzy numbers, then, it can be acquired:

(1) $a \oplus b = (u_a + u_b - u_a u_b, v_a v_b)$;

(2) $a \otimes b = (u_a u_b, v_a + v_b - v_a v_b)$;

(3) $\lambda a = (1 - (1 - u_a)^\lambda, (v_a)^\lambda), \lambda > 0$;

(4) $a^\lambda = ((u_a)^\lambda, 1 - (1 - v_a)^\lambda), \lambda > 0$.

4.2. Aggregation Operators and Score Function

Based on these operations, a series of aggregation operators with intuitionistic fuzzy information are developed:

Definition 2 [15]. Let a_j(j = 1, 2, …, n) be a collection of IFSs. A intuitionistic fuzzy weighted averaging (IFWA) operator is a mapping $\Theta^n \rightarrow \Theta$ such that

$$\text{IFWA}(a_1, a_2, \ldots, a_n) = \mathop{\oplus}_{j=1}^{n}(w_j a_j) = \{1-\prod_{j=1}^{n}(1-u_j)^{w_j}, \prod_{j=1}^{n} v_j^{w_j}\}, \quad (3)$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weight vector of $a_j (j = 1, 2, \ldots, n)$ with $0 \leq w_j \leq 1$ $(j = 1, 2, ..., n)$ and $\sum_{i=1}^{n} w_j = 1$.

When $w = (1/n, 1/n, \ldots, 1/n)^T$, the IFWA operator reduces to the intuitionistic fuzzy averaging (IFA) operator:

$$\text{IFA}(a_1, a_2, \ldots, a_n) = \mathop{\oplus}_{j=1}^{n}(\frac{1}{n} a_j) = \{1-\prod_{j=1}^{n}(1-u_j)^{1/n}, \prod_{j=1}^{n} v_j^{1/n}\}. \quad (4)$$

Definition 3 [15]. Let $h_j (j = 1, 2, \ldots, n)$ be a collection of IFSs. A intuitionistic fuzzy weighted geometric (HFWG) operator is a mapping $\Theta^n \rightarrow \Theta$ such that

$$\text{IFWG}(a_1, a_2, \ldots, a_n) = \mathop{\oplus}_{j=1}^{n}(a_j^{w_j}) = \{\prod_{j=1}^{n} u_j^{w_j}, 1-\prod_{j=1}^{n}(1-v_j)^{w_j}\}, \quad (5)$$

where $w = (w_1, w_2, \ldots, w_n)^T$ is the weight vector of $a_j (j = 1, 2, \ldots, n)$ with $0 \leq w_j \leq 1$ $(j = 1, 2, ..., n)$ and $\sum_{i=1}^{n} w_j = 1$.

When $w = (1/n, 1/n, \ldots, 1/n)^T$, the IFWG operator reduces to the intuitionistic fuzzy geometric (HFG) operator:

$$\text{IFG}(a_1, a_2, \ldots, a_n) = \mathop{\oplus}_{j=1}^{n}(a_j^{1/n}) = \{\prod_{j=1}^{n} u_j^{1/n}, 1-\prod_{j=1}^{n}(1-v_j)^{1/n}\}. \quad (6)$$

Definition 4 [15]. Let a be an IFN. The score function of a can be obtained as follow:

$$S(a) = u_a - v_a, \quad (7)$$

Definition 5 [15]. Let a be an IFN. The accuracy function of a can be obtained as follow:

$$H(a) = u_a + v_a, \quad (8)$$

Definition 6 [14]. For two IFN a_1 and a_2, we have
if $S(a_1) > S(a_2)$, then a_1 is better than or preferred to a_2, denoted by $a_1 > a_2$;
if $S(a_1) = S(a_2)$, then
  if $H(a_1) > H(a_2)$, a_1 is better than or preferred to a_2, denoted by $a_1 > a_2$;
  if $H(a_1) = H(a_2)$, a_1 is indifferent to a_2, denoted by $a_1 = a_2$;
  if $H(a_1) < H(a_2)$, a_2 is better than or preferred to a_1, denoted by $a_1 < a_2$.

4.3. Process of Evaluation Model

In this section, we will propose a procedure to form this evaluation model based on mentioned methods, where attribute values take the form of intuitionistic fuzzy numbers. The procedure includes the following steps:

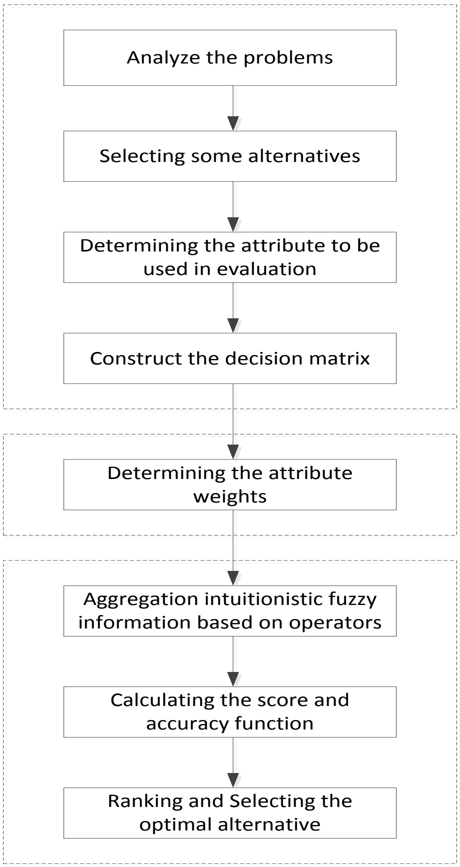

Figure 3. The Procedure of Green Supply Chain Coordination Assessment

5. Illustrative Example

The process of evaluation model, as the key of green supply chain coordination mechanism, will be demonstrated in section with the proposed method in this paper under intuitionistic fuzzy environment.

Investigation of pressures and drivers for adoption and improving coordination performance arises from a number of external and internal groups or stakeholders. Firms are pressured by stakeholders to be more environmentally conscious and to integrate environmental management into their supply chain management. Green supply chain refers to efforts to minimize the negative impact of firms and their supply chain on the natural environment and social environment. By coordination mechanism in green supply chain, it can help enterprises obtain a sustainable competitive advantage and risk reduction.

In order to verify the proposed evaluation methods in green supply chain coordination mechanism, we invite an expert as the decision maker to propose a project. As one of main tasks in the project, we investigate how to help the decision maker select optimal region where coordination preference of green supply chain is better than others.

Step 1: Four regions are selected by the decision maker as the alternatives including Beijing (A_1), Shanghai (A_2), Guangzhou (A_3), Hongkong (A_4) from China. Based on the coordination mechanism, the decision maker identifies four attributes denoted as C_1, C_2, C_3, C_4 demonstrated in Table 1. Meanwhile, they give the weight vector of these four attributes denoted as $w = (0.3, 0.2, 0.25, 0.25)^T$.

Table 1. Description of the Seven Attributes

Attributes	Explanation
C_1	Economic benefits
C_2	Social benefits
C_3	environmental benefits
C_4	Enterprise benefits

Step 2: The decision maker and experts give their preference of every region on each attribute, respectively. Therefore, an intuitionistic fuzzy decision matrix $D=[\tilde{h}_{ij}]_{4\times 5}$ is provided and illustrated in Table 2.

Table 2. Original Intuitionistic Fuzzy Decision Matrix

	A_1	A_2	A_3	A_4
C_1	{0.6,0.2}	{0.7,0.3}	{0.2,0.6}	{0.7,0.2}
C_2	{0.7,0.3}	{0.6,0.2}	{0.3,0.5}	{0.5,0.4}
C_3	{0.4,0.3}	{0.6,0.3}	{0.4,0.4}	{0.6,0.3}
C_4	{0.8,0.1}	{0.5,0.4}	{0.4,0.5}	{0.7,0.2}

Step3: As mentioned in Definition 3 and Definition 4, the intuitionistic fuzzy assessments can be aggregated in Figure 4.

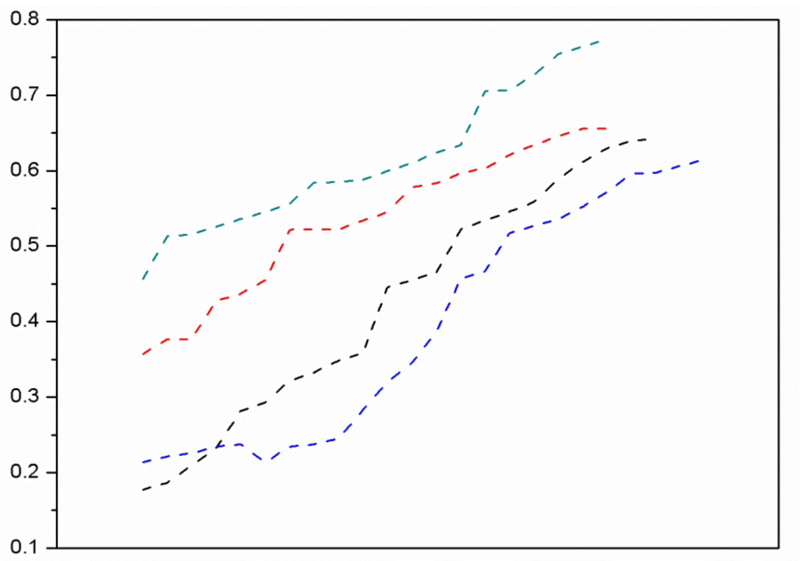

Figure 4. The Aggregation Based on IFWA Operator

Step 4: Based on Section 3, it can be obtained the scores of each alternative showed in Table 3.

Table 3. Scores and Rank-Order

	score	rank
A_1	0.5211	3
A_2	0.5867	2
A_3	0.4150	4
A_4	0.6325	1

Then, the rank of this assessment problem is demonstrated as $A_4 \succ A_3 \succ A_2 \succ A_1$ from Table 6 and Table 7. It is easy to know that Hongkong denoted as A_4 is the optimal region that coordination preference of green supply chain is better than others.

6. Conclusion

As enterprises attempt to move toward sustainability of supply chain, management must extend their efforts to improve coordination performance to establish green supply chain which combines economy, society, environment and enterprise. The green supply chain can be considered as a system. Thus, the four aspects can be considered as four subsystems. Based on this analysis, we construct a new coordination mechanism of green supply chan. The evaluation of coordination performance is a key step in this coordination mechanism of green supply chain. Because of the inherent vagueness of human preferences as well as the objects being fuzzy and uncertain, the attributes involved in decision making problems are not always expressed in real numbers, and some are better suited to be denoted by fuzzy values, such as intuitionistic fuzzy values. Therefore, we define the new operators of intuitionistic fuzzy sets combining with attribute weights. Meanwhile, we propose a score function to aggregate the assessments of different alternative on each attribute. Finally, an illustrative example is demonstrated to verify the reliability and applicability of the proposed method.

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