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A Fuzzy TOPSIS Based Evaluation Method for Supply Chain Collaborative Technological Innovation

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Abstract

The collaboration between the company and its partners is becoming a competitive advantage to achieve long-term business success. Especially from the perspective of the supply chain, corporate profitability depends increasingly on their overall competitiveness in the supply chain rather than a single company. This paper is an attempt to the current issues and development of the supply chain collaborative technological innovation, and fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is employed to assess the performance of the collaborative technological innovation from the supply chain perspective. An empirical study is illustrated to testify the effectiveness of this method. The managerial implications and suggestions for future research are also discussed.

Keywords: *Collaborative technological innovation, Supply chain, Fuzzy TOPSIS, Empirical study*

1. Introduction

Innovation plays a key role in the development and progress of enterprise. It drives the enterprise to go forward and reflects the development potential and competitive advantages of the enterprise in the long run. The study of the Shrivastava [1] suggests that enterprises can be differentiate themselves from others by using innovation.

Innovation can be made in the form of process, product, technical, management, incremental or radical [2,3]. Innovation is necessary - simply for survival, as well as development. Enterprises can make new products, new technologies, new processes or services to satisfying the customer. Technological innovation can boost the company's performance, resolve the company's difficulties and improve the company's competitive advantage [4].

What's more, the transmission of information between companies just puts forward the collaboration of companies and makes it more likely for technological innovation [5]. The collaboration between companies is vitally important for achieving long-term success[6]. In supply chain, corporate profitability comes from the competitiveness of the supply chain collaboration rather than a single company.

There are many papers that study the supply chain collaboration which just pay attention to the information sharing and inventory management. But there is little quantitative analysis literature about the collaboration on product technological innovation from the supply chain perspective. From observations, however, there exist many issues and challenges in the current supply chain collaborative technological innovation process. In order to provide practical insight and guidelines for improving the promotional effectiveness of the supply chain collaborative technological innovation, an investigative empirical study to evaluate the performances of the collaborative technological innovation is needed, which is the primary motivation of this research.

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The paper is organized as follows. The next section introduces the related literature about supply chain product technological innovation collaboration. Following is a brief introduction about the fuzzy TOPSIS method used in this research. Section 4 describes an empirical analysis of evaluating the performances of technological innovation in the selected 10 supply chains in China's automobile industry. The primary data for this research are collected through a comprehensive questionnaire. Finally, major issues and challenges for these companies in promoting their supply chain collaborative technological innovation are identified and discussed along with the related managerial implications.

2. Literature Review

2.1 Supply Chain Product Technological Innovation Collaboration

Supply chain is a dynamic network that integrates material, information, capital and resources to achieve the goal of competitive strategy, which is composed by many geographically dispersed business entities [7]. Supply chain collaboration, as a mode of supply chain management, is used to manage the resources of supply chain to achieve the goal of using less and gaining more [8]. Enterprises cooperate in supply chain to make sure smooth circulation of information flow and capital flow. As a result, they can benefit from the supply chain [9], such as profits and quality improving, as well as cost reducing and elastic operation faced with uncertain demand [10]. There have many researches about supply chain product technological innovation, which focus on inventory management, information sharing [11], operation process improving between enterprise [12], and scenario analysis[13]. The study by Morten put forward four barriers about collaboration in supply chain enterprises, which are unwillingness to seek input, unwillingness to help, inability to ask for expertise and not work together [14]. There have four motives that many enterprises take action of technological innovation in supply chain collaboration: requirement from the development of technological innovation, reduction of risk and uncertainty, effect of resources and competence, the trend of professionality and integration on supply chain. For that, many researches identify the main benefits of technological innovation including new product development, quality improvement[15] and cost saving[16]. Some articles focus on product innovation. They point out the purpose of product innovation is to meet customers' expectations [17]. The study of Mark suggests that the optimal allocation of resources at enterprise level to transform technological innovation to successful products depended on the effective assessment and selection of projects [18].

2.2 Evaluation of Collaborative Product Technological Innovation in Supply Chain

The supply chain collaboration needs many enterprises to take part in, so when evaluating the collaboration of product technological innovation, great attention should be paid. A suitable and effective evaluation mechanism is needed. Prajogo and Sohal argue that the criteria of technological innovation are the rate of innovation, the number of innovations, the degree of innovation and the time coming into market [19]. Some related studies just point out good collaboration in product technological innovation included four elements: information sharing, decision-making, cooperative distribution and coordinating input [20]. But the standard of collaboration is that every participant can be benefited [21], which are not always working for the present situations. In fact, suppliers in supply chain can not be fair, it may occur that one supplier pay effort, other suppliers benefit [22]. Therefore, a suitable and effective assessment mechanism is needed.

Multi criteria decision making (MCDM) method is a well-known decision making method when dealing comprehensive evaluation with various indicators problem. Fuzzy set theory combined with MCDM methods has been widely used to deal with uncertainty problems in the supplier selection [23]. It comes up with a method to deal with imprecise criteria, being able to integrate the analysis of quantitative and qualitative factors. At present, lots of problems are uncertain. And because of lacking of enough data, various scenarios cannot be modeled. Then the technique for order preference by similarity to ideal solution (TOPSIS) method was proposed. TOPSIS is a linear weighting method and has been widely used to solve multi criteria decision making problems under uncertainty in many different fields [24].

In summary, the evaluation of performance of the collaborative technological innovation both in theory and in practice has proven to be very important and quite complex, and there have been limited researches in the current literature.

3. Methodology

3.1 Fuzzy Sets and Fuzzy Numbers

First, it is necessary to review the related Fuzzy Theory:

Definition 1: Let $\tilde{a} = (a_1, a_2, a_3)$ and $\tilde{b} = (b_1, b_2, b_3)$ be two triangular fuzzy numbers. According to Kwang [25], a distance measure function ($\tilde{a}$, $\tilde{b}$) can be defined as below:

$$d(\tilde{a},\tilde{b}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]}$$

Definition 2: Let a triangular Fuzzy number $\tilde{a}$, then α -cut defined as below:

$$\tilde{a}_\alpha = [(a_2 - a_1)\alpha + a_1, a_3 - (a_3 - a_2)\alpha]$$

Definition 3: Let $\tilde{a} = (a_1, a_2, a_3)$, $\tilde{b} = (b_1, b_2, b_3)$ be two triangular Fuzzy number and $\tilde{a}_\alpha$, $\tilde{b}_\alpha$ be α -cut, $\tilde{a}$ and $\tilde{b}$, then the method is defined to calculate the divided between $\tilde{a}$ and $\tilde{b}$ as follows:

$$\frac{\tilde{a}_\alpha}{\tilde{b}_\alpha} = [\frac{(a_2 - a_1)\alpha + a_1}{-(b_3 - b_2)\alpha + b_3}, \frac{-(a_3 - a_2)\alpha + a_3}{(b_2 - b_1)\alpha + b_1}]$$

When $\alpha = 0$,

$$\frac{\tilde{a}_0}{\tilde{b}_0} = [\frac{a_1}{b_3}, \frac{a_3}{b_1}]$$

When $\alpha = 1$

$$\frac{\tilde{a}_1}{\tilde{b}_1} = [\frac{(a_2 - a_1) + a_1}{-(b_3 - b_2) + b_3}, \frac{-(a_3 - a_2) + a_3}{(b_2 - b_1) + b_1}]$$

$$\frac{\tilde{a}_1}{\tilde{b}_1} = [\frac{a_2}{b_2}, \frac{a_2}{b_2}]$$

So the approximated value of $\tilde{a} / \tilde{b}$ will be

$$\frac{\tilde{a}}{\tilde{b}} = [\frac{a_1}{b_3}, \frac{a_2}{b_2}, \frac{a_3}{b_1}]$$

$$\tilde{a} \times \tilde{b} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3)$$

$$\tilde{a} + \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$$

3.2 Fuzzy Membership Function

In the evaluating process, the weights expressed with the linguistic terms. These linguistic terms are categorized into very low (VL), low (L), medium (M), high (H) and very high (VH). Assume that all linguistic terms can be transferred into triangular fuzzy numbers. Based on assumptions above, a transformation table can be found as shown in Table 1. Figure 1 illustrates the Fuzzy membership function [26,27].

Table 1. Transformation for Fuzzy Membership Functions

Rank	Sub-criteria grade	Membership function
Very Low (VL)	1	(0.00,0.10,0.25)
Low (L)	2	(0.15,0.30,0.45)
Medium (M)	3	(0.35,0.50,0.65)
High (H)	4	(0.55,0.70,0.85)
Very High (VH)	5	(0.75,0.90,1.00)

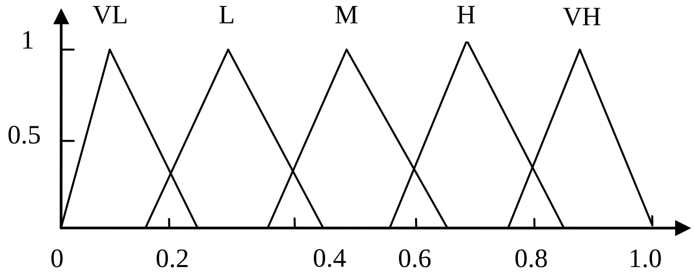


Figure 1. Fuzzy Triangular Membership Functions

3.3 Fuzzy TOPSIS model

The FMCDM (Fuzzy Multiple Criteria Decision Making) problem can be concisely expressed in matrix format as follows:

$$\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{13} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \tilde{x}_{23} & \cdots & \tilde{x}_{2n} \\ \tilde{x}_{31} & \tilde{x}_{32} & \tilde{x}_{33} & \cdots & \tilde{x}_{3n} \\ \vdots & & & & \\ \tilde{x}_{n1} & \tilde{x}_{n1} & \tilde{x}_{n1} & \cdots & \tilde{x}_{n1} \end{bmatrix} \end{array}$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \cdots \tilde{w}_n]$$

Where $x_{ij}, i = 1,2,\cdots,m; j = 1,2,\cdots,n$ and $\tilde{w}_j, j = 1,2,\cdots,n$ are linguistic triangular Fuzzy numbers, $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (a_{j1}, b_{j2}, c_{j3})$. The normalized Fuzzy decision matrix is denoted by $\tilde{R} = [\tilde{r}_{ij}]_{m \times n}$.

The weighted Fuzzy normalized decision matrix is shown as follows:

$$V = \begin{bmatrix} \tilde{v}_{11} & \tilde{v}_{12} & \tilde{v}_{13} & \cdots & \tilde{v}_{1n} \\ \tilde{v}_{21} & \tilde{v}_{22} & \tilde{v}_{23} & \cdots & \tilde{v}_{2n} \\ \tilde{v}_{31} & \tilde{v}_{32} & \tilde{v}_{33} & \cdots & \tilde{v}_{3n} \\ \vdots & & & & \\ \tilde{v}_{n1} & \tilde{v}_{n1} & \tilde{v}_{n1} & \cdots & \tilde{v}_{n1} \end{bmatrix}$$

$$= \begin{bmatrix} \tilde{w}_1\tilde{r}_{11} & \tilde{w}_2\tilde{r}_{12} & \tilde{w}_3\tilde{r}_{13} & \cdots & \tilde{w}_n\tilde{r}_{1n} \\ \tilde{w}_1\tilde{r}_{21} & \tilde{w}_2\tilde{r}_{22} & \tilde{w}_3\tilde{r}_{23} & \cdots & \tilde{w}_n\tilde{r}_{2n} \\ \tilde{w}_1\tilde{r}_{31} & \tilde{w}_2\tilde{r}_{32} & \tilde{w}_3\tilde{r}_{33} & \cdots & \tilde{w}_n\tilde{r}_{3n} \\ \vdots & & & & \\ \tilde{w}_1\tilde{r}_{m1} & \tilde{w}_2\tilde{r}_{m2} & \tilde{w}_3\tilde{r}_{m3} & \cdots & \tilde{w}_n\tilde{r}_{mn} \end{bmatrix}$$

Given the above Fuzzy theory, the proposed Fuzzy TOPSIS procedure is then defined as follows:

Step 1: choose the $x_{ij}, i = 1, 2, \cdots, m; j = 1, 2, \cdots, n$ for alternatives with respect to criteria and $\tilde{w}_j, j = 1, 2, \cdots, n$ for the weight of the criteria.

Step 2: Construct the weighted normalized Fuzzy decision matrix V .

Step 3: Identify positive ideal (A^+) and negative ideal (A^-) solutions:

$$A^+ = \left\{\tilde{v}_1^+, \tilde{v}_2^+, \cdots \tilde{v}_n^+\right\}$$

$$= \left\{(\max_i \tilde{v}_{ij} \left| i = 1, 2, \cdots, m), j = 1, 2, \cdots, n\right.\right\}.$$

$$A^- = \left\{\tilde{v}_1^-, \tilde{v}_2^-, \cdots \tilde{v}_n^-\right\}$$

$$= \left\{(\min_i \tilde{v}_{ij} \left| i = 1, 2, \cdots, m), j = 1, 2, \cdots, n\right.\right\}.$$

Considering that the elements $\tilde{v}_{ij}$ are normalized positive triangular fuzzy numbers and their ranges belong to the closed interval [0, 1], the positive ideal and negative ideal solutions can be defined as $\tilde{v}_j^+ = (1,1,1)$ and $\tilde{v}_j^- = (0, 0, 0), j = 1, 2, \cdots, n$ [28].

Step4: Calculate separation measures. The distance of each alternative from A^+ and A^- can be identified as follows:

$$d_i^+ = \frac{1}{n}\sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^+), i = 1, 2, \cdots, m$$

$$d_i^- = \frac{1}{n}\sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-), i = 1, 2, \cdots, m$$

Step 5: Calculate the similarities to ideal solution:

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}$$

Step 6: Rank preference order. Rank alternatives according to CC_i in descending order.

4. Assessment Measures Identification and Data Collection

In this paper, four dimensions are identified regarding to evaluate the performance of the supply chain collaborative technological innovation, including collaboration foundation, technology innovation, supply chain collaboration and cost of the collaboration. The specific criteria are shown in Table 2.

Table 2. Dimensions and Criteria of the Evaluating System

Objective	Dimensions	Criteria
Assessment of the performance of the supply chain collaborative technological innovation	Collaboration Foundation(A1)	The extent of cooperation(C_1)
		Compactness in supply chain (C_2)
		Matching degree regarding capacity (C_3)
		Technical and economic conditions (C_4)
		Strategy alliance(C_5)
	Technology Innovation(A2)	Innovation input (C_6)
		Innovation implementation (C_7)
		Innovation management (C_8)
		Innovation realization (C_9)
		Learning ability (C_{10})
	Supply Chain Collaboration(A3)	Collaboration arrangement (C_{11})
		Collaboration operations (C_{12})
		Collaboration incentive mechanism (C_{13})
		Knowledge exchange capacity (C_{14})
	Collaboration Cost (A4)	Communication cost (C_{15})
		Procurement cost (C_{16})
		Rework cost (C_{17})
		R& D cost (C_{18})
		Transportation cost (C_{19})

A questionnaire including the above nineteen criteria is designed to collect the related information and data from the companies in ten supply chains in China. All of the companies are manufacturers or supplier in automobile industry. Three raters are participated in each company to make an appropriate rating, and the selected items from all websites are rated with the widely used Little Scale, i.e., from a scale of 1 (being the worst) to 5 (meaning excellent) accordingly.

5. Solutions from Fuzzy AHP and TOPSIS Analysis

As mentioned in section 3, the important degrees of the above sub-criteria weights are given with linguistic terms, as shown in table 1, employed by four decision makers, as shown in Table 3.

Table 3. The Fuzzy Weights Given by Four Decision Makers

Criteria	DM_1	DM_2	DM_3	DM_4
C_1	M	L	M	H
C_2	VL	L	VL	L
C_3	M	L	L	L
C_4	H	VH	M	H
C_5	H	M	M	H
C_6	M	M	L	L
C_7	H	M	VH	M
C_8	M	L	H	L
C_9	H	VH	M	H

C_{10}	L	L	VL	L
C_{11}	H	M	M	L
C_{12}	H	M	L	M
C_{13}	VL	L	VL	VL
C_{14}	L	VL	L	M
C_{15}	L	VL	VL	L
C_{16}	M	L	L	M
C_{17}	M	L	VL	M
C_{18}	H	VH	H	M
C_{19}	L	VL	L	L

The original decision matrix is identified by the raters by observing the websites, and the normalized decision matrix is then derived from the original data as shown in Table 4.

The larger, the better type:

$$r_{ij} = \frac{\left[x_{ij} - \min\left\{ x_{ij} \right\} \right]}{\left[\max\left\{ x_{ij} \right\} - \min\left\{ x_{ij} \right\} \right]}$$

The smaller, the better type:

$$r_{ij} = \frac{\left[\max\left\{ x_{ij} \right\} - x_{ij} \right]}{\left[\max\left\{ x_{ij} \right\} - \min\left\{ x_{ij} \right\} \right]}$$

Table 4. Part of the Normalized Decision Matrix for TOPSIS Analysis

No.	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
SC_1	0.8	0.6	0.4	0.8	0.4	0.2	0.6	0.8	0.8	1	0.8	0.6
SC_2	0.8	0.6	0.6	1	0.6	0.2	0.4	0.6	0.6	0.6	0.8	0.6
SC_3	0.8	0.6	0.6	1	0.4	0.4	0.6	1	1	0.8	0.8	0.6
SC_4	0.8	0.4	0.6	0.8	0.6	0.2	0.2	0.6	0.6	0.6	0.8	0.4
SC_5	1	0.4	0.6	1	0.8	0.2	0.8	0.6	0.8	0.8	1	0.4
SC_6	0.8	0.8	0.4	1	0.6	0.4	0.6	0.6	0.8	0.6	0.8	0.8
SC_7	0.8	0.6	0.6	1	0.6	0.6	0.8	0.4	0.6	0.8	0.8	0.6
SC_8	0.8	0.4	0.6	0.8	0.4	0.2	0.6	0.6	0.8	0.6	0.8	0.4
SC_9	1	0.4	0.6	1	0.4	0.6	0.4	0.8	0.8	0.8	1	0.4
SC_{10}	1	0.4	0.4	0.8	0.4	0.2	0.6	0.6	0.6	0.6	1	0.4

Then the normalized decision matrix using Fuzzy linguistic variables shown in Table 5 can be identified by the Fuzzy membership function proposed in Section 3.2.

Table 5. Part of the Normalized Decision Matrix using Fuzzy Linguistic Variables

No.	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
SC_1	H	M	L	H	L	VL	M	H	H	VH	H	M
SC_2	H	M	M	VH	M	VL	L	M	M	M	H	M
SC_3	H	M	M	VH	L	L	M	VH	VH	H	H	M
SC_4	H	L	M	H	M	VL	VL	M	M	M	H	L
SC_5	VH	L	M	VH	H	VL	H	M	H	H	VH	L
SC_6	H	H	L	VH	M	L	M	M	H	M	H	H
SC_7	H	M	M	VH	M	M	H	L	M	H	H	M
SC_8	H	L	M	H	L	VL	M	M	H	M	H	L

SC_9	VH	L	M	VH	L	M	L	H	H	H	VH	L
SC_{10}	VH	L	L	H	L	VL	M	M	M	M	VH	L

The Fuzzy linguistic variable is then transformed into a Fuzzy triangular membership function as shown in Table 6, and then the resulting Fuzzy weighted decision matrix can be derived based on Table 8 and the weights identified before. The distance of each alternative from A^+ and A^-, as well as the similarities to an ideal solution (*CCi*), is obtained in Table 7.

Table 6. Part of the Fuzzy Decision Matrix

No.	C_1	C_2	C_3	C_4	C_5
SC_1	(0.55,0.70,0.85)	(0.55,0.70,0.85)	(0.55,0.70,0.85)	(0.55,0.70,0.85)	(0.75,0.90,1.00)
SC_2	(0.35,0.50,0.65)	(0.35,0.50,0.65)	(0.35,0.50,0.65)	(0.15,0.30,0.45)	(0.15,0.30,0.45)
SC_3	(0.15,0.30,0.45)	(0.35,0.50,0.65)	(0.35,0.50,0.65)	(0.35,0.50,0.65)	(0.35,0.50,0.65)
SC_4	(0.55,0.70,0.85)	(0.75,0.90,1.00)	(0.75,0.90,1.00)	(0.55,0.70,0.85)	(0.75,0.90,1.00)
SC_5	(0.15,0.30,0.45)	(0.35,0.50,0.65)	(0.15,0.30,0.45)	(0.35,0.50,0.65)	(0.55,0.70,0.85)
SC_6	(0.00,0.10,0.25)	(0.00,0.10,0.25)	(0.15,0.30,0.45)	(0.00,0.10,0.25)	(0.00,0.10,0.25)
SC_7	(0.35,0.50,0.65)	(0.15,0.30,0.45)	(0.35,0.50,0.65)	(0.00,0.10,0.25)	(0.55,0.70,0.85)
SC_8	(0.55,0.70,0.85)	(0.35,0.50,0.65)	(0.75,0.90,1.00)	(0.35,0.50,0.65)	(0.35,0.50,0.65)
SC_9	(0.55,0.70,0.85)	(0.35,0.50,0.65)	(0.75,0.90,1.00)	(0.35,0.50,0.65)	(0.55,0.70,0.85)
SC_{10}	(0.75,0.90,1.00)	(0.35,0.50,0.65)	(0.55,0.70,0.85)	(0.35,0.50,0.65)	(0.55,0.70,0.85)

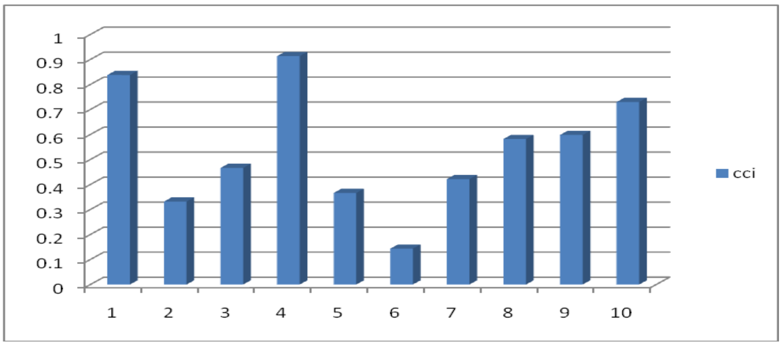
Table 7. The Distance of Each Alternative from A^+ and A^-

No.	d_i^+	d_i^-	CC_i
SC_1	0.045	0.234	0.83786768
SC_2	0.187	0.093	0.33171108
SC_3	0.149	0.130	0.46621846
SC_4	0.024	0.255	0.91356193
SC_5	0.177	0.102	0.36613627
SC_6	0.239	0.040	0.14337878
SC_7	0.162	0.118	0.42158423
SC_8	0.117	0.163	0.58181397
SC_9	0.112	0.167	0.59819928
SC_{10}	0.076	0.204	0.73002612

In order to see the result more clearly, the resulting Fuzzy TOPSIS analysis is shown in Figure 2.

The result of selected supply chains shows that most of the values of the similarities to an ideal solution (70% of the websites selected) are lower than 0.60. Put it into words, that is, most supply chains have a room for a significant improvement in terms of promoting their collaborative technological innovation.

Figure 2. Summary of the Assessment of the Performance of the Collaborative Technological Innovation



6. Conclusions and Suggestions for Future Research

This study is focused on comparing and evaluating the performance of the supply chain collaborative technological innovation in China. The objectives for this research are threefold: (1) to examine and evaluate the effectiveness of 10 supply chains in automobile industry in China; (2) to identify major issues and challenges for those companies in utilizing their supply chain management in promoting the technological innovation; and (3) to discuss and explore the potential managerial implications for future research.

The primary data for this research are collected through a comprehensive questionnaire. Fuzzy TOPSIS is employed to evaluate the current status and effectiveness of 10 selected supply chains in automobile industry. According to the criteria weights derived from this section earlier, the relative top three important measures to evaluate supply chain collaborative technological innovation are (1) Technical and economic conditions; (2) Innovation realization; and (3) R&D cost. As such, several important managerial implications are: (a) improve the technical and economic conditions for the supply chain companies; (b) improve the ability in terms of realizing the collaborative technological innovation; and (c) reduce the R&D cost of the technological innovation in the supply chain collaboration.

Based on the results of this research, our recommendations for improving supply chain companies in terms of enhancing their collaborative technological innovation performances are: (1) expanding the cooperative scope; (2) setting up collaboration incentive mechanism; (3) improving the technical and economic conditions; (4) reducing the R&D cost; and (5) improving the ability of realizing the collaborative technological innovation .

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