An Application of Fuzzy Delphi and Fuzzy AHP for Multi-criteria Evaluation on Bicycle Industry Supply Chains

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Abstract: - Under global saving energy and carbon wave and increasing incomes, the bicycle not only is a traditional transportation but also has become a tour and sport tool. Concerning the bicycle industry, the prior researches worked on analyzing bicycle tire suppliers and focused on the business strategy and cost analysis. Therefore, the purpose of this study is to identify critical factors related to the bicycle supplier selection. Primary criteria to evaluate supplier selection is obtained by the literatures survey and applying fuzzy Delphi method (FDM), and then fuzzy analytic hierarchy process (FAHP) is employed to calculate the weights of these criteria, so as to build the fuzzy multi-criteria model of bicycle supplier selection. The results indicate a greatest weight on the dimension of bicycle supplier selection, and four critical evaluation criteria related to bicycle supplier selection are delivery time, service quality, optimum price, and product quality.

Key-Words: - Bicycle Industry, Supply Chain, Analytic Hierarchy Process (AHP), Fuzzy Delphi Method (FDM), Fuzzy Analytic Hierarchy Process (FAHP).

1 Introduction

Facing the global saving energy and carbon wave and increasing incomes, the bicycle not only is a traditional transportation but also has become a tour and sport tool. For Taiwan and China, the bicycle industry is like a development paradigm industry. Therefore, it has become a new subject by how to prompt current position of bicycle industry and their supplier.

Actually, the bicycle has changed very little since the establishing form of a main structural design in the 1890s. In the bicycle industry chain, the components (i.e. brakes, pedals, tires, cranks and hubs) themselves have been upgraded considerably through a process of incremental innovation and service, but the way that the components operate and how they connect together to form a functional product has changed little [15]. Since then, the bicycle industry has combined a process within component suppliers to become the entire product architecture. Thus, it is very important to select the component suppliers because they must link together closely within the product connects and interacts with surrounding components in a limited number of ways and making the bicycle a modular product [15].

Concerning the bicycle industry, the prior researches worked on analyzing bicycle tire suppliers and focused on the business strategy and cost analysis. Today the bicycle industry sees component suppliers being an inside manufactured within a broader industry system with little or no reference or other manufacturing firms. It is a key success factor how the bicycle manufactory chooses a matched component supplier to support internal standard and customized manufacturing, what is mean for industry structure and supplier selection to influence the level of architectural and radical development of them. Beside, it is impossible to successfully produce low cost and high quality products without satisfactory vendors under competitive operating environment [35]. One of the most important decisions is to select a competent group of suppliers [35]. Thus, this paper purpose is to find out a more complete and concerned collection of explanatory variables and identify critical factors of bicycle supplier selection from the collections. In our study, we adopted a perspective of bicycle manufactory to explore the supplier selection criteria when the manufactory chose the tire suppliers.

In our research, the survey of studies is to identify critical factors related to the bicycle supplier selection, and the collection of variables are divided into four groups to serve as preliminary evaluation dimensions. Primary criteria to evaluate supplier selection is obtained by the literatures survey and applying FDM, and then FAHP is employed to calculate the weights of these criteria, so as to build the fuzzy multi-criteria model of bicycle supplier selection. The selection criteria include characteristics of delivery time, service quality, optimum price, and product quality. Hence, the aim of this paper are: (1) to identify bicycle manufactory to select and n practices based on the industry's opinion and literature reviews in supply chain, and (2) to built the actual selection criteria when manufactory makes decisions.

The questionnaire investigation with three stages is conducted in this study. At the first stage, according the literatures review, we design the instruments to explore and extract potential variables related to bicycle supplier selection. And, potential explanatory variables related to bicycle supplier are obtained from literature survey and collected to form the first-stage questionnaire. Then, at the second stage, the questionnaire investigation of explanatory variables is conducted by FDM. The variables with more concerns by experts' consensus serve as primary evaluation criteria in bicycle industry. To select the professionals with the experience from the bicycle industry, such as, the senior managers of Giant Inc. and Merida Inc., the section manage of Kenstone Inc., the assistant senior manager of Ming Cycle Inc., and the assistant president managers of Youn Live Inc. and Joy Move Inc. Inc. as the questionnaire subjects. At this stage, the questionnaire is designed in a fuzzy linguistic scale, and every expert rates the importance of individual criterion in the form of a triangular fuzzy number, and then they reach a consensus in determining the importance to serve as the primary evaluation criteria of bicycle industry. At the third stage, the statistic results are provided to these experts and pair-comparison of all criteria is made, thus the weight of individual criteria is calculated by FAHP. Hence, the fuzzy multi-criteria model of bicycle industry is established through the process of the experts' rating of the criteria.

The remainder of the paper is structured as follows. In Section 2, we discussed the literatures concerning our topic. Section 3 we describe our methodology including choosing the experts and characteristics, survey design, and the application of FDM and FAHP. In Section 4, we analyze empirical study. Finally, section 5 presents our final conclusions and suggestions.

2 Literature Review

2.1 Bicycle Industry

Under global saving energy and carbon wave and increasing incomes, the bicycle not only is a traditional transportation but also has become a tour and sport tool. Therefore, today, most people see the bicycle industry as one relatively new and stable high technology industry [11]. New niches have been opened, there are a variety and attractive of bicycle forms to satisfy the market needs.

In the bicycle industry, the component suppliers include the brakes, pedals, tires, cranks, hubs…etc. This industry is few characterized by some key dominant firms to support and control, likes the Shimano Inc. which is a famous firm in producing derailleur system. Most of component suppliers are the smaller players. And, the suppliers in the bicycle industry produce component parts for sale in three related markets, the market for original equipment manufacturers (OEM), the original design manufacturing (ODM), and own branding and manufacturing (OBM). The OEM manufactories must base on the terminal customers to select the component suppliers, and are usually characterized by component groups, a collection of many of the mechanical parts required to assemble a bicycle [22]. Like, the firm, Ideal Bike Inc., manufactured only and expanded into other components. The ODM manufactories need cooperate with the customer to choose the component suppliers, such as the Giant Inc. which design new bicycle with the component suppliers. And the OBM manufactories can select the component suppliers by himself through designing and manufacturing, like Giant Inc. and Merida Inc. which own the brand in the bicycle market.

Actually, to produce and fabricate one bicycle can mix and match many parts from many different manufacturers, in a word, the result is a bicycle that does not operate as smoothly as one equipped solely with parts from single manufacturer. Supply chains in this industry exhibit interesting structure and variation, but are not as so complex as the motor vehicle industries to prohibit measurement and comparison [31]. The component parts are easily understandable and evaluated by relevant consumer. Other variables mitigating the cost of variety and increasing quality and service, such as flexible production technology and degree of product modularity, are similar across firms, making the critical decision in choosing suppliers and managing supply chain [31]. Thus, Isely and Roelofs [22] posit one of the defining characteristics of the component industry is called "technical lock-in." The purpose of lock-in is the primary reason to expect a smoothly linking to different bicycle component supplier together [31]. Most important, lock-in exists in bicycle component suppliers because many of them are designed to work specifically, or at least work most efficiently, with matching components from the same manufacturer alike [22].

Although there are many famous bicycle companies in Taiwan, such as Giant Inc. and Merida Inc., and the Giant is one of the first companies attempting to build a global brand, the bicycle component market is similar to the primary market for the computer industry, while the related, which is characterized by a higher degree of competition [22]. Hence, component supplier selection not only plays an important role in bicycle industry chain due to increasing the quality and service but also is a critical in building and maintaining competition.

2.2 Relative Multi-Criteria of Supplier Selection

More business organizations pay attention to the evaluation and selection among alternative suppliers [2][8][14][33][35][36]. To manufactory, the selection and evaluation is one of the most critical activities by which to attempt to achieve positional competitive advantage. Today, from a managerial point of view, a lot set of supplier selection criteria have to be identified in any industry. Regarding the supplier selection criteria literatures, many researchers have addressed the supplier selection criteria in many industries [2][8][10][12][13][14][33][34][35][36].

The manufactory must usually trade-offs to select the supplier among the existing various criteria. In prior research, Dulmin and Mininno [13] consider the manufactory selection based on cost and supplier's ability to meet quality requirements and delivery schedule. Dickson [10] studied and analyzed the vendor selection systems and decisions, and posited the 23 evaluations and criteria to select the suppliers. Based on the Dickson's research [10], Weber et al. [35] analyzed and summarized the literatures of supplier choice, and addressed 11 criteria factors (quality, delivery, net price, geographical location, production facilities and capacity, technical capability, attitude, management and organization, packaging, operational controls, and repair service) to select vendor of just-in-time systems. In linking purchasing to corporate competitive strategy, Watts et al. [34] posited 8 criteria (process capability, product capability, operation capability, management capability, technology, quality, delivery, and cost) to select supplier. Swift [33] analyzed 21 instruments and extracted the items to 5 criteria factors (product, availability, dependability, experience, and price) to evaluate the supplier. Choi and Hartley [8] explored the supplier selection practices and extracted 26 instruments to 8 criteria factors (finances, consistency, reliability, relationship, technological capability, flexibility, price, and service) to choose the supplier cross the supply chain. Dowlatshahi [12] addressed 12 propositions criteria to evaluate and design the buyer-supplier relationship. For interested readers, all of the supplier selection criteria of the literatures were summarized in Table 1.

Table 1 Summary the supplier selection criteria literatures

Literatures	Supplier selection criteria factors
Dowlatshahi [12]	Strategic alliances with suppliers are the most crucial aspects of sourcing. Strategic alliances with suppliers require R&D investment by suppliers. The relationships between buyers and suppliers must be based on confidence and trust. Purchasing should reduce the number of suppliers in every part category. There must be a free yow and sharing of information between buyer and suppliers in part and product design stage. Buyers should have formal and organized plant visitations to suppliers' plants. Supplier selection, evaluation, and certification should be based on long-term strategic partnerships. Supplier training and meetings are at the core of buyer-supplier relationships. Buyer-supplier relationships require a clear delivery policy and minimal or no inspection. The support and encouragement of top management is imperative for developing strategic supplier relationships. The purchasing function should be on par with other functional areas of an organization before designer — buyer-supplier relationships can be established. The purchasing activities should be driven by the strategic values of a firm.

Cont. Table 1 Summary the supplier selection criteria literatures

Literatures	Supplier selection criteria factors
Choi and Hartley [8]	Finances, Consistency, Reliability, Relationship, Technological capability, Flexibility, Price, and Service.
Dickson [10]	Quality, Delivery, Performance history, Warranties and claim policies, Production facilities and capacity, Price, Technical capability, Financial position, Procedural compliance, Communication system, Reputation and position in industry, Desire for business, Management and organization, Operating controls, Repair service, Attitude, Impression, Packaging ability, Labor relations record, Geographical location, Amount of past business, Training aids, and Reciprocal arrangements.
Swift [33]	Product, Availability, Dependability, Experience, and Price
Watts et al. [34]	Process capability, Product capability, Operation capability, Management capability, Technology, Quality, Delivery, and Cost.
Weber et al. [35]	Quality, Delivery, Net price, Geographical location, Production facilities and capacity, Technical capability, Attitude, Management and organization, Packaging, Operational controls, and Repair service.

In sum, Choi and Hartley [8] consider supplier selection criteria differ among industries different layers levels of supply chain, direct suppliers, and indirect suppliers. Although supplier selection is an important strategic issue that has been explored by researchers [2][8][10][12][13][14][33][34][35][36] in many different topics and industries, the bicycle supplier selection criteria used by bicycle industry in direct and indirect supplier firms are less well understood. We doubt the bicycle supplier selection criteria may be less different with the prior researches. Therefore, we adopt the literatures and industry experiences regarding bicycle supplier selection criteria to our study.

2.3 FDM and FAHP

The role of decision-making has become more complicated today. And, the importance of decision-making model and experts' suggestion can be more emphasized and applied in various fields. Delphi method is a technique for structuring an effective group communication process by providing feedback of contributions of information and assessment of group judgments to enable individuals to re-evaluate their judgments. Since its development in the 1960s at Rand Corporation, Delphi method has been widely used in various fields. On the other hand, Delphi Method use crisp number and mean to become the evaluation criteria, these shortcomings might distort the experts' opinion.

In order to deal with the fuzziness of human participants' judgments in traditional Delphi method, Ishikawa et al. [23] posited fuzzy set theory proposed by Zadeh [37] into the Delphi method to improve time-consuming problems such as the convergence of experts' options presented by Hwang and Lin [21]. Fuzzy set theory is increasingly applied in many researches such as by Caballero et al. [4] and by Lin et al. [26]. Furthermore, because people are often uncertain in assigning the evaluation in crisp number, to overcome the problem, this study adopts the fuzzy linguistic scale.

The AHP methodology was a systematic method developed by Saaty [32]. It is a powerful and flexible method in solving complex, and multi-criteria decision problems. AHP method helps decision-makers' organize the critical components and aspects of a problem into a hierarchical structure similar to a family tree. By reducing complex decisions to a series of simple pair wise comparisons and rankings, then synthesizing the results, the AHP not only helps the analysts to arrive at the best decision, but also provides a clear rationale for the choices made. Cheng, Chen, and Chuang [7] employed the fourth party logistics using the concept of FAHP method to assist supply chain integration capabilities and information technology capabilities. Antón et al. [1] and Oddershede et al. [30] also employ the AHP method to solve their decision-making problems. Besides, due to the defect of traditional AHP application by Buckley [3] such as the characteristics of subjectiveness, fuzziness, and imprecision, many researches incorporated the Fuzzy theory into the AHP method to improve its application [6]. Concerning AHP in supplier selection literatures, Narasimhan [28], Nydick and Hill [29], and Barbarosoglu and Yazgac [2] posit the application of AHP to drive the imprecision problems in supplier selection. Hence, AHP approach has been widely applied in various relative fields to solve the decision-making problems with multiple hierarchies under the situation of uncertainty.

Beside, FAHP method is adopted increasingly by researchers. Hsieh et al. [19] employed FAHP method to solve the problem of planning and design tenders selection in public office building. And FAHP method was also applied in the research of Chen, Tzeng and Tang [5] to evaluate expatriate assignments. Thus, in this study, due to the fuzziness existed in the part of evaluation criteria, we decide to adopt the FDM to form the primary evaluation criteria of bicycle supplier selection, and employ the FAHP to calculate the weight of individual criteria so as to establish the Fuzzy Multi-criteria Model of bicycle supplier selection criteria.

3 Methodology and the Analysis of Results

3.1 The Survey

The survey methodology was used to gather data and build the bicycle supplier selection criteria. A pre-test was performed with three expert academics and two Ph.D. students on a questionnaire consisting of 28 items of the survey instrument to consider improvement in its content and appearance. The responses suggested only minor cosmetic changes, and no statements were removed. After minor changes were made, and further review by two other expert academics, the instrument was deemed ready to be sent to a large sample in order to gather data for testing our research model. A survey package, including a cover letter explaining the research objectives, the questionnaire, and a stamped, return-addressed envelope, was distributed to purchasing managers and practiced staffs of each participating firm. The respondents were asked to complete the all questionnaires and as well as on the overall appearance and content of the instruments.

3.2 Survey Instruments

Our overall survey instrument was based on both past literature published surveys [2][8][10][12][13][14][33][34][35][36] and the industrial experiences. To consider the bicycle supplier selection practices in Taiwan and China, we built on the supplier selection criteria of Choi and Hartley [8], Dowlatshahi [12], Swift [33], and Weber et al. [35]. We also adopted some criteria that had not been included in earlier studies but those that researchers had suggested as important [16][18]. We gathered and developed the instruments of supplier selection criteria from these different sources. All of instruments were distributed in 4 critical factors, including delivery time, service quality, optimum price, and product quality. All of the instruments were represented in Table 2.

Table 2 Bicycle supplier selection instruments

No.	Content of instruments
1	Quality yield
2	Product reliability
3	Capability for incremental improvements
4	Delivery time accuracy
5	Consistent meeting of delivery deadlines
6	Company's reputation for integrity
7	Brand well-know
8	Complain process and responsibility
9	Prompt response to requests
10	After-sales support
11	Offer the order information and progress in time
12	Ability to change production volumes rapidly
13	Ability to set up for new products at short notice
14	Response to the order changed quickly
15	Short delivery lead time
16	Financial conditions - assets and liabilities
17	Supplier representative's competence
18	Technical capability
19	Design capability
20	Offer of the lowest price
21	Suppliers absorb the transportation cost
22	Purchasing cost
23	Cost-reduction capability and feedback to price
24	Degree of Commutation smoothly
25	Establishing the long-tern relationship
26	Willingness to reveal financial records
27	Purchasing and delivery model
28	Information system connected and data exchanged capability

3.3 Choosing the Experts

This study focuses on the analysis of evaluation criteria of bicycle supplier selection. Thus, the experts chosen are the professionals in the fields related to our study with the experience of industrial and academic experts. Besides, they should be have at least 5 years of working experience with the bicycle industry experiences, and their positions are at least the rank of managers or assistant professors. In general, the numbers of expert are from three to fifteen [27]. This study is sent out to six industrial experts as the questionnaire subjects from the bicycle industry in Taiwan, such as the Giant, Merida, Kenstone, Ming Cycle, Youn Live, and Joy Move. All of the industrial experts were listed in Table 3.

3.4 Determining the Evaluation Criteria

The factor analysis and FDM are employed to explore the important criteria of bicycle supplier selection, and the questionnaire investigation with three stages is conducted in this study. The processes are listed as follows.

Table 3 Interview list of experts

Company	Title	Name
Giant	senior manager	Mr. Lai
Merida	senior manager	Mr. Chang
Kenstone	section manager	Mr. Chang
Ming Cycle	assistant senior manager	Mr. Fu
Youn Live	assistant president managers	Mr. Kuo
Joy Move	assistant president managers	Mr. Liu

3.5 Determining the Evaluation Criteria

The factor analysis and FDM are employed to explore the important criteria of bicycle supplier selection, and the questionnaire investigation with three stages is conducted in this study. The processes are listed as follows.

3.4.1 Building and Extracting the Evaluation Criteria

According our developing and designing instruments, the survey instrument was conducted to be sent to purchasing managers and practiced staffs of bicycle industry in Taiwan and China. We sent 40 surveys to our target population, and retrieved 28 effective responses. At the first stage survey, the response rate was 70%. Based on the collecting data, we used SPSS15 to analyze and extract the suitable instruments and factors. As a first step, we calculated the Kasier-Meyer-Olkin (KMO) value which is 0.815 and exceeded the recommended [24]. It meant that our instruments can be gone to next step to extract the factors used the factor analysis. At the second step, we identified the underlying construct factors among the 28 selection instruments using principal components analysis. And, factor analysis were interpreted based on a varimax rotation and were confirmed by eigenvalue that was greater than 1[38]. The extraction sum of squared was 72.54% in the 4 factors.

At the final step, we confirmed the reliability and validity of factors. To assess the reliability and validity of the constructs, Conbatch' α reliability and content validity were facilitated. All of the Conbatch' α values, ranging from a low of 0.757 to a high of 0.930 exceeded the recommended value of 0.70 [9]. And, the content validity of factors was greater than 0.70 in all case and met the target value [17]. Hence, our instruments were adopted to this study. Thus, we summarized the instruments results of mean, S.D, loadings, reliability, and validity in Table 4.

Table 4 Factor analysis of supplier selection criteria

Factors	Item No.	Mean	S.D.	Loadings	Conbatch' α	Content validity
Product quality	1	6.46	0.793	0.465	**0.930**	**0.964**
	2	6.29	0.763	0.694		
	3	6.07	0.940	0.741		
	6	5.54	0.881	0.738		
	7	5.50	0.962	0.786		
	12	5.75	1.005	0.845		
	13	5.79	0.833	0.819		
	16	5.71	1.013	0.831		
	17	4.93	0.858	0.724		
	18	5.96	0.838	0.729		
	19	5.89	0.832	0.608		
Delivery time	4	0.650	0.745	0.849	**0.757**	**0.870**
	14	6.07	0.858	0.700		
	15	5.79	1.067	0.849		
Optimum price	20	6.32	0.772	0.394	**0.848**	**0.921**
	21	5.79	0.957	0.773		
	22	6.07	0.900	0.830		
	23	6.18	0.772	0.781		
Service quality	5	6.04	0.962	0.597	**0.890**	**0.943**
	8	5.93	0.766	0.552		
	9	6.00	0.943	0.616		
	10	5.75	0.844	0.511		
	11	5.82	0.723	0.677		
	24	5.86	0.651	0.633		
	25	5.89	0.832	0.542		
	26	5.39	0.832	0.573		
	27	5.54	0.962	0.812		
	28	5.54	0.999	0.712		

3.4.2 Collecting the Experts' Opinions

At this stage, we designed the questionnaire in a 9-point fuzzy semantic differential scale of "absolutely important", "very important", "pretty important", "quite important", "no comment", "fairly unimportant", "quite unimportant", "very unimportant", and "absolutely unimportant". And, we asked the selected experts to answer instrument survey. The selected experts assigned a relative importance to every collected variable with respect to four dimensions of delivery time, service quality, optimum price, and product quality in order to confirm critical factors as the evaluation criteria of bicycle supplier selection.

3.4.3 Applying the FDM to Select Critical Evaluation Criteria

At the third stage, we used the FDM to select the critical evaluation criteria through the three step processes.

Step 1. Establishing the Triangular Fuzzy Function

All experts' estimations gathered by prior step are used to establish the triangular fuzzy function of each individual criterion through the process of FDM proposed by Ishikawa et al. [23]. The process of application is as follows:

(1) The elements of evaluation set are determined by expert questionnaires of bicycle supplier selection. Given a score of 100 and 0 to the traditional binary logics of "absolutely important" and "absolutely unimportant" respectively, the other elements of evaluation set are quantified objectively through the treatment of FDM.

(2) The questionnaires are designed for the elements of evaluation set other than "absolutely important" and "absolutely unimportant", and selected experts are invited to fill the quantitative score interval of every element in the evaluation set. The maximum of interval value is the experts' most optimistic cognition of the quantitative score for the element, and the minimum of interval value is the experts' most conservative cognition of the quantitative score for the element.

(3) Solving the minimum L, geometric mean M, and the maximum U of all experts' most optimistic cognition score for each individual element, along with the minimum l, geometric mean m, and the maximum u of all experts' most conservative cognition score for each individual element, respectively.

Triangular fuzzy number $A = (L, M, U)_{L\text{-}R}$ of all experts' most optimistic cognition for each individual element and triangular fuzzy number $a = (l, m, u)_{L\text{-}R}$ of all experts' most conservative cognition for each individual element are established respectively and illustrated in Figure 1.

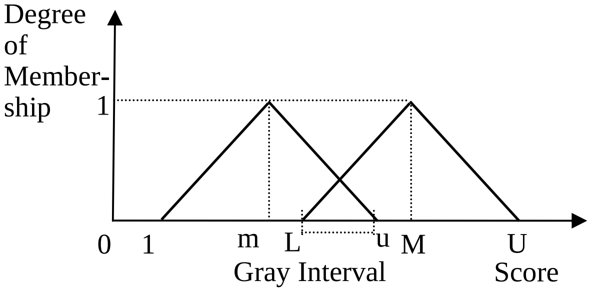

Fig.1. Triangular fuzzy number of the most optimistic cognition and the most conservative cognition

Step 2. Analyzing the Value of Triangular Fuzzy Function

To organize and analyze the expert questionnaires collected, triangular fuzzy function with respect to every potential variable is established as represented in Table 5.

Step 3. Selecting Critical Evaluation Criteria

When selecting the evaluation criteria, it is generally considered important if relative importance is greater than 80%. It is for gaining the criteria, hence, we calculate the median of gray interval for every potential variable and take 78 as the threshold to filter out those variables with the score of less than 78 on the median of gray interval. Thus, important criteria consistently agreed by selected experts are accordingly obtained.

According to the above filtering treatment, we obtained from the collected experts' questionnaires, there are 9 important criteria commonly agreed by 6 experts. And, totally 19 instrument items are eliminated. They are listed as follows.

(1) Product quality: No. 1: Quality yield and No. 2: Product reliability.

(2) Delivery time: No. 4: Delivery time accuracy and No. 14: Response to the order changed quickly.

(3) Optimum price: No. 20: Offer the lowest price

and No. 23: Cost-reduction capability and feedback to price.

(4) Service quality: No. 8: Complain process and responsibility, No. 11: Offer the order information and progress in time, and No. 24: Degree of Commutation smoothly.

Table 5 The triangular fuzzy function with respect to every potential variable

Factor Dimensions	Potential Variables No.	The Most Conservative Cognition (min, med, max)	Gray Interval	The Most Optimistic Cognition (min, med, max)	The Median of Gray Interval
Product quality	1	[57, 63.8885, 86]	[71,86]	[71, 92.5829, 100]	78.5
	2	[57, 63.8885, 86]	[71,86]	[71, 92.5829, 100]	78.5
	3	[43, 49.4877, 86]	[57,86]	[57, 92.5829, 100]	71.5
	6	[43, 49.4877, 86]	[57,86]	[57, 63.8885, 100]	71.5
	7	[43, 49.4877, 86]	[57,86]	[57, 63.8885, 100]	71.5
	12	[43, 49.4877, 86]	[57,86]	[57, 63.8885, 100]	71.5
	13	[43, 49.4877, 86]	[57,86]	[57, 78.2472, 100]	71.5
	16	[29, 34.9930, 86]	[43,86]	[43, 63.8885, 100	64.5
	17	[29, 34.9930, 71]	[43,71]	[43, 63.8885, 86]	57.0
	18	[43, 49.4877, 86]	[57,86]	[57, 78.2472, 100]	71.5
	19	[43, 49.4877, 86]	[57,86]	[57, 78.2472, 100]	71.5
Delivery time	4	[57, 63.8885, 86]	[71,86]	[71, 92.5829, 100]	78.5
	14	[57, 63.8885, 86]	[71,86]	[71, 92.5829, 100]	78.5
	15	[29, 34.9930, 86]	[43,86]	[43, 78.2472, 100	64.5
Optimum price	20	[57, 63.8885, 86]	[71,86]	[71, 92.5829, 100]	78.5
	21	[57, 49.4877, 86]	[57,86]	[57, 63.8885, 100]	71.5
	22	[43, 49.4877, 86]	[57,86]	[57, 92.5829, 100]	71.5
	23	[57, 63.8885, 86]	[71,86]	[71, 78.2472, 100]	78.5
Service quality	5	[43, 49.4877, 86]	[57,86]	[57, 92.5829, 100]	71.5
	8	[57, 63.8885, 86]	[71,86]	[71, 78.2472, 100]	78.5
	9	[43, 49.4877, 86]	[57,86]	[57, 92.5829, 100]	71.5
	10	[43, 49.4877, 86]	[57,86]	[57, 63.8885, 100]	71.5
	11	[57, 63.8885, 86]	[71,86]	[71, 78.2472, 100]	78.5
	24	[57, 63.8885, 86]	[71,86]	[71, 78.2472, 100]	78.5
	25	[43, 49.4877, 86]	[57,86]	[57, 78.2472, 100]	71.5
	26	[43, 49.4877, 86]	[57,86]	[57, 63.8885, 100]	71.5
	27	[29, 34.9930, 86]	[43,86]	[43, 78.2472, 100]	64.5
	28	[43, 49.4877, 86]	[57,86]	[57, 78.2472, 100]	71.5

Note: Gray zones are the sum of weight that exceeds 78 percent.

3.6 Applying the FAHP Method

We apply the FAHP to calculate the weights of individual dimension and individual criteria of bicycle supplier selection. The process is listed as follows.

Step 1. Building the Hierarchical Structure

First is to build the hierarchical structure. The hierarchical structure is described as follows. The goal is placed at the top of hierarchy, and the general criteria are placed at second level. The secondary sub-criteria with respect to each dimension are placed at third level.

In our case, the ultimate goal at the top level is “evaluation of bicycle supplier selection”, and there are four general criteria, “product quality”, “delivery time”, “optimum price”, and “service quality” at second level. As to each individual criterion, there are subordinate sub-criteria listed at third level. For example, five sub-criteria including (1) product quality: No. 1: quality yield and No. 2: product reliability, (2) delivery time: No. 4: delivery time accuracy and No. 14: response to the order changed quickly, (3) optimum price: No. 20: offer the lowest price and No. 23: cost-reduction capability and feedback to price, and (4) service quality: No. 8: complain process and responsibility, No. 11: offer the order information and progress in time, and No. 24: degree of Commutation smoothly. The detail of hierarchical structure is illustrated as Figure 2.

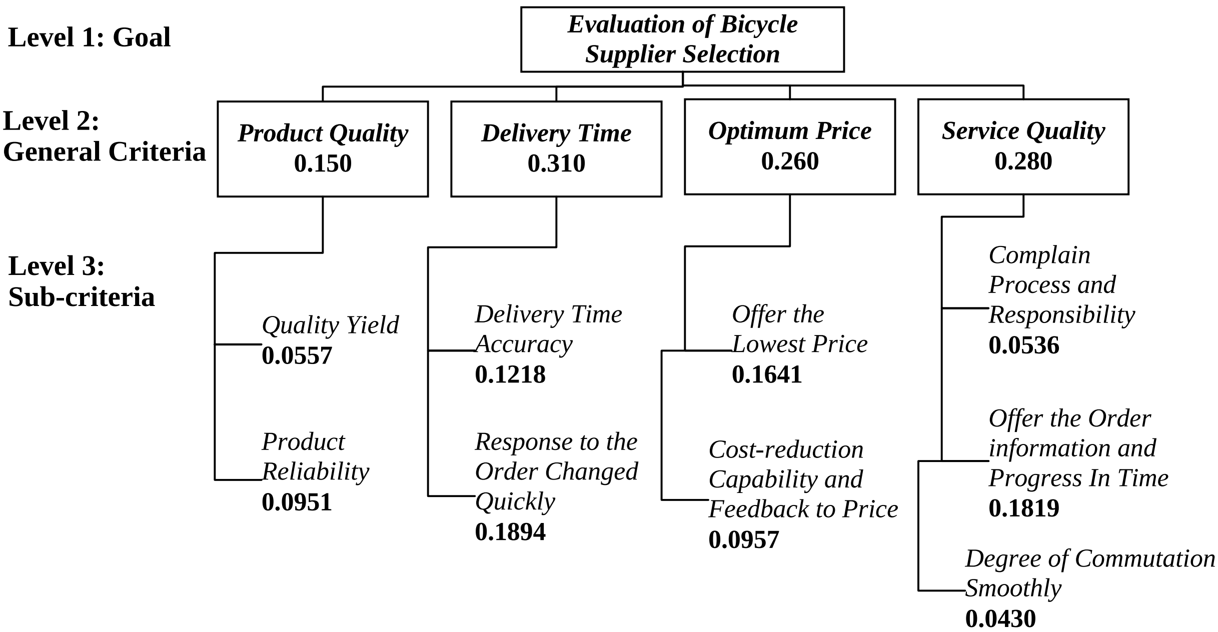

Fig. 2. Hierarchy structure for evaluation criteria of bicycle supplier selection

Step 2. Building the Pair-wise Comparison Matrix
By the second questionnaires gathered from selected experts, we obtain the relative importance of paired criteria factors at level n+1 under the evaluation of criteria at level n by individual experts' opinions, and the pair-wise comparison matrix is accordingly conducted.

Step 3. Calculating Triangular Fuzzy Numbers
Concerning the relative importance of each individual evaluation factor in pair-wise comparison matrix, triangular fuzzy number is calculated to integrate all experts' opinions. It can be used to present the fuzziness of all experts' opinions with respect to the relative importance of paired factors.

$$\tilde{\alpha}_{ij} = \left(\alpha_{ij}, \beta_{ij}, \delta_{ij}\right)_{L-R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where

$\tilde{\alpha}_{ij}$: Triangular fuzzy number

α_{ij} : The minimum of the j-th sub-criterion subordinated to the i-th general criterion

β_{ij} : The geometric mean of the j-th sub-criterion subordinated to the i-th general criterion

δ_{ij} : The maximum of the j-th sub-criterion subordinated to the i-th general criterion

L-R: Fuzzy interval of triangular fuzzy numbers

Step 4. Building the Fuzzy Positive Reciprocal Matrix
After triangular fuzzy numbers are solved to represent the fuzziness of experts' opinions, the fuzzy positive reciprocal matrix A can be further built.

$$A = \left[\tilde{\alpha}_{ij}\right]$$
$$\tilde{\alpha}_{ij} = \left[\alpha_{ij}, \beta_{ij}, \delta_{ij}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Step 5. Calculating the Fuzzy Weights of Fuzzy Positive Reciprocal Matrix
In our study, the method developed by Buckley [3] and improved by Hsu [20] is employed to calculate the fuzzy weights. This method is based on the experts' precise value and synthesizes the experts' opinions with the geometric mean instead of the fuzzy numbers input directly by experts. Thus, not only the consistency but also the concept of normalization is easily achieved. Through the following formulas, the positive reciprocal geometric

mean Z_i of triangular fuzzy numbers and the fuzzy weight $\overline{W_i}$ can be obtained.

$$Z_i = [\tilde{\alpha}_{i1} \otimes ... \otimes \tilde{\alpha}_{in}]^{1/n}, \forall_i$$
$$\overline{W_i} = Z_i \otimes (Z_1 \oplus ... \oplus Z_n)^{-1} \quad (3)$$
$$\tilde{\alpha}_1 \otimes \tilde{\alpha}_2 \cong (\alpha_1 \times \alpha_2, \beta_1 \times \beta_2, \delta_1 \times \delta_2) \quad (4)$$
$$\tilde{\alpha}_1 \oplus \tilde{\alpha}_2 \cong (\alpha_1 + \alpha_2, \beta_1 + \beta_2, \delta_1 + \delta_2) \quad (5)$$
$$Z_1^{-1} = (\delta_1^{-1}, \beta_1^{-1}, \alpha_1^{-1})_{L-R} \quad (6)$$
$$\tilde{\alpha}_1^{\frac{1}{n}} = \left(\alpha_1^{\frac{1}{n}}, \beta_1^{\frac{1}{n}}, \delta_1^{\frac{1}{n}} \right) \quad (7)$$

Step 6. Defuzzification
Since the weights of all evaluation criteria are fuzzy values, it is necessary to compute a non-fuzzy value by the process of defuzzification. In our study, the Centroid method is employed to defuzzy because of two reasons: (1) the Centroid method is widely used in relative literatures such as Klir's and Yuan's [25], and (2) the solution can be figured out quite quickly. Through the following formulas, the defuzzified weight W_i can be obtained.

$$W_i = \frac{W_{\alpha i} + W_{\beta i} + W_{\delta i}}{3} \quad (8)$$

$W_{\alpha i}$: The right-end value of the fuzzy weight

$W_{\beta i}$: The value of the fuzzy weight with the degree of membership as 1

$W_{\delta i}$: The left-end value of the fuzzy weight

Step 7. Normalization
In order to effectively compare the relative importance among evaluation criteria, we normalize the obtained weights using the following formula.

$$NW_i = \frac{W_i}{\sum_{i=1}^{i=n} W_i} \quad (9)$$

Step 8. Synthesis of Hierarchy
The weight of each individual evaluation criterion at bottom level can be obtained by the implementation of step 1 through step 7. And the weights of criteria or sub-criteria at upper level are the synthesis of the weights of their subordinations applying the following formula. Hence, the weights of all criteria at every level of hierarchy can be obtained.

$$NW_k = NW_i \times NW_{ip} \quad (10)$$

4 Empirical Study

In this research, we apply the FAHP method to calculate the relative importance of criteria and sub-criteria on the evaluation of bicycle supplier selection. The weights of all criteria and sub-criteria along with the ranks of evaluation criteria at the bottom level are calculated and displayed in Figure 2. Where the obtained weights are the decimals below each individual criterion and sub-criterion, and the rank of every evaluation criterion at the bottom level is the number in parentheses below the weight. According the developing criteria model and to illustrate the fuzzy group MCDM approach, we present the tire supplier selection problem faced by a Taiwan's and China's to the supplier criteria model. We gathered relative information of three tire suppliers (i.e. Kenda Inc., Cheng Shin Rubber Inc., and Duro Inc.) which set up the factories in Taiwan and China and focused on producing the tire to support bicycle manufactory. To maintain its dominant position and competitive in Taiwan's and China's tire market, the tire supplier needed to set up factories to near the bicycle manufactory and upgraded its services and quality to customer. Of course, to match the increasing demand for bicycle and facing the competitive market, the bicycle manufactory has to make rational decisions about which type of tire to purchase for its fleet. Concerning the developing bicycle supplier selection criteria, we displayed the case information in Table 6.

Three tire supplier, including Kenda (Case A), Cheng Shin Rubber (Case B), and Duro (Case C), are to be evaluated with respect to 9 sub-criteria, which are grouped into three categories (criteria). Six decision makers are involved in the evaluation process. The sub-criteria measures involve both quantitative and qualitative assessments, for which numerical data and triangular fuzzy numbers are used, respectively. Since the qualitative assessments are to be subjectively made by the six decision makers and the 9 sub-criteria are independent of each other, this tire supplier selection problem can be solved by the fuzzy group MCDM approach developed. We briefly discuss the evaluation criteria within each case below.

First, we asked the six decision makers to fill the questionnaires by case through considering the problem information. And, we confirmed and summarized the six decision makers' opinions to conduce the performance ratings by case. The performance ratings of three tire suppliers are shown in Table 7.

Second, after gathering the performance ratings of three tire suppliers, we led the numerical data to our developing bicycle supplier selection model, such as Fig. 2, hierarchy structure for evaluation criteria of bicycle supplier selection. And, we conduced the fuzzy weight comprehensive evaluation each case. The overall index evaluations [L, M, U] are [0.285, 0.296, 0.304] in case A, [0.096, 0.097, 0.096] in case B, and [0.063, 0.052,0.046] in case C. All case results are represented in Table 8.

Finally, with the fuzzy group weight vector in the last column of Table 8, the crisp preference value for each case type can be generated. Table 9 shows the result and the corresponding ranking order. And, the case A is the first priority to be selected to become the tire supplier by the bicycle manufactory.

Table 6 Evaluation criteria for the tire supplier selection problem

Criteria Items		Problem Information		
Criteria	Sub-criteria	A Case	B Case	C Case
Product quality	Quality yield	High	Median	Low
	Product reliability	High-Rank 1	High- Rank 2	High- Rank 3
Delivery Time	Delivery time accuracy	High	Median	Low
	Response to the order changed quickly	High, response < 3 days	Median, response between 3 and 5 days	Low, response < 7 days
Optimum Price	Offer the lowest price	Low , manufactory has low price bargaining	Median, manufactory has price bargaining	High, manufactory has high price bargaining
	Cost-reduction capability and feedback to price	Less	Less	Less
Service Quality	Complain process and responsibility	Median, structured organization leads partial request can't be satisfy.	High, supplier can support the request fully.	Low, supplier can't support the request fully.
	Offer the order information and progress in time	High	High	Low
	Degree of commutation smoothly	Response < 7 days, but don't report the quality information.	Response about 7 days, and report the quality information.	Response about 10 days, and usually accept the complaints.

Table 7 Performance ratings of three tire suppliers

Criteria and sub-criteria	Case A			Case B			Case C		
Product quality	[L	M	U]	[L	M	U]	[L	M	U]
Quality yield	[0.79	0.80	0.81]	[0.14	0.13	0.12]	[0.07	0.07	0.07]
Product reliability	[0.76	0.79	0.81]	[0.17	0.16	0.15]	[0.07	0.06	0.05]
Delivery Time									
Delivery time accuracy	[0.72	0.76	0.80]	[0.20	0.17	0.14]	[0.08	0.07	0.06]
Response to the order changed quickly	[0.74	0.74	0.74]	[0.20	0.20	0.20]	[0.06	0.06	0.06]
Optimum Price									
Offer the lowest price	[0.32	0.36	0.40]	[0.27	0.30	0.33]	[0.41	0.33	0.27]
Cost-reduction capability and feedback to price	[0.63	0.65	0.67]	[0.21	0.22	0.22]	[0.16	0.13	0.11]
Service Quality									
Complain process and responsibility	[0.55	0.54	0.53]	[0.28	0.27	0.27]	[0.17	0.18	0.20]
Offer the order information and progress in time	[0.70	0.71	0.71]	[0.23	0.24	0.24]	[0.05	0.05	0.06]
Degree of commutation smoothly	[0.48	0.53	0.56]	[0.32	0.35	0.38]	[0.20	0.11	0.06]

Table 8 Fuzzy weight comprehensive evaluation

Criteria and sub-criteria	Case A			Case B			Case C		
Product quality	[L	M	U]	[L	M	U]	[L	M	U]
Quality yield	[0.292	0.296	0.300]	[0.051	0.048	0.044]	[0.026	0.026	0.026]
Product reliability	[0.479	0.498	0.510]	[0.107	0.101	0.095]	[0.044	0.038	0.032]
Delivery Time									
Delivery time accuracy	[0.281	0.296	0.312]	[0.078	0.066	0.055]	[0.031	0.027	0.023]
Response to the order changed quickly	[0.451	0.451	0.451]	[0.122	0.122	0.122]	[0.037	0.037	0.037]
Optimum Price									
Offer the lowest price	[0.202	0.227	0.252]	[0.170	0.189	0.208]	[0.258	0.208	0.170]
Cost-reduction capability and feedback to price	[0.233	0.241	0.248]	[0.078	0.081	0.081]	[0.059	0.048	0.041]
Service Quality									
Complain process and responsibility	[0.132	0.103	0.080]	[0.067	0.051	0.041]	[0.041	0.034	0.030]
Offer the order information and progress in time	[0.406	0.469	0.518]	[0.133	0.158	0.175]	[0.029	0.033	0.044]
Degree of commutation smoothly	[0.091	0.080	0.067]	[0.061	0.053	0.046]	[0.038	0.017	0.007]
Overall	[0.285	0.296	0.304]	[0.096	0.097	0.096]	[0.063	0.052	0.046]

Table 9 Preference value and ranking of three tire suppliers types

Supplier types	Comprehensive evaluation			Crisp preference value	Rank
Case A	0.285	0.296	0.304	0.295	**1**
Case B	0.096	0.097	0.096	0.096	**2**
Case C	0.063	0.052	0.046	0.054	**3**

5 Conclusions and Suggestions

To evaluate decision alternatives in a new and complex problem setting often involves subjective evaluation by a group of decision makers with respect to a set of qualitative criteria. The aim of the study is to offer an evaluation framework of bicycle supplier built by the key criteria in the complex business environment. To address this decision problem, we have presented a FDM and FAHP to develop the criteria model in a fuzzy group MCDM approach with an effective to extend the concept of the degree of optimality. In the result, we find that there are night sub-criteria in the four dimensions of bicycle supplier selection criteria.

In our empirical study, we approve the four dimensions of delivery time, service quality, optimum price, and product quality are the critical criteria to choose the bicycle component suppliers. However, the results indicate that there are different weight criteria between the industrial experiences and our results. Concerning the Taiwan's and China's bicycle manufactories, they always considered the "price" is the most important criterion dimension under cost in the past. Actually, the results show that the priority weight is delivery time, service quality, optimum price, and product quality. It means that the component supplier is no longer a price oriented in bicycle industry chain. The bicycle manufactory will firstly judge the delivery time accuracy and response to the order changed quickly with respect to the criterion of delivery time. Under the conditions, next, they would consider the dimension of optimum price. Thus, the component suppliers should be attempted to improve the service of delivery time to meet the customer's request.

This study contributes to extract critical factors related to more complete dimensions rather than only cost ones on the selection of bicycle component supplier and to estimate the relative importance of these factors in the industrial experts' views. It can be used to facilitate the decision-making process of evaluation of bicycle component supplier selection. Our results can be referred and extended in the future to develop more in-depth researches. Many fuzzy multi-attribute decision-making methods, like fuzzy DEA, fuzzy TOPSIS, and fuzzy ANP, can be used to build different evaluation models and then their results can be analyzed and compared.

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