Fuzzy AHP for supplier selection: a case study in an electronic component manufacturer

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การคัดเลือกผู้จำหน่ายส่งผลกระทบสำคัญอย่างมากต่อประสิทธิภาพการดำเนินงานเครือข่ายห่วงโซ่อุปทานทั้งระบบ บริษัทกรณีศึกษาเป็นผู้ผลิตถาดบรรจุซิมการ์ดขนาดนาโน โดยการนำสี่วัสดุหลักมาผ่านกระบวนการจนกลายเป็นสี่ชิ้นส่วนสำคัญ คือ พลาสติก นิกเกิล ฟอสเฟอร์บรอนซ์ และสแตนเลส อย่างไรก็ตามบริษัทกรณีศึกษาต้องเผชิญกับ การเสียค่าปรับ และปริมาณการสั่งซื้อที่ลดจำนวนลง เนื่องมาจากปัญหาด้านคุณภาพของวัสดุ แม้ว่าจากบันทึกการประเมินของบริษัทกรณีศึกษาจะแสดงให้เห็นถึงความสามารถในการเลือกผู้จำหน่ายที่เหมาะสม แต่ราคากลับกลายเป็นปัจจัยหลักในการจัดลำดับผู้เสนอขาย อันนำไปสู่ความเสี่ยงที่เพิ่มมากขึ้นในบริบทต่างๆ ได้แก่ การเสียค่าปรับ การแก้ไขงาน และการลดจำนวนปริมาณการสั่งซื้อ นอกจากนี้ บันทึกการประเมินซึ่งถูกประเมินโดยฝ่ายจัดซื้อ อคติ และความชอบส่วนบุคคลมีความเป็นไปได้ที่จะส่งผลต่อการตัดสินใจ วิทยานิพนธ์ฉบับนี้นำเสนอกระบวนการวิเคราะห์ตามลำดับขั้นแบบฟัซซี่สำหรับการคัดเลือกผู้จำหน่ายโดยการเก็บรวบรวมข้อมูลจากสองฝ่าย ฝ่ายจัดซื้อจัดจ้างและวิศวกรรม และฝ่ายผู้จ้างผลิต เพื่อแก้ไขปัญหาเชิงคุณภาพ และเชิงปริมาณ ในองค์ประกอบต่างๆ ได้แก่ ความไม่แน่นอน และความคลุมเครือด้านภาษา โดยอ้างอิงจากสถานการณ์ในบริษัทกรณีศึกษาในสามส่วน ส่วนแรก เกณฑ์หลักและเกณฑ์รองจะถูกคัดเลือกโดยเชื่อมโยงกับผู้มีอำนาจในการตัดสินใจ ส่วนถัดมาคือการใช้กระบวนการวิเคราะห์ตามลำดับขั้นแบบฟัซซี่ในวัสดุแต่ละชนิดจากแต่ละผู้จำหน่าย และส่วนสุดท้ายคือการประยุกต์ใช้การคิดวิเคราะห์ความไวเพื่อสังเกตความเปลี่ยนแปลงในการตัดสินใจเมื่อรูปแบบพารามิเตอร์เปลี่ยนไป เช่น ความคงที่ด้านคุณภาพ ความล่าช้าในการจัดส่ง ฯลฯ รูปแบบที่นำเสนอสามารถให้ข้อมูลที่ดีขึ้น และได้คำตอบเพื่อให้ผู้มีอำนาจในการตัดสินใจของบริษัทกรณีศึกษาสามารถแยกแยะความสำคัญของเกณฑ์หลักและรอง เพื่อคัดเลือกผู้จำหน่ายวัสดุที่เหมาะสมที่สุดได้อย่างมีประสิทธิผล

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Supplier selection has become an essential effect on the entire electronic supply chain network on performance. The case study company produces a nano sim-card connector which four primary raw materials are processed into four primary parts (Plastic, Nickel, Phosphor bronze, and Stainless steel). Nevertheless, the case study company faces a penalty and order reduction because of the quality issue. Although an appraisal record from the case study company is able to select a proper raw material supplier, the cost becomes the priority when the candidate suppliers are categorized as the same level, leading to increasing potential risks, e.g., a penalty, rework in OEM, and order reduction. Additionally, the appraisal record is measured by the procurement team that the probability bias and personal preference tend to affect the final decision. This thesis proposes a Fuzzy Analytic Hierarchy Process (Fuzzy AHP) model for raw material supplier selection by collecting data from two departments (Procurement and Engineering) and clients to address qualitative and quantitative elements, uncertainty, and linguistic vagueness based on the case study company scenario in three parts. First, the main criteria and sub-criteria are selected by related decision makers. Second, the Fuzzy AHP is proposed to identify scores for each raw material supplier. Then, the sensitivity analysis is applied to observe how the decision changes when the model parameters, e.g., the quality consistency, delivery delays, etc., change. The proposed model can offer better information and solutions for the DM in the case study company to differentiate the crucial main criteria and sub-criteria and select the suitable raw material suppliers effectively.

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Chapter 1 Introduction

1.1. Research background

In the global competition, supply chain network has become more complex than before, indicating that organizations have spent more time on identifying and selecting a suitable supply source in their supply chain to achieve high efficiency and effectiveness. Chan et al. (2008) explain that the boundaries between businesses have diminished which manufacturers have an opportunity to seek their supply sources globally. This explains that the entire supply chain, from the upstream to the downstream, is connected closely. Ting and Cho (2008) and Wetzstein et al. (2016) point out that in the past decades, gaining global competitiveness has become essential, explaining that manufacturers are able to supply high quality products at reasonable prices. Also, Paramaporn (2020) indicates that with an appropriate supplier selection, a company is able to dwindle negative risks to have better supply chain performance.

Recently, the environmental awareness has risen. The entire supply chain has considered those environmental aspects in their operation strategy (Hao et al., 2018; Gupta et al., 2019; Gao et al., 2020). Notably, in the smartphone industry, most of the recognizable brands have already been involved in their entire supply chain to be a green supply chain. Moreover, in recent years, organizations have relied on suppliers more than before, which indicates that the frequency of poor decision-making in supplier selection will affect the entire framework of supply chain performance. This forces the upstream supply chain to be crucial in selecting an appropriate supplier and providing high-quality products. Thus, supplier selection has become significant for manufacturers to spend time considering their strategic processes.

In this thesis, the objective of this research is to identify the suitable raw material supplier in supplier selection in the upstream smartphone supply chain, which can be qualified by the manufacturer's decision criteria in the nano sim-card connector. Indeed, the manufacturer needs to consider tangible and intangible elements to convert into numbers. Fuzzy Analytic Hierarchy Process (Fuzzy AHP) methodology can solve qualitative and quantitative criteria; also, triangular fuzzy numbers can deal with linguistics vagueness and personal preference. The first part of this research is to evaluate five main criteria and twelve sub-criteria selected by the department of engineering and procurement. The second part presents the suitable raw material supplier selection in four primary materials that involve the weight of all criteria from the first part and linguistic vagueness from respondents including clients to compute and rank raw material suppliers. Sensitivity analysis is the third part of adjusting the weight to explore whether to be a new raw material supplier in different scenarios. The result of this study offers the data on the structure of the Fuzzy Analytic Hierarchy Process, which in turn will provide a different aspect in supplier selection environment or sustainable development guideline in the manufacturer's aspect in the electronic industry.

The main contribution of this thesis explores a new perspective that involves two departments, engineering and procurement, and clients to identify and select the suitable raw material suppliers in the nano sim-card connector in the smartphone supply chain instead of a single source or department. Besides, personal preference and linguistic vagueness can be addressed by the fuzzy set theory that provides more accurate data to evaluate and select the appropriate raw material supplier. The new supplier selection not only provides better information to select a raw material supplier but also reduces the potential risks (e.g., components defect rate, a penalty from clients, and order reduction) in the case study company.

This thesis is organized as follows. In the next section, the literature review explores the relevant study for this research, including an overview of the AHP and Fuzzy AHP methodology in supplier selection. This chapter also involves the related topic with AHP and Fuzzy AHP methodology; meanwhile, investigating the current situation for the case study company in nano sim-card connector and four primary materials (Plastic, Nickle, Phosphor Bronze, and Stainless Steel) are utilized in this research. In section 3, the research method, the main and sub-criteria are described. In section 4, the research result by Fuzzy AHP is provided, discussed, and analyzed. In section 5, the result from Sensitivity analysis is provided and analyzed. Ultimately, section 6 provides the conclusion, limitation, and suggestion for further research.

1.2. Company Background

As a case study in China, an electronic company, named A, has been manufacturing hardware for its clients from different industries such as smartphones and automobiles. The company produces a variety of components in Figure 1 to 3 To be specific, since the first smartphone was launched in the global market, the volume of smartphones has reached 1.37 billion units in 2019 (Statista, 2020). This points out that in the smartphone market, the competition has been in full swing. Therefore, smartphone companies should have focused on both hardware and software to maintain customer loyalty and appeal to potential customers. Notably, the hardware parts are necessary to be monitored because the software is established on the hardware parts that have a high possibility to affect the smartphone companies' reputation, market share, and even the smartphone supply chain.

Figure 1 Semi-finished goods

Figure 2 Micro Type B (JAE, 2020)

Figure 3 Nano sim-card connector

Furthermore, as the first supplier to produce nano sim-card connectors for smartphone companies, and only a few electronic companies are able to produce a number of connectors to fulfill orders per year, the case study company covers the large share of the market in premium smartphones in three android smartphone companies in Asia. In addition, in Figure 4, the nano sim card connector is produced on a small-scale, which is in millimeter, and assembled into different material parts such as Plastic, Nickle, Copper, and other materials. Thus, the component, the nano sim-card connector from the case study company, has played an essential role that not only produces the stable quality of components to receive reception from the telecom carriers but also affects the companies' reputation and profitability.

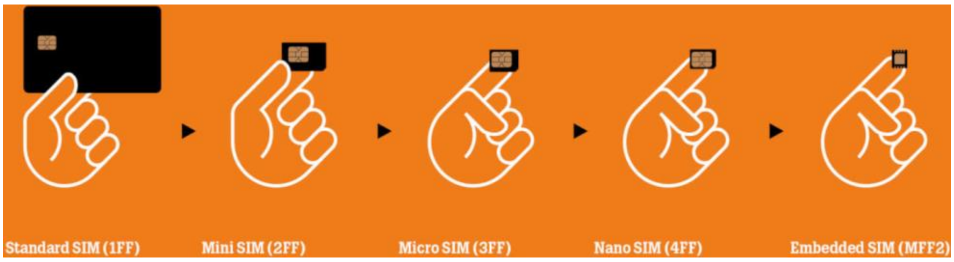


Figure 4 Evolution of Sim card (TELE2, 2019)

1.3. Product and process overview

The nano sim-card component produced by a case study company is included four primary materials: Plastic, Nickel, Phosphor bronze, and Stainless steel. In the smartphone supply chain in Figure 5, from the manufacturing component to the end customers can be considered as an internal supply chain that is relative. Accurately, on the one hand, before manufacturing the nano sim-card connector, the case study company laboratory would evaluate a variety of scenarios on how users utilize and what temperature and humidity are; collecting data that clients provide is the other information to improve the design of the connector. By integrating data from the lab and clients, the quality nano sim-card component can be improved in term of

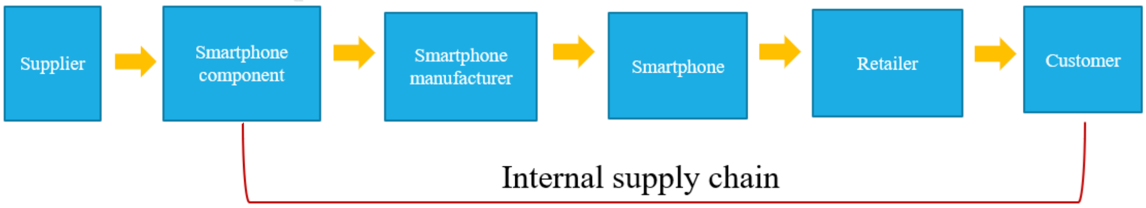


Figure 5 The supply chain of the smartphone

life expectancy and enhanced its obdurability. For instance, in Figure 6, the pin detector, marked with the red circle, used to be produced individually. Nevertheless, a report from the clients showed that the variance was high so that elastic fatigue was achieved rapidly. Hence, after receiving the data, the production process was redesigned to involve the pin detector in the main body to be molded in one. This brought an advantage that the variance dwindled, and the times of insertion/withdrawal were improved. On the other hand, once one of the components is detected an issue in original equipment manufacturing (OEM), the assembly line will be suspended until the issues are solved. In this situation, the whole internal supply chain performance would be affected. For instance, when one of the components has a high defect rate, this leads to a severe issue so that the smartphone supply is not able to fulfill the demands of the end customers. Due to the technical issue in production, the delivery delay of smartphones causes order reduction and directly affects the order of components. Hence, smartphone components can be defined as one of the essential roles in the smartphone supply chain.

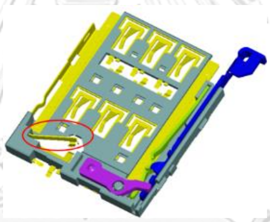
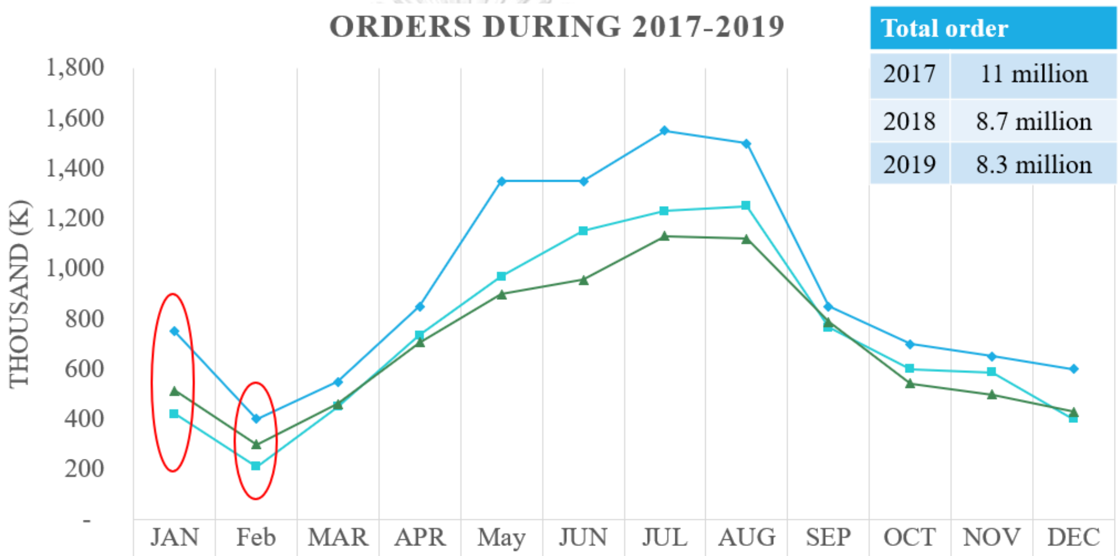


Figure 6 The pin of nano sim-card connector

1.4. Problem Statement

As the entire smartphone supply chain, if upstream of the supply chain occurs in some situations (e.g., insufficient capacity, high defect rate, and raw material delays), it would have negative impact on the downstream supply chain that a final product would be postponed. In addition, the revenue and reputation would directly affect the performance of the case study company. Due to the high competition in the smartphone market, many smartphone companies debut a new model every year in order to achieve more market share.

The case study company, which is in the upstream supply chain, provides approximately ten million nano sim-card connectors, assembled into a flagship handset, to its client per year. In Figure 7, the case study company received roughly 11 million orders in 2017, 8.7 million orders in 2018, and 8.3 million in 2019. The orders were reduced in 2018 because the issue has occurred in December 2017. In December 2017, the case study company received the issue from clients that the nano sim card connector could not weld on the printed circuit board (PCB)



	JAN	Feb	MAR	APR	May	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2017	750	400	550	850	1,350	1,350	1,550	1,500	850	700	650	600
2018	420	210	450	735	969	1,150	1,230	1,250	765	600	586	400
2019	513	300	460	705	899	956	1,130	1,120	788	543	499	430

Figure 7 The order during 2017 - 2019

because of flatness in Figure 8. During the time in Table 1, 1,423 out of ten thousand pieces of nano sim-card connectors were detected in the same situation. This issue was eventually identified that the case study company switched the raw material supplier in Stainless steel in order to reduce the cost and improve the profitability.

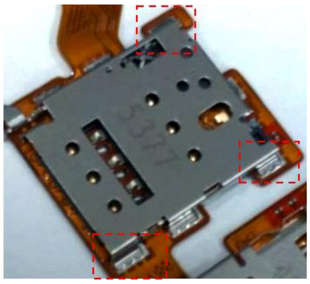


Figure 8 Issue of connector

Table 1 Numbers of defective connector

Numbers of connectors that the client used	**Defect rate = around 10%**
10K	1,423pcs

Indeed, the case study company did employ the appraisal record for supplier survey to categorize in different levels in Appendix I to select a raw material supplier. However, only five criteria are identified whether a raw material supplier is qualified. Taking one of four primary materials, Stainless steel, in the nano sim-card connector as an example in Table 2, three stainless-steel suppliers are categorized as the same level, B. To be specific, compared to supplier 1 and 3, the supplier 3 still achieves 90 to 95 percent of quality which shows that supplier 3 is still a qualified supplier. Also, the supplier survey was only scored by the procurement team, so that the information might be inaccurate to select the suitable supplier. Moreover, due to the contract, the case study must reduce two percent of the cost to clients for five quarters. In order to maintain or improve the profitability to be around thirty percent, the procurement team first considerably reduced the cost of the raw material. Integrating all the factors, the procurement team in the case study company decided to switch the stainless-steel supplier from supplier 1 to supplier 3 in order to decrease ten percent of material cost in November 2017. This should maintain profitability; even the case study company reduces the total ten percent of the connector's price to its client. In contrast, the flatness issue happened, which had brought an adverse effect so that the case study company neither received more orders nor brought profit eventually. Also, this issue caused a negative impact on the further corporation with the client. First, the case study company lost the profit and paid the penalty of approximately ten thousand US dollars to its client. Additionally, the further influence was that 200 thousand connectors, produced in the same period and lasered the same code, returned to the case study company. Finally, the red frame in January and February in 2018 in Figure 7 showed that its clients purchased more orders from the second supplier until the connector was certificated by clients again. After the issue occurred in December 2017, the case study company switched back to the supplier 1, and a similar issue did not occur again.

Table 2 Current classification of three raw material suppliers in Stainless steel

Supplier	Quality	Price	Delivery	Customer	Response	Total score	Level
1	30	10	20	8	5	73	B
2	25	15	20	5	5	70	B
3	25	20	15	5	5	70	B

Furthermore, the nano sim-card connector is assembled into four primary materials, which explains that each part is produced in millimeters and less than one gram in Table 3. Under this condition, although existing technology is able to monitor and improve the connector's manufacturing process, the primary materials come from different raw material suppliers. This explains that the raw materials they produce are based on their internal standard operating procedure (SOP). Undeniably, most of the raw material suppliers are certificated by an international standard such as ISO and IECQ. Nevertheless, the difference between each raw material supplier is their manufacturing process directly affecting the quality of raw materials.

Table 3 The current weight of each material in the nano sim-card connector

Name of material	Weight (g)
Nickel	0.66
Stainless steel	0.78
Phosphor bronze	0.64
Plastic	0.86

According to those conditions, technology has the possibility to deal with it even though the case study company switched the raw material supplier in Stainless steel that provided the lower quality material. However, concerning the capital expenditure and profitability, over-investing in technology would not be the first alternative, for it might not be cost-effective to bring benefit to the case study company. Hence, based on existing technology in the case study company, selecting the suitable raw material supplier by utilizing Fuzzy AHP is the primary option for creating a win-win for itself and the whole smartphone supply chain.

1.5. Objective of this thesis

The objective of this thesis is to propose a Fuzzy Analytic Hierarchy Process (Fuzzy AHP) model for raw material supplier selection for the case study nano sim-card connector manufacturer. The selected supplier should be the most suitable according to all criteria considered.

1.6. Thesis Scope

1. The considered product is a nano sim-card connector produced in millimeter. The focused materials are Plastic, Nickel, Phosphor bronze, and Stainless steel which are the most problematic materials in the current situation.
2. The involved departments who answer the questionnaires are department of procurement and engineering, and clients. Three questionnaire survey

(Selecting main and sub-criteria, Level of importance, and Linguistic approximation) are conducted for the Fuzzy AHP to collect data from respondents.

3. Based on the literature review and internal meeting in the case study company, five main criteria and twelve sub-criteria are selected. The main criteria that were selected by the case study company are Material quality, Purchasing cost, Reliability, Financial status, and Partnership. Each of them has its own sub-criteria that were selected from the related decision makers.
4. By employing sensitivity analysis, the decision of raw material supplier might be switched or remained when the model parameters in the top five sub-criteria change.

1.7. The benefits of this thesis

1. The company is able to benefit from selecting the suitable raw material suppliers to reduce the defect rate.
2. The company is able to improve the quality and value of nano sim-card connectors or other electronic components in the market.
3. The company is able to receive stable orders from existing clients or potential prospectors.

Chapter 2 Literature Review

This chapter demonstrates the literature surrounding the Fuzzy AHP methodology and presents its practices in electronic and related fields. Section 2.1 describes the importance of supplier selection. Section 2.2 details AHP methodology practices. Section 2.3 presents the difference between AHP and Fuzzy AHP that Fuzzy AHP can deal with uncertainty and personal preference. Finally, according to the current scenario in the case study, Fuzzy AHP is able to identify the main and sub-criteria to select the appropriate raw material supplier in the nano sim-card connector. Also, utilizing sensitivity analysis is to adjust the weight of linguistic approximation in different scenarios to obtain a new raw material supplier selection.

2.1. Importance of supplier selection

In globalization, many companies have been cooperating with domestic and international suppliers in order to strengthen their efficiency, effectiveness, and profitability. Nowadays, the supply chain has become a more complex network, from raw material to the end consumers, consisting of all processes such as purchasing, manufacturing, risks, and other factors (Ting and Cho, 2008). In order to improve the entire supply chain network to be competitive in the market, appropriate suppliers would promote a product to achieve high quality with customer satisfaction (Chan et al., 2008). Hence, supplier selection has become one of the crucial roles in the supply chain to achieve greatest benefits and better performance.

Many researchers have done supplier selection by utilizing different approaches for dealing with the Multi-Criteria Decision Making Problem (MCDM) in order to select the appropriate suppliers in the supply chain in relative fields in Table 4.

Table 4 Literature review in relative fields

Reference	Scope	Methodology	Reference	Scope	Methodology
Chan and Chan (2004)	Semico nductor	AHP	Parthiban, Zubar, and Garge (2012)	Automotive industry	AHP
Chan et al. (2008)	Global supplie r	Fuzzy AHP	Gold and Awasthi (2015)	Focal companies	Fuzzy AHP
Chiou et al. (2008)	PC	Fuzzy AHP	Dweiri et al. (2016)	Automotive industry	AHP and Sensitivity Analysis
Ting and Cho (2008)	PC	Questionnaire, analytical hierarchy process (AHP), and Multi-objective linear programming (MOLP)	Galankashi et al. (2016)	Automotive industry	Balanced scorecard and Fuzzy AHP
Chamodraka s et al. (2010)	Electro nic industr y	Fuzzy Preference Programming (FPP)	Gupta et al. (2019)	Automotive industry	Fuzzy (AHP, TOPSIS, WASPAS, and MABACI)
Amid et al. (2011)	Manufa cturer	AHP	Nirmala and Uthra (2019)	Electronic industry	AHP with Intuitionistic Fuzzy Number
Kilincci and Onal (2011)	Washin g machin e	Fuzzy AHP			

2.2. Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) developed by Saaty (1980) is one of the systematic approaches to categorize different factors to deal with multi-criterion problems, including subjective and objective evolution. He demonstrated that the hierarchy procedure was able to provide consistent measures and alternatives to reduce the difficulty of decision-making. Hence, AHP is able to clarify qualitative and quantitative elements to be measured so that decision-makers (DMs), procurement teams or top management teams can select the optimal suppliers by numbers. Chan and Chan (2004) proposed that based on multiple criteria, the company had to consider selecting optimal suppliers in order to fulfill requirements, utilizing AHP to identify five main criteria and twenty-one sub-criteria to compute the final weight for supplier selection is valid in semiconductor equipment. Ting and Cho (2008) mentioned that multinational companies had relied on outsourcing more than before, showing that an appropriate supplier selection and purchasing decision would influence their entire supply chain whether to be efficient and effective. They demonstrated that AHP was able to identifyboth quantitative and qualitative criteria to weight each criterion in the PC industry. Amid et al. (2011) stated that DMs could handle multi-criteria making problems by AHP. They discovered a clear vision for organizations to manage their supplier chain performance on cost, quality, and service. Parthiban et al. (2012) handled multi-criteria decision problems that affect the supplier selection and identify the relation between each criterion to select the best automotive component supplier by employing AHP in the automotive industry. Based on AHP, the company was able to select an appropriate component supplier, for the particular component has 20 suppliers. Dweiri et al. (2016) proposed that AHP provided a clear vision to identify the various criteria in the automotive industry, and sensitivity analysis was able to adjust the variance based on different factors. They explained that based on the hierarchy structure and ranking suppliers, DMs were capable of selecting suppliers consistently and confidentially.

2.3. Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

Although AHP has become one of the effective solutions to deal with MCDM in real situations, in globalization and digitalization, vast information has existed in the decision environment so that the DMs and procurement teams have a limitation to collect, compute, and memorize all data to calculate all alternatives to select a suitable supplier in the supply chain; also, they have their preference and judgement (Chamodrakas et al., 2010; Kilincci and Onal, 2011; Galankashi et al., 2016; Nirmala and Uthra, 2018). Chamodrakas et al. (2010) pointed out that modern industries had become the global competition in which companies obtain vast information in a complex environment to execute the optimal strategy in the market. With these limitations and global competition, an appropriate supplier was able to satisfy a company's requirements in different needs (Kilincci and Onal, 2011; Galankashi et al., 2016). Additionally, AHP had some existing defects that might make decision-making to be crisp andimprecise in Table 5 (Gnanavelbabu and Arunagiri, 2018). As a result, those uncertainties are able to be solved by the fuzzy set theory from Buckley (1985).

Table 5 Shortcomings of AHP (Gnanavelbabu and Arunagiri, 2018)

1.	Judgement is based on personal preference leading to an unbalanced scale
2.	Not involving in linguistic vagueness
3.	The result is affected by DMs based on their preference
4.	Individuals' measurement on qualitative attributions exists bias, heterogeneity, and imprecise

Van Laarhoven and Pedrycz (1983) was the first paper who demonstrated the Fuzzy AHP concept to deal with the bias decision on criteria by employing the triangular member function. Then, Buckley (1985) developed a new Fuzzy AHP method by utilizing fuzzy priorities of comparison ratios to handle the judgements. Chan et al. (2008) proposed that in global competition, not only common criteria, such as quality and cost, but also other vital variances, such as delays and partnership, were essential to be involved. They utilized the Fuzzy AHP framework to tackle the data in global supplier selection. Chiou et al. (2008) stated that a green supplier selection and multi-criteria needed to be associated to determine the relative importance. They demonstrated that Fuzzy AHP could explore the differences in three foreign companies in China and concluded that the groups from three countries were capable of identifying the optimal ranking for green supplier selection. Also, Chamodrakas et al. (2010) indicated that the main cost of a product was constituted by the cost of materials and components in a washing machine field. Those costs occupied a large proportion of revenue, which affected the performance of a company. They employed Fuzzy Preference Programming (FPP) in electronic marketplaces to alleviate the information overload and deal with inconsistency and uncertainty to select suitable suppliers in a metal manufacturing company. Kilincci and Onal (2011) utilized Fuzzy AHP to select an optimal supplier in order to achieve customers' needs. Gold and Awasthi (2015) proposed that general decision-making tools do not involve sustainability risks, such as civil society, into the supply chain. They demonstrated that Fuzzy AHP provided appropriate information for DMs to deal with issues and select a proper supplier. Galankashi et al. (2016) integrated the balanced scorecard with Fuzzy AHP to weight each criterion and rank the final score of each supplier in the automobile industry. Nirmala and Uthra (2019) integrated Nearest Weighted Intuitionistic Interval Approximation (NWIA) into Triangular Intuitionistic fuzzy number (TIFN) for dealing with vagueness and uncertainty to select the optimal vendor suppliers in the supply chain. Gupta et al. (2019) explained that in assemble machined planning in the automotive industry, companies required not only location, quality, and material but also highly skilled employees to achieve high quality and optimization. They utilized Fuzzy AHP and three techniques, which were Multi-Attributive Border Approximation Area Comparison (MABAC), Weighted Aggregated Sum-Product Assessment (WASPAS), and Technique for order preference by similarity to ideal solution (TOPICS) to measure each criterion weight to identify the optimal green suppliers.

Other research that are related to Fuzzy AHP can be found in Kahraman et al. (2003), Rezaei and Ortt (2013), and Olabanji and Mpofu (2020).

Most of researchers are directly to evaluate and analyze supplier selection in Original Equipment Manufacturer (OEM) in Figure 9. The role of OEM is to select a suitable component supplier in order to enhance the supplier chain (Chan and Chan, 2004; Chiou et al., 2008; Ting and Cho, 2008; Chamodrakas et al., 2010; Dweiri et al., 2016). Also, the components they selected are on maturity level and fixed size. Nowadays, in the global competitive electronic market, the connection in the supply chain has suppressed than before, which requires more criteria and involves uncertainty and preference. Notably, the smartphone can be defined as a fashion good which quality is essential to user experience. This indicates that the supply chain of the smartphone has established a higher connection. When the upstream has some issues, the entire supply chain would be affected.

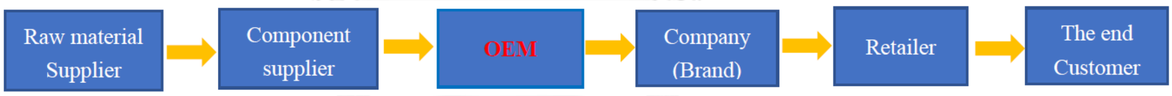


Figure 9 The role of OEM in the electronic industry

2.4. Contribution of this thesis

The existing appraisal record in the case study company is measured by the department of procurement, which might lead to an imprecise decision due to some bias and preference. In order to tackle the issue, in this thesis, two departments and clients are included to identify the main and sub-criteria, and personal preference and linguistic vagueness can be addressed to provide more precise information to select the suitable raw material supplier in four primary materials in the nano sim-card connecter. Also, one raw material supplier is selected for each material. Compared the volume of orders with other electronic components in the electronic and automobile industry per year in the case study company, in Table 6, the total weight in each material is less than ten tons, and the average weight per month is less than 600 kilograms, which indicate that one raw material supplier can fulfill the orders from the case study company.

Table 6 The weight of each material order during 2017, 2018, and 2019

2017 Total weight (KG)		Average per month	2018 Total weight (KG)		Average per month	2019 Total weight (KG)		Average per month
Nickel	7,330	610	Nickel	5,740	478	Nickel	5,506	459
Stainless steel	9,440	787	Stainless steel	7,390	616	Stainless steel	7,092	591
Phosphor bronze	7,110	592	Phosphor bronze	5,570	464	Phosphor bronze	5,340	445
Plastic	9,550	796	Plastic	7,480	623	Plastic	7,175	598

Although it might have a possibility that the raw material supplier is unable to supply because another client purchases most of the orders or the order from the case study company is a small batch in the slack season, an agent whose role is similar to a forwarder is in contract with the raw material supplier, for many small and medium enterprises (SMEs) require a small batch order. The case study company is still able to order the same material from the agent.

Unlike other literature, this thesis proposes a methodology for the case study component manufacturer to select a suitable raw material supplier that focuses on the nano sim-card connector produced in millimeters and assembled by four primary material parts. More importantly, the trend of the product has continued to become smaller or multifunction. In order to reduce the risks (e.g., flatness, broken pin, insertion/withdrawal times, and other serious issues.) in the assembly line in OEM, the role in selecting an appropriate supplier would move up one level in the upstream to be the component supplier to recognize the suitable raw material supplier in each material part in the nano sim-card connector in Figure 10. We utilize Fuzzy AHP to identity the main criteria and sub-criteria to select the suitable raw material supplier in the nano sim-card connector by collecting data from two departments (procurement and engineering) and clients. Also, Fuzzy AHP can measure qualitative and quantitative data and deal with uncertainty and personal preference to select the suitable raw material suppliers in four primary materials (Plastic, Nickel, Phosphor bronze, and Stainless steel) in the nano sim-card connecter to achieve high quality and value-added, reduce the potential risks, and explore a new perspective in supplier selection to provide precise information to DM in the case study company. Ultimately, utilizing Sensitivity analysis is to deal with different scenarios by adjusting the linguistic approximation in the top five sub-criteria from respondents for each raw material to identify the suitable raw material supplier.

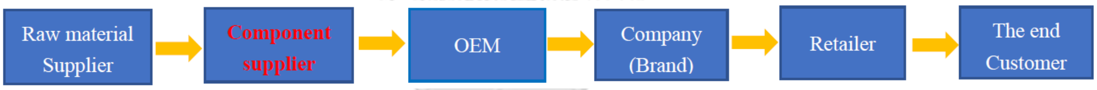


Figure 10 The role in component supplier in this thesis

Chapter 3 Methodology

This chapter is to describe the methodology of the research study, the feedback from respondents, and data analysis techniques, including data collection, study design, and procedure of raw material supplier selection. In this study, Fuzzy AHP is to interpret and select the suitable raw material supplier in the nano sim-card connecter. Sensitivity analysis is able to adjust the variances when the case study company receives the updated information from raw material suppliers.

3.1. Data collection

This thesis aims to improve the supplier selection to enhance the quality of the connector and reduce the potential risks (e.g., defect rate, penalty, and order reduction) that directly affect the company's performance. Regarding the early stage of data explorations, collecting relevant data and documents from other researchers and internal discussion in the case study company can identify the main criteria and sub-criteria that directly affect the performance in the current scenario. Also, from the survey respondents' details, two departments (procurement and engineering) and clients are involved that directly relate to the performance of nano sim-card connectors in the smartphone supply chain.

3.2. Company Data for this research

In the case study company, the capacity of two production lines is 1.32 million nano sim-card connectors per month. Based on monthly data during 2017, 2018, and 2019 in Table 7, the average number of orders per year was approximately ten million, which the case study company is able to complete the orders from clients every month. Besides, in Table 8, compared to a volume of raw material in the electronic and automobile industry, the volume is a small portion which is an average of 600 kilograms per month, indicating that the case study company rarely encounters any shortage from raw material suppliers. Moreover, receiving more information and potential issues from the downstream supply chain is able to reduce some potential risks to improve or maintain the quality of connectors.

Table 7 Order during 2017, 2018, and 2019

2017	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Order (thousand)	750	400	550	850	1,350	1,350	1,550	1,500	850	700	650	600
2018	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Order (thousand)	420	210	450	735	969	1,150	1,230	1,250	765	600	586	400
2019	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Order (thousand)	513	300	460	705	899	956	1,130	1,120	788	543	499	430

Table 8 Total weight of each material order during 2017, 2018, and 2019

2017 Total weight (KG)		Average per month	2018 Total weight (KG)		Average per month	2019 Total weight (KG)		Average per month
Nickel	7,330	610	Nickel	5,740	478	Nickel	5,506	459
Stainless steel	9,440	787	Stainless steel	7,390	616	Stainless steel	7,092	591
Phosphor bronze	7,110	592	Phosphor bronze	5,570	464	Phosphor bronze	5,340	445
Plastic	9,550	796	Plastic	7,480	623	Plastic	7,175	598

Furthermore, a smartphone can be categorized into fashion goods, for smartphone competitors have been trying to provide more functions at a similar size of a smartphone in order to appeal to more customers to purchase. Under this competition, the sales of the next-generation flagship model will be tremendously influenced by the previous version. Based on those conditions, smartphone components are the fundamental level to provide high quality and reinforce the sales of smartphones. Once any component has any issue, the entire smartphone supply chain will be affected. For instance, one component has a high defect rate to weld on the PCB, so that the flagship model is postponed launching in the market. Or, when the end customers do not feel user-friendly because of components, the sales volume of the smartphone will be reduced in the next few months. Integrating both internal and external data, both qualitative and quantitative criteria are able to be identified to affect the value and quality of each material part to assemble into the nano sim-card component. Those data can also be the first step to establishing a hierarchy structure in order to identify the relations between each other.

3.3. Fuzzy AHP

In this thesis, the suitable raw supplier in the four primary materials would be selected in order to provide more accurate information for DM and purchasing team; also, the performance of the case study company is able to be reinforced, which not only provides high-quality nano sim-card connectors but also increases the profit stably. Overall, the methodology is to identify different factors and select the appropriate raw material suppliers in Figure 11.

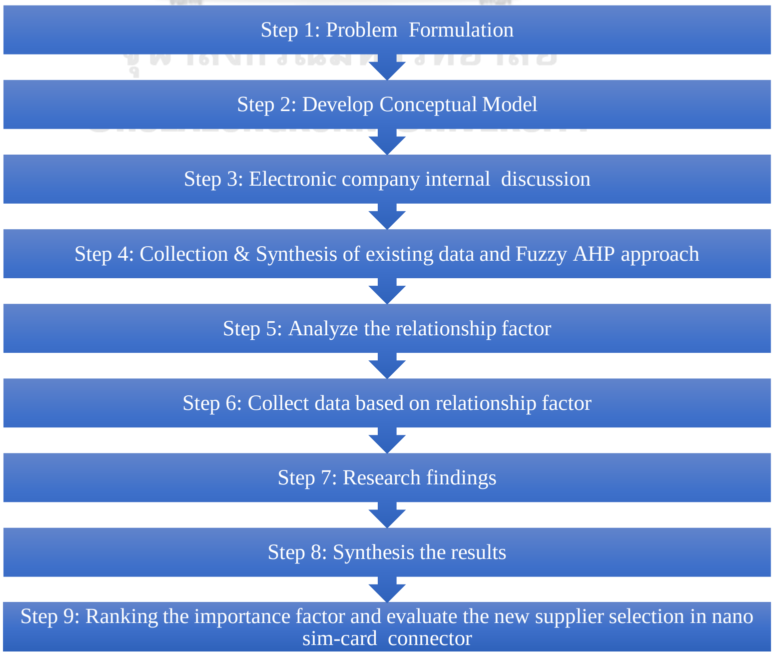


Figure 11 Research framework for the raw material supplier selection

3.3.1. Step 1: The hierarchical structure for selecting raw material suppliers

AHP is one of MCDM approaches to break down the factors into smaller constituent parts (Saaty, 1980). Several criteria and sub-criteria are identified in Table 9. With those common criteria and sub-criteria, the first questionnaire can be designed to select the essential criteria in the nano sim-card connector in Appendix II. After collecting twelve surveys from

Table 9 Main criteria and sub-criteria from literature in relative fields

Main criteria	Sub-criteria	Author
Cost	1. Material cost 2. Credit time 3. Ordering cost 4. Transportation cost	Kahraman et al., 2003; Chan and Chan, 2004; Chan et al., 2008; Chiou et. al., 2008; Ting and Cho, 2008; Chamodrakas et al., 2010; Gold and Awasthi, 2015; Dweiri et al., 2016 Gupta et al., 2019
Quality	1. Quality consistency 2. Defect Rate 3. Packaging quality	Kahraman et al., 2003; Chan and Chan, 2004; Chan et al., 2008; Chiou et al., 2008; Ting and Cho, 2008; Chamodrakas et al., 2010; Kilincci and Onal, 2011; Gold and Awasthi, 2015; Dweiri et al., 2016; Gupta et al., 2019
Reliability	1. Delivery-delay 2. Delivery-shortage 3. Minimum order requirement	Chan and Chan, 2004; Ting and Cho, 2008; Chamodrakas et al., 2010; Kilincci and Onal, 2011; Dweiri et al., 2016
Risks	1. Distance 2. Legal environment 3. Political stability	Chan et al., 2008; Chiou et al., 2008; Gold and Awasthi, 2015
Financial status	1. Cash flow 2. Assets and debts 3. Income	Kahraman et al., 2003; Chan et al., 2008; Ting and Cho, 2008; Galankashi et al., 2016
Service/ Partnership	1. Contract 2. Proactive information 3. Lead time to order. 4. Response after defect 5. Flexibility	Kahraman et al., 2003; Chan et al., 2008; Ting and Cho, 2008; Kilincci and Onal, 2011; Dweiri et al., 2016; Gupta et al.,2019

the case study company, five main criteria and twelve sub-criteria are identified that would affect the quality and value of the nano sim-card connector in Figure 12. The characteristics of the main criteria and sub-criteria are described below:

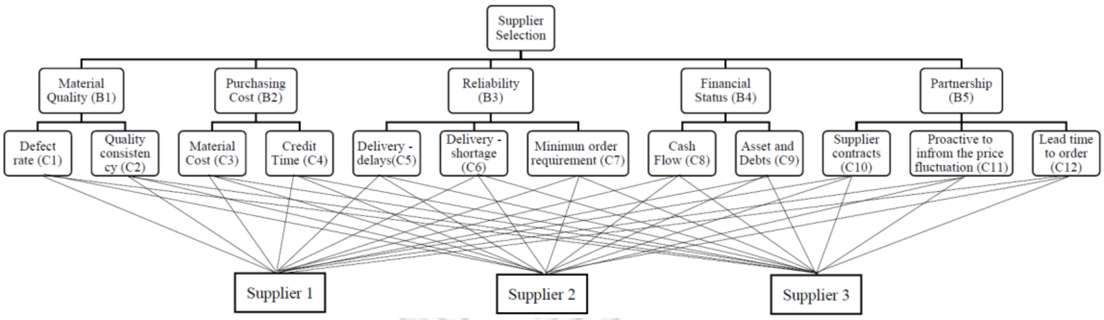


Figure 12 Raw material supplier selection criteria

B1. Material quality: the nano sim-card connector is produced in a millimeter that is the essential criterion in the supplier selection process.

- Defect rate(C1): defective rate from four materials' part report
- Quality consistency(C2): internal testing report of quality standards for raw material

B2. Purchasing cost: the profit can be directly affected by the total raw material acquisition costs.

- Material Cost (C3): the latest price is offered by the raw material suppliers
- Credit time (C4): the number of days that the case study company is allowed to wait before paying the invoice

B3. Reliability: the performance of the raw material suppliers is able to meet the due day; also, the purchasing team can receive the precise quantity orders from the raw material suppliers.

- Delivery-delays (C5): delivery schedule report

- Delivery-shortage(C6): raw material delivery report
- Minimum order requirement (C7): the latest minimum order information from the raw material suppliers

B4. Financial Status: The clients of the case study company provide a list of which raw material suppliers can be adopted. The accounting statement represents whether they are capable of receiving specific raw material orders from the purchasing team.

- Cash flow (C8): the raw material suppliers' annual cash flow in the annual report
- Assets and Debts (C9): the raw material suppliers' balance sheet in the annual report

B5. Partnership: based on globalization, the price is fluctuated by the time in each month, whichinfluences the operation cost. Also, the raw material suppliers plan to have a long-term trade with the case study company that creates a stable supply and demand. In addition, the cycle time that the raw materials are manufactured is affected by the production schedule.

- Supplier contract (C10): the time of fixed cost
- Proactive to inform the price fluctuation (C11): updated the price fluctuation one month earlier
- Lead time to order (C12): the lead time schedule from production to delivery

3.3.2. Step 2: Questionnaire

Buckley (1985) explains that traditional AHP is not able to present an individual's subjective judgement and uncertainty appropriately. In the conventional AHP questionnaire in Table 10, each linguistic approximately is independent which is not related to each other. This might lead the result to be imprecise. Also, several weaknesses can be identified in Table 5. Nevertheless, in the real-world decision environment, criteria evaluation has always corelated each other which Fuzzy linguistic in Figure 13 is able to collect all data. Hence, the fuzzy set theory is able to address the shortcomings of AHP to provide more accurate information in supplier selection. A triangular fuzzy number (TFN) in the fuzzy AHP evaluation criterion semantic scale in Table 11 would be utilized to create a questionnaire filled in from fifteen respondents in Table 12. Each respondent in a higher position (e.g., supervisor, manager, and senior manager) has been in the electronic field for more than five years which is qualified to be involved in the supplier selection in the nano sim-card connector.

Table 10 AHP evaluation criterion semantic scale (Saaty, 1980)

Evaluation criterion	**Meaning**
1	Equal importance
3	Weak importance
5	Essential importance
7	Very strong importance
9	Absolute importance
2,4,6, and 8	Intermediate values

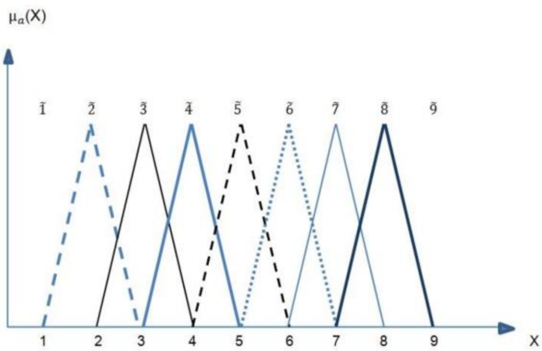


Figure 13 Fuzzy linguistic (Buckley,1985)

Table 11 Fuzzy AHP evaluation criterion semantic scale

Fuzzy evaluation criterion	Meaning

$\tilde{1}$ = **(1,1,1)**	Equal importance
$\tilde{2}$ = **(1,2,3)**	Intermediate values
$\tilde{3}$ = **(2,3,4)**	Weak importance
$\tilde{4}$ = **(3,4,5)**	Intermediate values
$\tilde{5}$ = **(4,5,6)**	Essential importance
$\tilde{6}$ = **(5,6,7)**	Intermediate values
$\tilde{7}$ = **(6,7,8)**	Very strong importance
$\tilde{8}$ = **(7,8,9)**	Intermediate values
$\tilde{9}$ = **(9,9,9)**	Absolute importance

Table 12 Fifteen respondents in the case study company

Department	**Number**
Engineering	6
Procurement	6
Client	3
Total	**15**

3.3.3. Step 3: Establishing a pairwise comparison matrix

After collecting data from the two departments and clients, the elements are compared pairwise to establish a pairwise comparison matrix. Also, utilizing TFN on a scale of $\tilde{1}\ to\ \tilde{9}$ is to address the individual's preference and judgement. Nine TFNs $\tilde{1}\ to\ \tilde{9}$ are employed in this study where $\tilde{1}$ is equal importance, and $\tilde{9}$ is absolute importance in Table 11. In addition, the pairwise comparison has reciprocal property. If a ratio of factor i and factor j is $\tilde{a}_{ij}$. Then, element i and element j is 1/ $\tilde{a}_{ij}$. If $\tilde{A}$= 〔 $\tilde{a}_{ij}$ 〕 = (L, M, U) then reciprocal value is $\widetilde{A^{-1}}$ = 〔 $\widetilde{a_{ij}^{-1}}$ 〕 = $(L, M, U)^{-1}$ = ($\frac{1}{U}$, $\frac{1}{M}$, $\frac{1}{L}$). Thus, the elements of the comparison matrix are as follows:

$$\tilde{A} = \left[\tilde{a}_{ij} \right] = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} =$$

$$\begin{bmatrix} (1,1,1) & (a12_L,\ a12_M, a12_U) & \cdots & (a1n_L,\ a1n_M, a1n_U) \\ (1/a12_U, 1/\ a12_M, 1/a12_L) & (1,1,1) & \dots & (a2n_L,\ a2n_M, a2n_U) \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ (1/a1n_U, 1/\ a1n_M, 1/a1n_L) & (1/a2n_U, 1/\ a2n_M, 1/a2n_L) & \cdots & (1,1,1) \end{bmatrix} \quad (1)$$

After establishing the pairwise comparison $\left[\tilde{a}_{ij} \right]$, a weight $\left[\widetilde{W}_{ij} \right]$ from each level of the hierarchy can be measured. Normalization of the Geometric Mean of the Rows (NGM) is utilized to measure the weight. Then, the eigenvalue $\tilde{\lambda}_{max}$ is the next step to measure consistency.

$$\widetilde{W}_{ij} = \sqrt[n]{\textstyle\prod_j^n \tilde{a}_{ij}} \,/\, \textstyle\sum_i^n \sqrt[n]{\prod_j^n \tilde{a}_{ij}}\ , \text{i,j} = 1,2, \dots, \text{n} \quad (2)$$

$$\tilde{A} \times \widetilde{W} = \tilde{\lambda}_{max} \times \widetilde{W} \quad (3)$$

$$\tilde{A} = \begin{bmatrix} \widetilde{W}_1/\widetilde{W}_1 & \widetilde{W}_1/\widetilde{W}_2 & \cdots & \widetilde{W}_1/\widetilde{W}_n \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{W}_n/\widetilde{W}_1 & \widetilde{W}_n/\widetilde{W}_2 & \cdots & \widetilde{W}_n/\widetilde{W}_n \end{bmatrix} \begin{bmatrix} \widetilde{W}_1 \\ \widetilde{W}_2 \\ \vdots \\ \widetilde{W}_n \end{bmatrix} = \begin{bmatrix} \widetilde{W}_1{}' \\ \widetilde{W}_2{}' \\ \vdots \\ \widetilde{W}_n{}' \end{bmatrix} \quad (4)$$

$$\tilde{\lambda}_{max} = \frac{1}{n} \left(\frac{\widetilde{W}_1{}'}{\widetilde{W}_1} + \frac{\widetilde{W}_2{}'}{\widetilde{W}_2} + \dots + \frac{\widetilde{W}_n{}'}{\widetilde{W}_n} \right) \quad (5)$$

3.3.4. Step 4: Consistency

After obtaining the aggregate judgement matrix from all pairwise comparisons, the consistency index (C.I) and the consistency ratio (C.R) are determined the judgement whether it is consistent. If not, it can be adjusted to avoid imprecise decision making. Saaty (2008) suggests that if C.I $<$ 0.1, the error is optimal acceptance. If C.I $<$ 0.2, the error is acceptable. Also, R.I is the random consistency index that the value is given from Table 13. If C.R $<$ 0.1, the judgement matrix is satisfied whereas C.R > 0.1, it can be considered inconsistency. The measurements are as follow:

$$C.I = \frac{\lambda_{max} - m}{m-1} \quad (6)$$

$$C.R = \frac{C.I}{R.I} \quad (7)$$

$\tilde{\lambda}$max = the first priority of the pairwise comparison matrix

m = the number of classes

R.I = the ratio indexes the value of R.I

Table 13 Ratio index (R.I) for different value of n (Saaty, 2008)

Order (n)	1	2	3	4	5	6	7	8	9	10
R.I	0	0	0.52	0.89	1.12	1.25	1.34	1.4	1.45	1.49

3.3.5. Step 5: Defuzzification

Defuzzification is to convert fuzzy to an exact value. If utilizing the center of gravity method is to calculate the fuzzy number of membership function to find the exact value of the fuzzy number.

$$G(A) = \frac{\int_U \mu_a(x) \times x dx}{\int_U \mu_a(x) dx}, \text{ and } \int_U \mu_a(x)\, dx \neq 0$$

When the fuzzy number is the triangular fuzzy number (TFN), the center of gravity can be converted to the linear formula:

$$DF = \frac{(M_i - L_i) + (U_i - L_i)}{3} + L_i, \forall_i$$

(8)

Based on DF, the final score can be ranked to identify the priority of sub-criteria in each hierarchy.

3.3.6. Step 6: Sub-weight

Based on the DF, the weight of main criteria multiple the weight of sub-criteria to receive the sub-weight ($\widetilde{W}_i = (L_{wi}, M_{wi}, U_{wi})$) from each respondent where $\widetilde{W}_i$ is assessment criterion of the fuzzy weight, s is numbers of respondents. $\widetilde{W}_i$ can be described as follow:

$\widetilde{W}_i = (L_{wi}, M_{wi}, U_{wi})$, j = 1, 2, …. N

$L_{wi} = min\{W_{si}\}$, $\forall j$,

$M_{wi} = ave\{W_{si}\}$, $\forall j$,

$U_{wi} = max\{W_{si}\}$, $\forall j$, where min is the lowest weight, average is the geometric mean, and max is the largest weight from the total numbers of experts. (9)

After collecting each sub-weight from fifteen respondents to calculate the final sub-weight in Figure 14, the $\widetilde{W}_i$ can be listed. It can be described as follow:

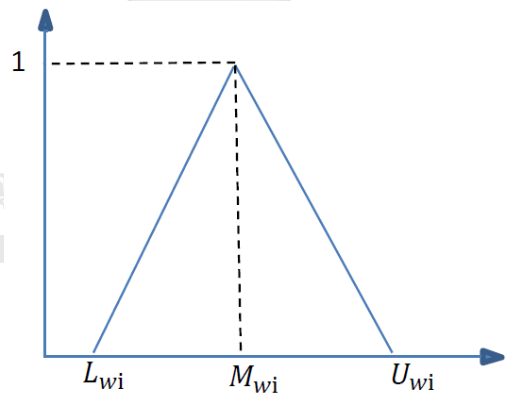
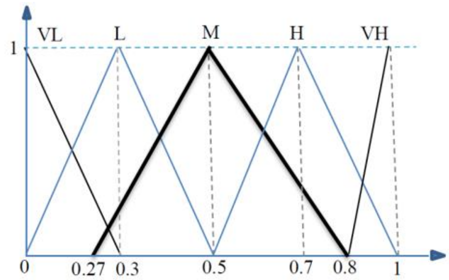


Figure 14 TFN $\widetilde{W}_i = (L_{wi}, M_{wi}, U_{wi})$ of membership of function

$$f_{\tilde{A}}(\widetilde{W}_i) = \begin{cases} 0 & , \ \widetilde{W}_i < L_{wi} \\ \frac{\widetilde{W}_i - L_{wi}}{M_{wi} - L_{wi}} & , \ L_{wi} < \widetilde{W}_i < M_{wi} \\ \frac{U_{wi} - \widetilde{W}_i}{U_{wi} - M_{wi}} & , \ M_{wi} < \widetilde{W}_i < U_{wi} \\ 0 & , \ \widetilde{W}_i > U_{wi} \end{cases} \quad (10)$$

3.3.7. Step 7: Linguistic approximation

Liang and Wang (1991) explain that the linguistic variable is able to address each respondent's preference in supplier performance. Five scales can be identified in Figure 15. Based on respondents' experience and knowledge in the 0 to 100 percent ratio scale, a questionnaire can be created to identify each respondent's judgement and preference.



VL = very low	L = low	M = medium	H = high	VH = very high

Figure 15 Five scales of Linguistic approximation (Liang and Wang, 1991)

After collecting data, the fuzzy synthetic value (X_{ij}^k) can be identified. If X_{ij}^k shows that k respondent is for i supplier under the j fuzzy synergy value. $LX_{ij}^k, MX_{ij}^k, and\ UX_{ij}^k$ can be measured by Normalization of the Geometric Mean of the Rows (NGM). It can be described as follow:

$$X_{ij}^k = (LX_{ij}^k, MX_{ij}^k, UX_{ij}^k)$$

$$LX_{ij}^k = \sqrt[m]{\prod_j^m LX_{ij}^k} \,/\, \sum_i^m \sqrt[m]{\prod_j^m LX_{ij}^k}$$

$$MX_{ij}^k = \sqrt[m]{\prod_j^m MX_{ij}^k} \,/\, \sum_i^m \sqrt[m]{\prod_j^m MX_{ij}^k}$$

$$UX_{ij}^k = \sqrt[m]{\prod_j^m UX_{ij}^k} \,/\, \sum_i^m \sqrt[m]{\prod_j^m UX_{ij}^k}$$, where m is number of respondents. (11)

3.3.8. Step 8: Fuzzy synthetic decision

The fuzzy synthetic decision is to combine fuzzy sub-weight ($\widetilde{W}_i$) and fuzzy synthetic value (X^s) with being a hierarchy in series in order to measure the entire fuzzy synthetic value ($\tilde{V}$). It can be described as follow:

$\tilde{V} = \widetilde{W}_i \circ X^s$, where ° is presented the fuzzy pairwise comparison matrix including fuzzy multiplication and fuzzy addition. (12)

After the score from the $\tilde{V}$ = (L, M, U), $DF = \frac{(M-L)+(U-L)}{3} + L$ is to receive the final weight to rank each supplier in four raw materials.

3.4. Sensitivity Analysis

Sensitivity analysis is to measure when the percentage of factors is adjusted, it might have a possibility to improve the overall weight performance of raw material suppliers. First, the top five sub-weight (after defuzzification) would be a fixed value as follow:

$$W_i = \frac{(M_{wi}-L_{wi})+(U_{wi}-L_{wi})}{3} + L_{wi} \quad (13)$$

The score (MX_{ij}^k) in the fuzzy synthetic value would be selected to adjust the weight. The maximum overall weight (K_b) from each top sub-weight (W_i) is collected from the score (MX_{ij}^k) in the very high (VH) in linguistic approximation from each respondent by Normalization of the Geometric Mean of the Rows (NGM) as follow:

$$MAX\ \ K_b = W_i \times \sqrt[m]{\prod_j^m MX_{ij}^k} \,/\, \sum_i^m \sqrt[m]{\prod_j^m MX_{ij}^k} \quad (14)$$

Finally, by adjusting the linguistic approximation, the weight of MX_{ij}^k in each sub-criterion is able to compute to receive a new weight of synthetic value decision for a new selection ranking.

Chapter 4 Empirical Result, Discussion, and Analysis

In this chapter, the research results consist of three parts; the first is data analysis from Fuzzy AHP, which identifies the level of importance in main and sub-criteria and the top five of sub-weight. Second, based on the fuzzy synthetic decision, the final rank can be identified as the suitable raw material supplier in each raw material. Ultimately, the Fuzzy AHP methodology identifies the important factors in main and sub-criteria based on part 4.2. Also, analyzing the relation between factors to provide a new supplier selection in the four raw materials based on part 4.3.

4.1. Main criteria and sub-criteria selection

Collecting data from other research in relative fields and internal discussion in the case study company is to develop the first questionnaire in Appendix II. Based on the questionnaire, twelve questionnaires are valid from the department of procurement and engineering in the case study company. The results are obtained in Figure 16 and 17, which five main criteria (Purchasing Cost, Material Quality, Reliability, Financial Status, and Partnership) and twelve sub-criteria (Quality consistency, Defect rate, Material cost, Credit time, Delivery-delays, Delivery-shortage, Minimum order requirement, Cash flow, Asset and debts, Contract, Proactive information, and Lead time to order) are selected.

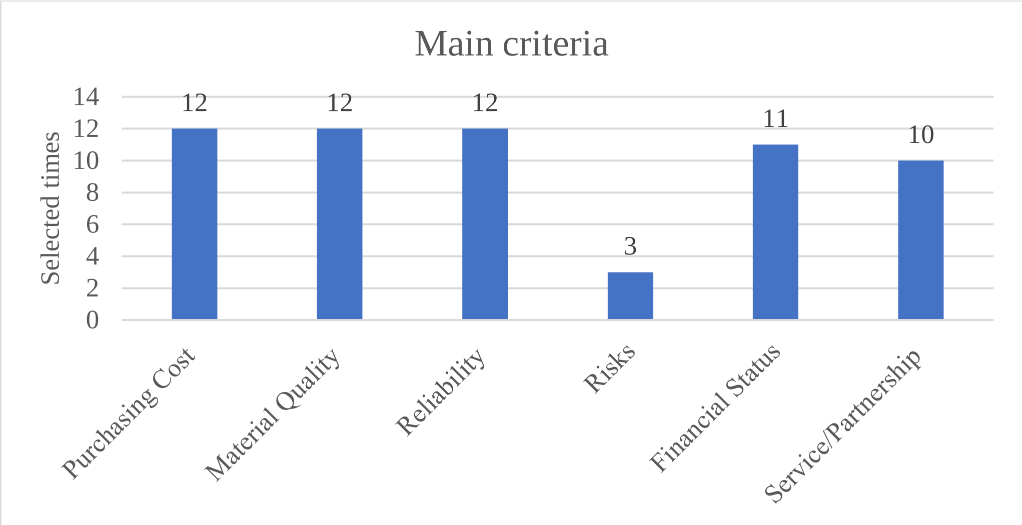


Figure 16 The result of main criteria from twelve respondents

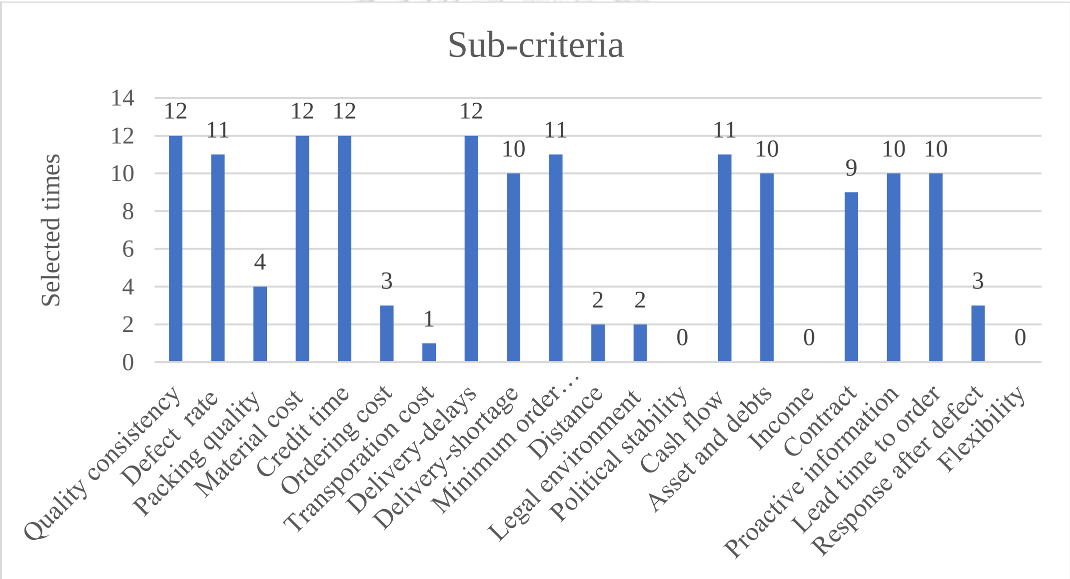


Figure 17 The result of sub-criteria from twelve respondents

4.2. The level of importance and sub-weight

This study is based on the questionnaire in Appendix III to measure the weight of main criteria and sub-criteria from respondents. The data from the respondents is utilized to calculate the pairwise comparison matrix with a geometric mean by the excel software.

Step 1: the pairwise questionnaire (Appendix III) is filled in by thirteen respondents to assess the relative weights among the main and sub-criteria. The result from the main criteria is received in Table 14, and the rest of results from the sub-criteria are obtained in Appendix V.

Table 14 The pairwise comparison matrix in main criteria (B1 to B5)

1.	B1			B2			B3			B4			B5		
B1	1	1	1	9	9	9	2	3	4	2	3	4	4	5	6
B2	1/9	1/9	1/9	1	1	1	1/6	1/5	1/4	1	1	1	1/6	1/5	1/4
B3	1/4	1/3	1/2	4	5	6	1	1	1	1	1	1	1	1	1
B4	1/4	1/3	1/2	1	1	1	1	1	1	1	1	1	1	1	1
B5	1/6	1/5	1/4	4	5	6	1	1	1	1	1	1	1	1	1
2.	B1			B2			B3			B4			B5		
B1	1	1	1	6	7	8	4	5	6	2	3	4	2	3	4
B2	1/8	1/7	1/6	1	1	1	1/4	1/3	1/2	1/6	1/5	1/4	1/4	1/3	1/2
B3	1/6	1/5	1/4	2	3	4	1	1	1	1	1	1	1	1	1
B4	1/4	1/3	1/2	4	5	6	1	1	1	1	1	1	1/4	1/3	1/2
B5	1/4	1/3	1/2	2	3	4	1	1	1	2	3	4	1	1	1
3.	B1			B2			B3			B4			B5		
B1	1	1	1	4	5	6	1	1	1	4	5	6	1	1	1
B2	1/6	1/5	1/4	1	1	1	1/8	1/7	1/6	1/4	1/3	1/2	1/8	1/7	1/6
B3	1	1	1	6	7	8	1	1	1	2	3	4	2	3	4
B4	1/6	1/5	1/4	2	3	4	1/4	1/3	1/2	1	1	1	1	1	1
B5	1	1	1	6	7	8	1/4	1/3	1/2	1	1	1	1	1	1
4.	B1			B2			B3			B4			B5		
B1	1	1	1	4	5	6	1	1	1	2	3	4	1	1	1
B2	1/6	1/5	1/4	1	1	1	1/4	1/3	1/2	1	1	1	1/6	1/5	1/4
B3	1	1	1	2	3	4	1	1	1	1	2	3	2	3	4
B4	1/4	1/3	1/2	1	1	1	1/3	1/2	1	1	1	1	1/3	1/3	1/2
B5	1	1	1	4	5	6	1/4	1/3	1/2	2	3	3	1	1	1
5.	B1			B2			B3			B4			B5		
B1	1	1	1	5	6	7	1	1	1	2	3	4	2	3	4
B2	1/7	1/6	1/5	1	1	1	1/3	1/2	1	1	2	3	1/5	1/4	1/3
B3	1	1	1	1	2	3	1	1	1	2	3	4	1	2	3
B4	1/4	1/3	1/2	1/3	1/2	1	1/4	1/3	1/2	1	1	1	1/4	1/3	1/2
B5	1/4	1/3	1/2	3	4	5	1/3	1/2	1	2	3	4	1	1	1
6.	B1			B2			B3			B4			B5		

B1	1	1	1	4	5	6	2	3	4	1	2	3	2	3	4
B2	1/6	1/5	1/4	1	1	1	1	1	1	1/6	1/5	1/4	1/3	1/2	1
B3	1/4	1/3	1/2	1	1	1	1	1	1	1/3	1/2	1	1/4	1/3	1/2
B4	1/3	1/2	1	4	5	6	1	2	3	1	1	1	2	3	4
B5	1/4	1/3	1/2	1	2	3	2	3	4	1/4	1/3	1/2	1	1	1
7.	B1			B2			B3			B4			B5		
B1	1	1	1	6	7	8	2	3	4	4	5	6	2	3	4
B2	1/8	1/7	1/6	1	1	1	1/4	1/3	1/2	1/3	1/2	1	1/3	1/2	1
B3	1/4	1/3	1/2	2	3	4	1	1	1	1	1	1	1	1	1
B4	1/6	1/5	1/4	1	2	3	1	1	1	1	1	1	1/4	1/3	1/2
B5	1/4	1/3	1/2	1	2	3	1	1	1	2	3	4	1	1	1
8.	B1			B2			B3			B4			B5		
B1	1	1	1	5	6	7	2	3	4	4	5	6	1	1	1
B2	1/7	1/6	1/5	1	1	1	1/4	1/3	1/5	1	1	1	1/6	1/4	1/5
B3	1/4	1/3	1/2	5	3	4	1	1	1	1	2	3	1	2	3
B4	1/6	1/5	1/4	1	1	1	1/3	1/2	1	1	1	1	1/4	1/3	1/2
B5	1	1	1	5	4	6	1/3	1/2	1	2	3	4	1	1	1
9.	B1			B2			B3			B4			B5		
B1	1	1	1	7	8	9	6	7	8	1	1	1	6	7	8
B2	1/9	1/8	1/7	1	1	1	1/4	1/3	1/2	1/4	1/3	1/2	1/5	1/4	1/3
B3	1/8	1/7	1/6	2	3	4	1	1	1	1	2	3	1	1	1
B4	1	1	1	2	3	4	1/3	1/2	1	1	1	1	1/3	1/2	1
B5	1/8	1/7	1/6	3	4	5	1	1	1	1	2	3	1	1	1
10.	B1			B2			B3			B4			B5		
B1	1	1	1	2	3	4	2	3	4	5	6	7	6	7	8
B2	1/4	1/3	1/2	1	1	1	1	1	1	1/4	1/3	1/2	1/4	1/3	1/2
B3	1/4	1/3	1/2	1	1	1	1	1	1	2	3	4	1	1	1
B4	1/7	1/6	1/5	2	3	4	1/4	1/3	1/2	1	1	1	1	1	1
B5	1/8	1/7	1/6	2	3	4	1	1	1	1	1	1	1	1	1
11.	B1			B2			B3			B4			B5		
B1	1	1	1	2	3	4	2	3	4	2	3	4	4	5	6
B2	1/4	1/3	1/2	1	1	1	1	1	1	1/6	1/5	1/4	1/4	1/3	1/2
B3	1/4	1/3	1/2	1	1	1	1	1	1	1	1	1	1	2	3
B4	1/4	1/3	1/2	4	5	6	1	1	1	1	1	1	1	1	1
B5	1/6	1/5	1/4	2	3	4	1/3	1/2	1	1	1	1	1	1	1
12.	B1			B2			B3			B4			B5		
B1	1	1	1	6	7	8	2	3	4	1	1	1	2	3	4
B2	1/8	1/7	1/6	1	1	1	1	1	1	1/6	1/5	1/4	1/4	1/3	1/2
B3	1/4	1/3	1/2	1	1	1	1	1	1	1	1	1	1	1	1
B4	1	1	1	4	5	6	1	1	1	1	1	1	2	3	4
B5	1/4	1/3	1/2	2	3	4	1	1	1	1/4	1/3	1/2	1	1	1

13.	B1			B2			B3			B4			B5		
B1	1	1	1	6	7	8	1	1	1	4	5	6	1	1	1
B2	1/8	1/7	1/6	1	1	1	1/6	1/5	1/4	1/4	1/3	1/2	1/8	1/7	1/6
B3	1	1	1	4	5	6	1	1	1	2	3	4	1	1	1
B4	1/6	1/5	1/4	2	3	4	1/4	1/3	1/2	1	1	1	1/6	1/5	1/4
B5	1	1	1	6	7	8	1	1	1	4	5	6	1	1	1

(Source: Developed for this study)

Step 2: This step demonstrates whether each item in the questionnaire conformed to consistency. As Saaty (2008) states that if C.I $<$ 0.1, the error is optimal acceptance. If C.I $<$ 0.2, the error is acceptable. The results in the main criteria are shown in the average consistency in Table 15. The C.I from twelve respondents is less than 0.1, and the C.I from one respondent is less than 0.2. In addition, the results in sub-criteria are shown in Appendix VI. The C.I from thirteen respondents is acceptable, which is less than 0.1. Overall, those data are acceptable that is valid to be involved in raw material supplier selection.

Table 15 Test consistency in main criteria (B1 to B5)

1.	Test Consistency		**8.**	Test Consistency	
λM	5.34		λM	5.26	
C.I.	0.09	**Accepted**	C.I.	0.06	**Accepted**
C.R.	0.08	**Accepted**	C.R.	0.06	**Accepted**
2.	Test Consistency		**9.**	Test Consistency	
λM	5.29		λM	5.78	
C.I.	0.07	**Accepted**	C.I.	0.20	**Accepted**
C.R.	0.06	**Accepted**	C.R.	0.18	**Accepted**
3.	Test Consistency		**10.**	Test Consistency	
λM	5.31		λM	5.63	
C.I.	0.08	**Accepted**	C.I.	0.16	**Accepted**
C.R.	0.07	**Accepted**	C.R.	0.14	**Accepted**
4.	Test Consistency		**11.**	Test Consistency	
λM	5.30		λM	5.50	
C.I.	0.07	**Accepted**	C.I.	0.12	**Accepted**
C.R.	0.07	**Accepted**	C.R.	0.11	**Accepted**
5.	Test Consistency		**12.**	Test Consistency	
λM	5.34		λM	5.31	
C.I.	0.09	**Accepted**	C.I.	0.08	**Accepted**
C.R.	0.08	**Accepted**	C.R.	0.07	**Accepted**
6.	Test Consistency		**13.**	Test Consistency	
λM	5.24		λM	5.09	

C.I.	0.06	**Accepted**	C.I.	0.02	**Accepted**
C.R.	0.05	**Accepted**	C.R.	0.02	**Accepted**
7.	Test Consistency				
λM	5.14				
C.I.	0.04	**Accepted**			
C.R.	0.03	**Accepted**			

(Source: Developed for this study)

Step 3: The defuzzification (DF) converts the fuzzy numbers to be the exact number that is able to identify the level of importance in main criteria and sub-criteria in Table 16. The result indicates that the top three crucial main criteria are B1 (Material quality), B3 (Reliability), and B4 (Partnership).

Table 16 Weight of main criteria and sub-criteria for supplier selection after defuzzification

Main criteria and Sub-criteria	Weight
B1: Material quality	0.41
C1: Defeat rate	0.50
C2: Quality consistent	0.50
B2: Purchasing Cost	0.06
C3: Material Cost	0.47
C4: Credit Time	0.53
B3: Reliability	0.20
C5: Delivery delays	0.58
C6: Delivery shortage	0.31
C7: Minimum order requirement	0.11
B4: Financial Status	0.14
C8: Cash flow	0.37
C9: Asset and debts	0.63
B5: Partnership	0.18
C10: Supplier contract	0.30
C11: Proactive to inform the price fluctuation	0.51
C12: Lead time to order	0.19

(Source: Developed for this study)

Step 4: After DF, the weight of the main criteria multiplies the weight of sub-criteria to receive the sub-weight that is obtained in Table 17 and 18. In Table 17, The result shows the top five sub-weight, C2 (Quality consistency), C1 (Defect rate), C5 (Delivery delays), C9 (Asset and debts), and C10 (Supplier contract).

Table 17 Main criteria multiple sub-criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Respondent 1	0.26	0.26	0.01	0.04	0.12	0.03	0.01	0.06	0.06	0.04	0.09	0.02
Respondent 2	0.12	0.37	0.01	0.04	0.10	0.01	0.01	0.02	0.11	0.03	0.14	0.03
Respondent 3	0.05	0.24	0.02	0.02	0.26	0.06	0.04	0.09	0.03	0.06	0.07	0.05
Respondent 4	0.14	0.14	0.04	0.04	0.13	0.13	0.05	0.08	0.04	0.04	0.13	0.06
Respondent 5	0.26	0.09	0.07	0.02	0.09	0.09	0.09	0.02	0.06	0.02	0.14	0.04
Respondent 6	0.20	0.20	0.02	0.05	0.06	0.01	0.02	0.05	0.24	0.01	0.12	0.02
Respondent 7	0.06	0.43	0.03	0.03	0.09	0.05	0.01	0.03	0.08	0.02	0.13	0.03
Respondent 8	0.10	0.29	0.02	0.05	0.05	0.16	0.02	0.06	0.02	0.16	0.02	0.06
Respondent 9	0.08	0.40	0.04	0.01	0.12	0.02	0.01	0.04	0.12	0.11	0.03	0.02
Respondent 10	0.39	0.13	0.07	0.01	0.07	0.07	0.01	0.06	0.06	0.02	0.10	0.01
Respondent 11	0.34	0.11	0.06	0.02	0.09	0.05	0.01	0.02	0.16	0.04	0.08	0.02
Respondent 12	0.34	0.05	0.03	0.03	0.10	0.02	0.01	0.04	0.25	0.03	0.04	0.06
Respondent 13	0.27	0.04	0.01	0.04	0.12	0.12	0.01	0.01	0.07	0.20	0.03	0.08

(Source: Developed for this study)

Table 18 Sub-weight

Sub-weight						
	Min	**Avg**	**Max**	**Error**	**DF**	**Rank**
C1	0.05	0.16	0.39	0.34	0.43	2
C2	0.04	0.17	0.42	0.39	0.47	1
C3	0.01	0.03	0.07	0.06	0.08	10
C4	0.02	0.03	0.05	0.03	0.06	12
C5	0.05	0.10	0.26	0.21	0.28	3
C6	0.01	0.05	0.16	0.14	0.17	6
C7	0.01	0.02	0.09	0.09	0.10	8
C8	0.01	0.04	0.09	0.07	0.09	9
C9	0.02	0.08	0.25	0.22	0.26	4
C10	0.01	0.04	0.20	0.19	0.21	5
C11	0.02	0.07	0.14	0.12	0.16	7
C12	0.01	0.03	0.08	0.07	0.08	10

(Source: Developed for this study)

4.3. Fuzzy synthetic decision

The linguistic approximation (Appendix IV) demonstrates the linguistic vagueness from the thirteen respondents that areobtained in Table 19 to understand the different ranges of linguistic variance.

Table 19 Linguistic approximation from thirteen respondents

	VL (very low)	L (low)	M (medium)	H (High)	VH (very high)
Respondent 1	10, 15, 20	20, 30, 45	45, 55, 60	60, 75, 85	85, 88, 92
Respondent 2	5, 20, 25	25, 40, 50	50, 55, 65	65, 77, 80	82, 93, 97

Respondent 3	10, 18, 30	25, 40, 55	55, 60, 70	65, 75, 83	83, 95, 100
Respondent 4	2, 6, 24	24, 35, 43	44, 50, 59	60, 69, 75	76, 85, 94
Respondent 5	1, 20, 35	35, 46, 49	49, 56, 65	66, 76, 81	81, 95, 95
Respondent 6	10, 10, 30	25, 40, 55	50, 60, 70	70, 75, 80	80, 90, 95
Respondent 7	1, 15, 30	31, 45, 50	51, 60, 65	66, 75, 80	82, 85, 90
Respondent 8	5, 10, 15	20, 30, 40	45, 50, 60	65, 70, 80	85, 95, 100
Respondent 9	10, 15, 30	25, 40, 50	50, 60, 65	65, 75, 85	85, 90, 95
Respondent 10	0, 0, 15	16, 30, 39	40, 50, 60	60, 65, 75	75, 85, 90
Respondent 11	2, 10, 18	20, 37, 47	52, 58, 63	65, 69, 74	82, 89, 93
Respondent 12	1, 1, 27	28, 32, 41	45, 50, 57	64, 72, 83	86, 89, 96
Respondent 13	0, 0, 16	23, 33, 38	40, 49, 59	62, 75, 79	84, 89, 98

(Source: Developed for this study)

Step 1: By comparing raw material suppliers, scoring them is to receive the fuzzy synthetic value by computing the Geometric Mean. The result is obtained in Table 20, and other results are shown in Appendix VII.

Table 20 Fuzzy synthetic value in Nickel

C1	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	45	55	60	60	75	85	85	88	92	60	75	85
Respondent 2	50	55	65	65	77	80	65	77	80	50	55	65
Respondent 3	25	40	55	65	75	83	65	75	83	25	40	55
Respondent 4	24	35	43	76	85	94	60	69	75	44	50	59
Respondent 5	35	46	49	66	76	81	66	76	81	66	76	81
Respondent 6	50	60	70	80	90	95	80	90	95	50	60	70
Respondent 7	31	45	50	66	75	80	66	75	80	51	60	65
Respondent 8	20	30	40	65	70	80	85	95	100	65	70	80
Respondent 9	25	40	50	85	90	95	85	90	95	50	60	65
Respondent 10	16	30	39	60	65	75	60	65	75	40	50	60
Respondent 11	20	37	47	65	69	74	82	89	93	52	58	63
Respondent 12	28	32	41	64	72	83	86	89	96	64	72	83
Respondent 13	40	49	59	84	89	98	84	89	98	62	75	79
Geometric Mean	29.554	41.546	50.538	68.827	77.131	84.504	73.806	81.543	87.484	50.772	60.594	69.309
Normalized	**0.296**	**0.415**	**0.505**	**0.688**	**0.771**	**0.845**	**0.738**	**0.815**	**0.875**	**0.508**	**0.606**	**0.693**
C2	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	45	55	60	60	75	85	85	88	92	45	55	60
Respondent 2	50	55	65	65	77	80	82	93	97	50	55	65
Respondent 3	55	60	70	65	75	83	65	75	83	55	60	70

Respondent 4	24	35	43	76	85	94	76	85	94	44	50	59
Respondent 5	49	56	65	81	95	95	81	95	95	49	56	65
Respondent 6	50	60	70	70	75	80	70	75	80	50	60	70
Respondent 7	31	45	50	82	85	90	66	75	80	66	75	80
Respondent 8	20	30	40	65	70	80	65	70	80	45	50	60
Respondent 9	25	40	50	85	90	95	85	90	95	65	75	85
Respondent 10	40	50	60	60	65	75	60	65	75	40	50	60
Respondent 11	52	58	63	82	89	93	82	89	93	65	69	74
Respondent 12	45	50	57	86	89	96	86	89	96	64	72	83
Respondent 13	40	49	59	84	89	98	84	89	98	62	75	79
Geometric Mean	38.485	48.364	57.055	73.286	80.976	87.679	75.364	82.380	88.724	53.083	60.937	69.426
Normalized	**0.385**	**0.484**	**0.571**	**0.733**	**0.810**	**0.877**	**0.754**	**0.824**	**0.887**	**0.531**	**0.609**	**0.694**
C3	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	45	55	60	20	30	45	45	55	60
Respondent 2	82	93	97	25	40	50	25	40	50	50	55	65
Respondent 3	65	75	83	25	40	55	25	40	55	55	60	70
Respondent 4	76	85	94	44	50	59	24	35	43	44	50	59
Respondent 5	81	95	95	35	46	49	35	46	49	49	56	65
Respondent 6	80	90	95	50	60	70	50	60	70	70	75	80
Respondent 7	82	85	90	31	45	50	1	15	30	66	75	80
Respondent 8	65	70	80	20	30	40	20	30	40	45	50	60
Respondent 9	85	90	95	50	60	65	25	40	50	50	60	65
Respondent 10	60	65	75	16	30	39	16	30	39	40	50	60
Respondent 11	82	89	93	20	37	47	2	10	18	52	58	63
Respondent 12	64	72	83	28	32	41	28	32	41	64	72	83
Respondent 13	62	75	79	40	49	59	23	33	38	62	75	79
Geometric Mean	71.982	80.902	87.702	30.965	42.988	51.782	16.227	31.190	41.823	52.478	60.129	67.865
Normalized	**0.720**	**0.809**	**0.877**	**0.310**	**0.430**	**0.518**	**0.162**	**0.312**	**0.418**	**0.525**	**0.601**	**0.679**
C4	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	20	30	45	45	55	60	60	70	85	60	75	85
Respondent 2	50	55	65	65	77	80	65	77	80	50	55	65
Respondent 3	25	40	55	55	60	70	55	60	70	65	75	83
Respondent 4	2	6	24	60	69	75	60	69	75	44	50	59
Respondent 5	49	56	65	66	76	81	66	76	81	49	56	65
Respondent 6	25	40	55	70	75	80	70	75	80	50	60	70
Respondent 7	31	45	50	51	60	65	51	60	65	31	45	50
Respondent 8	45	50	60	85	95	100	65	70	80	65	70	80

Respondent 9	50	60	65	65	75	85	65	75	85	50	60	65
Respondent 10	16	30	39	40	50	60	60	65	75	40	50	60
Respondent 11	52	58	63	65	69	74	82	89	93	65	69	74
Respondent 12	45	50	57	86	89	96	86	89	96	64	72	83
Respondent 13	40	49	59	62	75	79	62	75	79	40	49	59
Geometric Mean	27.965	39.167	52.361	61.344	70.083	76.432	64.525	72.566	79.900	50.557	59.594	68.241
Normalized	**0.280**	**0.392**	**0.524**	**0.613**	**0.701**	**0.764**	**0.645**	**0.726**	**0.799**	**0.506**	**0.596**	**0.682**
C5	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	60	75	85	60	75	85	60	75	85
Respondent 2	65	77	80	65	77	80	82	93	97	65	77	80
Respondent 3	55	60	70	65	75	83	65	75	83	55	60	70
Respondent 4	44	50	59	60	69	75	60	69	75	60	69	75
Respondent 5	49	56	65	66	76	81	49	56	65	49	56	65
Respondent 6	50	60	70	50	60	70	70	75	80	50	60	70
Respondent 7	65	75	80	65	75	80	82	85	90	82	85	90
Respondent 8	45	50	60	65	70	80	85	95	100	65	70	80
Respondent 9	65	75	85	85	90	95	85	90	95	85	90	95
Respondent 10	60	65	75	75	85	90	60	65	75	60	65	75
Respondent 11	52	58	63	65	69	74	82	89	93	52	58	63
Respondent 12	64	72	83	64	72	83	64	72	83	64	72	83
Respondent 13	62	75	79	62	75	79	84	89	98	62	75	79
Geometric Mean	56.093	64.484	72.807	64.708	74.124	80.914	70.337	78.192	85.448	61.416	69.458	77.170
Normalized	**0.561**	**0.645**	**0.728**	**0.647**	**0.741**	**0.809**	**0.703**	**0.782**	**0.854**	**0.614**	**0.695**	**0.772**
C6	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	20	30	45	60	75	85	60	75	85	45	55	65
Respondent 2	50	55	65	82	93	97	82	93	97	65	77	80
Respondent 3	55	60	70	65	75	83	83	95	100	65	75	83
Respondent 4	44	50	59	60	69	75	60	69	75	44	50	59
Respondent 5	1	20	35	66	76	81	66	76	81	66	76	81
Respondent 6	25	40	55	70	75	80	70	75	80	50	60	70
Respondent 7	51	60	65	66	75	80	66	75	80	51	60	65
Respondent 8	45	50	60	65	70	80	85	95	100	65	70	80
Respondent 9	25	40	50	85	90	95	65	75	85	50	60	65
Respondent 10	40	50	60	75	85	90	75	85	90	60	65	75
Respondent 11	52	58	63	82	89	93	82	89	93	52	58	63
Respondent 12	45	50	57	64	72	83	86	89	96	64	72	83
Respondent 13	40	49	59	62	75	79	62	75	79	62	75	79

Geometric Mean	29.532	45.293	56.341	68.902	78.024	84.442	71.824	81.530	87.374	56.266	65.024	72.438
Normalized	**0.295**	**0.453**	**0.563**	**0.689**	**0.780**	**0.844**	**0.718**	**0.815**	**0.874**	**0.563**	**0.650**	**0.724**
C7	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	80	88	92	45	55	60	45	55	70	60	75	85
Respondent 2	82	93	97	25	40	50	25	40	50	65	77	80
Respondent 3	83	95	100	25	40	55	25	40	55	65	75	83
Respondent 4	76	85	94	24	35	43	44	50	59	60	69	75
Respondent 5	81	95	95	49	56	65	49	56	65	66	76	81
Respondent 6	80	90	95	70	75	80	50	60	70	70	75	80
Respondent 7	66	75	80	51	60	65	31	45	50	66	75	80
Respondent 8	65	70	80	45	50	60	45	50	60	45	50	60
Respondent 9	85	90	95	25	40	50	50	60	65	65	75	85
Respondent 10	60	65	75	40	50	60	40	50	60	75	85	90
Respondent 11	92	89	93	52	58	63	2	10	18	65	69	74
Respondent 12	86	89	96	45	50	57	45	50	57	64	72	83
Respondent 13	62	75	79	62	75	79	40	49	59	40	49	59
Geometric Mean	76.114	83.964	89.703	40.429	51.263	59.703	31.531	44.183	54.407	61.210	70.123	77.519
Normalized	**0.761**	**0.840**	**0.897**	**0.404**	**0.513**	**0.597**	**0.315**	**0.442**	**0.544**	**0.612**	**0.701**	**0.775**
C8	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	60	75	85	60	75	85	60	75	85
Respondent 2	65	77	80	65	77	80	65	77	80	65	77	80
Respondent 3	65	75	83	65	75	83	65	75	83	65	75	83
Respondent 4	44	50	59	60	69	75	60	69	75	60	69	75
Respondent 5	66	76	81	66	76	81	81	95	95	66	76	81
Respondent 6	70	75	80	70	75	80	70	75	80	70	75	80
Respondent 7	51	60	65	66	75	80	66	75	80	51	60	65
Respondent 8	45	50	60	45	50	60	65	70	80	65	70	80
Respondent 9	65	75	85	50	60	65	65	75	85	65	75	85
Respondent 10	60	65	75	60	65	75	40	50	60	75	85	90
Respondent 11	82	89	93	82	89	93	65	69	74	65	69	74
Respondent 12	45	50	75	45	50	75	64	72	83	45	50	75
Respondent 13	62	75	79	84	89	98	62	75	79	40	49	59
Geometric Mean	59.024	67.488	76.272	61.856	70.098	78.624	63.036	72.619	79.533	60.079	68.781	77.392
Normalized	**0.590**	**0.675**	**0.763**	**0.619**	**0.701**	**0.786**	**0.630**	**0.726**	**0.795**	**0.601**	**0.688**	**0.774**
C9	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	60	75	85	60	75	85	60	75	85
Respondent 2	65	77	80	65	77	80	65	77	80	65	77	80

Respondent 3	65	75	83	65	75	83	65	75	83	65	75	83
Respondent 4	44	50	50	76	85	94	60	69	75	44	50	59
Respondent 5	66	76	81	66	76	81	66	76	81	66	76	81
Respondent 6	70	75	80	80	90	95	80	90	95	70	75	80
Respondent 7	66	75	80	82	85	90	82	85	90	66	75	80
Respondent 8	65	70	80	45	50	60	85	95	100	65	70	80
Respondent 9	50	60	65	65	75	85	85	90	95	65	75	85
Respondent 10	40	50	60	60	65	75	60	65	75	60	65	75
Respondent 11	52	58	63	65	69	74	82	89	93	52	58	63
Respondent 12	45	50	57	45	50	57	64	72	83	45	50	57
Respondent 13	40	49	59	84	89	98	84	89	98	62	75	79
Geometric Mean	54.923	63.559	69.990	64.863	72.761	80.340	71.422	80.011	86.768	59.801	68.174	75.289
Normalized	**0.549**	**0.636**	**0.700**	**0.649**	**0.728**	**0.803**	**0.714**	**0.800**	**0.868**	**0.598**	**0.682**	**0.753**
C10	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	20	30	45	60	75	85	60	75	85	45	55	60
Respondent 2	5	20	25	65	77	80	65	77	80	25	40	50
Respondent 3	25	40	55	65	75	83	65	75	83	55	60	70
Respondent 4	2	6	24	60	69	75	60	69	75	24	35	43
Respondent 5	35	46	49	49	56	65	66	76	81	34	46	49
Respondent 6	10	10	30	50	60	70	70	75	80	10	10	30
Respondent 7	31	45	50	66	75	80	66	75	80	51	60	65
Respondent 8	20	30	40	65	70	80	85	95	100	20	30	40
Respondent 9	50	60	65	65	75	85	65	75	85	50	60	65
Respondent 10	16	30	39	75	85	90	60	65	75	40	50	60
Respondent 11	20	37	47	82	89	93	82	89	93	52	58	63
Respondent 12	45	50	57	64	72	83	86	89	96	45	50	57
Respondent 13	40	49	59	84	89	98	84	89	98	62	75	79
Geometric Mean	10.978	20.115	36.017	57.794	68.176	75.994	64.238	74.454	80.607	28.219	35.856	48.659
Normalized	**0.110**	**0.201**	**0.360**	**0.578**	**0.682**	**0.760**	**0.642**	**0.745**	**0.806**	**0.282**	**0.359**	**0.487**
C11	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	20	30	45	45	55	60	45	55	60	20	30	45
Respondent 2	5	20	25	25	40	50	25	40	50	25	40	50
Respondent 3	25	40	55	55	60	70	25	40	55	10	18	30
Respondent 4	24	35	43	24	35	43	24	35	43	24	35	43
Respondent 5	1	20	35	35	46	49	35	46	49	1	20	35
Respondent 6	10	10	30	25	40	55	25	40	55	10	10	30
Respondent 7	1	15	30	31	45	50	31	45	50	31	45	50

Respondent 8	20	30	40	45	50	60	20	30	40	20	30	40
Respondent 9	10	15	30	50	60	65	25	40	50	25	40	50
Respondent 10	16	30	39	16	30	39	40	50	60	16	30	39
Respondent 11	20	37	47	20	37	47	52	58	63	52	58	63
Respondent 12	1	1	27	45	50	57	28	32	41	28	32	41
Respondent 13	23	33	38	40	49	58	62	75	79	40	49	59
Geometric Mean	8.297	18.982	36.287	32.866	45.020	53.407	31.731	43.716	52.568	17.748	30.782	43.175
Normalized	**0.083**	**0.190**	**0.363**	**0.329**	**0.450**	**0.534**	**0.317**	**0.437**	**0.526**	**0.177**	**0.308**	**0.432**
C12	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	45	55	60	45	55	60	45	55	60	45	55	60
Respondent 2	50	55	65	65	77	80	65	77	80	50	55	65
Respondent 3	25	40	55	55	60	70	65	75	83	55	60	70
Respondent 4	24	35	43	60	69	75	60	69	75	44	50	59
Respondent 5	66	76	81	49	56	65	49	56	65	49	56	65
Respondent 6	50	60	70	70	75	80	70	75	80	50	60	70
Respondent 7	51	60	65	66	75	80	51	60	65	31	45	50
Respondent 8	45	50	60	85	95	100	65	70	80	45	50	60
Respondent 9	50	60	65	65	75	85	85	90	95	50	60	65
Respondent 10	40	50	60	60	65	75	60	65	75	60	65	75
Respondent 11	20	37	47	65	69	74	82	89	93	52	58	63
Respondent 12	45	50	57	64	72	83	86	89	96	28	32	41
Respondent 13	40	49	59	62	75	79	84	89	98	40	49	59
Geometric Mean	40.286	50.991	59.825	61.675	69.911	76.817	65.291	72.734	79.463	45.162	52.725	61.041
Normalized	**0.403**	**0.510**	**0.598**	**0.617**	**0.699**	**0.768**	**0.653**	**0.727**	**0.795**	**0.452**	**0.527**	**0.610**

(Source: Developed for this study)

Step 2: After collecting data from the fuzzy synthetic value, the synthetic fuzzy decision can be measured by multiplying sub-weight and fuzzy synthetic value. The results are obtained in Table 21 and Appendix VIII. After defuzzification, raw material suppliers in each raw material can be ranked to select the suitable raw material supplier in Table 22 to 25. In Plastic, Supplier 1 is the priority; in Nickel, Supplier 3 becomes the first supplier; in Phosphor bronze, Supplier 2 is the first supplier; and in Stainless steel, Supplier 1 is the same result.

Table 21 The result of fuzzy synthetic decision in Plastic

Supplier1	$\widetilde{W_j}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.730	0.800	0.872	0.035	0.132	0.342
C2	0.038	0.167	0.430	0.787	0.865	0.926	0.030	0.144	0.398
C3	0.007	0.026	0.070	0.197	0.287	0.459	0.001	0.007	0.032
C4	0.022	0.029	0.053	0.601	0.681	0.760	0.013	0.020	0.040
C5	0.054	0.101	0.262	0.709	0.788	0.853	0.038	0.079	0.224
C6	0.013	0.048	0.155	0.657	0.736	0.815	0.008	0.036	0.126
C7	0.006	0.018	0.092	0.273	0.394	0.490	0.002	0.007	0.045
C8	0.014	0.038	0.087	0.574	0.651	0.727	0.008	0.025	0.063
C9	0.022	0.077	0.245	0.568	0.669	0.750	0.012	0.052	0.184
C10	0.015	0.041	0.202	0.656	0.733	0.763	0.010	0.030	0.154
C11	0.021	0.074	0.145	0.331	0.438	0.535	0.007	0.032	0.077
C12	0.008	0.030	0.075	0.600	0.689	0.760	0.005	0.021	0.057
						Total	**0.170**	**0.585**	**1.744**
Supplier 2	$\widetilde{W_j}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.638	0.721	0.786	0.031	0.119	0.308
C2	0.038	0.167	0.430	0.728	0.792	0.854	0.028	0.132	0.367
C3	0.007	0.026	0.070	0.441	0.524	0.617	0.003	0.013	0.043
C4	0.022	0.029	0.053	0.529	0.620	0.693	0.011	0.018	0.037
C5	0.054	0.101	0.262	0.680	0.765	0.843	0.036	0.077	0.221
C6	0.013	0.048	0.155	0.644	0.727	0.796	0.008	0.035	0.123
C7	0.006	0.018	0.092	0.315	0.420	0.539	0.002	0.007	0.050
C8	0.014	0.038	0.087	0.538	0.637	0.727	0.008	0.024	0.063
C9	0.022	0.077	0.245	0.627	0.699	0.769	0.014	0.054	0.189
C10	0.015	0.041	0.202	0.643	0.709	0.733	0.009	0.029	0.148
C11	0.021	0.074	0.145	0.281	0.452	0.561	0.006	0.033	0.081
C12	0.008	0.030	0.075	0.668	0.755	0.817	0.005	0.023	0.062
						Total	**0.162**	**0.566**	**1.692**
Supplier 3	$\widetilde{W_j}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.241	0.348	0.424	0.012	0.057	0.166
C2	0.038	0.167	0.430	0.438	0.521	0.605	0.017	0.087	0.260
C3	0.007	0.026	0.070	0.719	0.812	0.870	0.005	0.021	0.061
C4	0.022	0.029	0.053	0.168	0.315	0.447	0.004	0.009	0.024
C5	0.054	0.101	0.262	0.426	0.537	0.619	0.023	0.054	0.162
C6	0.013	0.048	0.155	0.156	0.321	0.424	0.002	0.016	0.066

C7	0.006	0.018	0.092	0.688	0.782	0.842	0.004	0.014	0.077
C8	0.014	0.038	0.087	0.524	0.627	0.705	0.008	0.024	0.061
C9	0.022	0.077	0.245	0.305	0.423	0.519	0.007	0.033	0.127
C10	0.015	0.041	0.202	0.137	0.224	0.395	0.002	0.009	0.080
C11	0.021	0.074	0.145	0.067	0.169	0.292	0.001	0.012	0.042
C12	0.008	0.030	0.075	0.182	0.341	0.448	0.001	0.010	0.034
						Total	**0.085**	**0.346**	**1.161**
Supplier 4	$\widetilde{W}_j$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.467	0.555	0.634	0.023	0.092	0.248
C2	0.038	0.167	0.430	0.590	0.679	0.756	0.022	0.113	0.325
C3	0.007	0.026	0.070	0.614	0.691	0.762	0.004	0.018	0.053
C4	0.022	0.029	0.053	0.397	0.512	0.605	0.009	0.015	0.032
C5	0.054	0.101	0.262	0.592	0.668	0.751	0.032	0.067	0.197
C6	0.013	0.048	0.155	0.475	0.565	0.640	0.006	0.027	0.099
C7	0.006	0.018	0.092	0.557	0.631	0.705	0.003	0.011	0.065
C8	0.014	0.038	0.087	0.570	0.646	0.725	0.008	0.025	0.063
C9	0.022	0.077	0.245	0.405	0.498	0.589	0.009	0.038	0.145
C10	0.015	0.041	0.202	0.450	0.545	0.635	0.007	0.023	0.128
C11	0.021	0.074	0.145	0.272	0.402	0.489	0.006	0.030	0.071
C12	0.008	0.030	0.075	0.452	0.538	0.617	0.004	0.016	0.047
						Total	**0.132**	**0.475**	**1.473**

(Source: Developed for this study)

Table 22 The rank in Plastic suppliers

	$\tilde{R}$			DF	Rank
Supplier 1	0.170	0.585	1.744	0.833	1
Supplier 2	0.162	0.566	1.692	0.807	2
Supplier 3	0.085	0.346	1.161	0.531	4
Supplier 4	0.132	0.475	1.473	0.693	3

(Source: Developed for this study)

Table 23 The rank in Nickel suppliers

	$\tilde{R}$			DF	Rank
Supplier 1	0.106	0.396	1.302	0.601	4
Supplier 2	0.166	0.581	1.737	0.828	2
Supplier 3	0.175	0.601	1.787	0.854	1
Supplier 4	0.137	0.480	1.499	0.705	3

(Source: Developed for this study)

Table 24 The rank in Phosphor bronze suppliers

	$\tilde{R}$			DF	Rank
Supplier 1	0.151	0.524	1.596	0.757	2
Supplier 2	0.167	0.574	1.730	0.824	1
Supplier 3	0.105	0.408	1.324	0.612	3

(Source: Developed for this study)

Table 25 The rank in Stainless steel suppliers

	$\tilde{R}$			DF	Rank
Supplier 1	0.172	0.589	1.743	0.835	1
Supplier 2	0.153	0.536	1.626	0.772	2
Supplier 3	0.123	0.453	1.431	0.669	3

(Source: Developed for this study)

4.4. Main criteria and sub-criteria

The proposed Fuzzy AHP model is applied to the supplier selection in the smartphone component manufacturer which to identify two parts by collecting data from fifteen respondents in the department of engineering and procurement and clients. The DM at the company needs to analyze the weight of main criteria and sub-criteria to identify the suitable raw material supplier in each material. The company would be able to achieve the maximum benefits and reduce potential risks (e.g., components defect rate, a penalty from clients, order reduction, and rework time). Those respondents are familiar with the Fuzzy AHP concept; each member goes through Fuzzy AHP independently and individually.

First, selecting the main and sub-criteria in Appendix II from the department of procurement and engineering focuses on Quality, Cost, Reliability, Financial status, and Partnership. In Quality, the nano sim-card connector is produced in millimeters, that a deviation in the product specification is rigorous. In this case, quality consistency and defect rate are essential to be involved in a supplier selection, for those two sub-criteria directly affect the final product of the nano sim-card connector. In contrast, packing quality is not selected by respondents, for most raw material suppliers follow their packing standard to reduce damage risks during the shipping process to avoid return and exchange. Second, material cost and credit time directly affect the case study company's profitability from an operating cost perspective. Nevertheless, ordering cost and transportation cost are not the primary factors because the raw material suppliers are located near the case study company. Third, Delivery (delays and shortage) in reliability directly affects production scheduling, leading to unsatisfying demands from clients. Also, minimum order requirement is the other factor in selecting a raw material supplier because of the smartphone off-peak season. Fourth, in financial status, monitoring the cash flow and asset and debts of raw material suppliers is crucial. When the operation status of raw material supplier becomes hazardous, it might have a high possibility to cause delivery-delays and shortage which affects further corporation in the upstream (the case study company) and downstream (smartphone companies). Partnership is the fifth one that involves supplier selection. Supplier contract is able to assure the volume of raw material for the nano sim-card connector, which reduces the potential risks (e.g., shortages, cost fluctuation). Proactive information is another factor that the case study company would prefer to obtain, for compared to other components, the order of each raw material in the nano sim-card connector is in small portion so that the case study company might not attain minimum volume for a long-term contract with the raw material supplier. In this case, receiving price information before time from the raw material suppliers creates an opportunity for the case study company to purchase a bulk order to reduce the cost fluctuation. Additionally, lead time to order is necessary to be one of the sub-criteria in supplier selection. In the case study company's current scenario, several components are produced per day (day and night shift), that production scheduling must be tight in order to satisfy clients' orders. Meanwhile, some production lines are shared, indicating that if the lead time to order is not taken in proper time limits, the capacity of the production line might not complete orders within the time that clients require. Finally, due to the off-peak season in the nano sim-card connector, occasionally, the raw material supplier might not accept the small portion, which is lower than minimum orders. The agent whose role is the same as a forwarder has a direct contract with the raw material suppliers. In this case, the case study company does not need to purchase the raw material through the raw material supplier. Thus, flexibility is not selected in this supplier selection.

Furthermore, Risk is not selected because China can be defined as a world factory in which international and domestic raw material suppliers operate their factories in the same area. The infrastructure in the road system is well-developed, so that distance is not necessary to be selected. Also, legal environment is not selected, for as one of the smartphone component suppliers, the case study company must follow the regulation from clients to be one of the green suppliers in the supply chain. This points out that raw material suppliers also need to comply with regulations to be green raw material suppliers in the smartphone supply chain. Ultimately, political stability is stable in China which the world bank (2020) releases the ease of doing business ranking that China is thirty-one in 190 counties. Hence, those factors are not considered in the raw material supplier selection in the case study company.

Thirteen respondents are valid to be utilized into the Fuzzy AHP model, in which the weight of the main criteria and sub-criteria are obtained in Table 26. We have found that the foremost essential criteria are Material quality (B1), Reliability (B3), and

Partnership (B5). Also, the most important sub-criteria under each foremost criterion are Defect rate (C1), Quality consistent (C2), Delivery delays (C5), and Proactive to inform price fluctuation (C11). Compared to other studies, the cost is still mainstream (Ting and Cho, 2008; Chamodrakas et al., 2010; Kilincci and Onal, 2011; Parthiban et al., 2012; Nguyen et al., 2018; Deshmukh and Vasudevan, 2019). Nevertheless, the role of this thesis is a component supplier in the smartphone supply chain, which not only the quality would affect the entire supply chain but also other criteria (e.g., delays and price fluctuation information) are essential to affect company performance. Considering the entire supply chain, when one issue is detected in the assembly line in OEM, the assembly line will be suspended so that the loss would affect the whole supply chain until the issue is solved. Also, the nano sim-card connector has been produced since 2016 which the break-even point was reached in 2018. In this case, the potential risks (penalty, time of rework, and order reduction from clients) directly impact the case study company's operation, which Purchasing cost (B2) is not the mainstream in this thesis.

Table 26 Weight of main criteria and sub-criteria for supplier selection (Defuzzification)

Rank	Main criteria	Weight	Sub-criteria	Weight
1	B1: Material quality	0.41	C1: Defeat rate C2: Quality consistent	0.50 0.50
2	B3: Reliability	0.20	C5: Delivery delays C6: Delivery shortage C7: Minimum order requirement	0.58 0.31 0.11
3	B5: Partnership	0.18	C10: Supplier contract C11: Proactive to inform the price fluctuation C12: Lead time to order	0.30 0.51 0.19
4	B4: Financial Status	0.14	C8: Cash flow C9: Asset and debts	0.37 0.63

5	B2: Purchasing Cost	0.06	C3: Material Cost C4: Credit Time	0.47 0.53

Moreover, based on the sub-weight ($\widetilde{W}_i$), the first part that DM is able to recognize the top five sub-criteria, which covers the most of weight, for the company to involve in their supplier selection that the result is shown in Table 27. First, Quality consistent (C2) is the most vital factor in selecting a raw material supplier, for if the raw material is not stable, the material part will not be able to be assembled into a nano sim-card connector which is related to Defect rate (C1). Also, Delivery-delays (C5) is the third one that the case study company pays attention to select raw material suppliers in each raw material. The case study company produces more than one thousand components, indicating that the production scheduling would be postponed or moved to the next cycle round when one of the raw materials is delayed. To be specific, some production lines produce more than one component, showing that a component needs to standby until the next production scheduling once raw materials are delayed. Although the case study company prepares safety stock for components, the safety stock might not be sufficient in peak season. In this case, it might be unable to fulfill the orders from clients, which leads to penalties, order reduction, and other issues. Asset and debts (C9) are the fourth to assure the raw material suppliers whether to operate their business normally. Finally, Supplier contract (C10) provides an opportunity to be a fixed cost that the case study company is able to control its cost to improve its profitability. Indeed, in Table 4.4.1, the weight of proactive to inform the fluctuation (C11) is higher than C10 because the volume of raw material is average 600 kilograms that is a small portion compared to other components. In contrast, with the supplier contract, the fixed cost can reduce the production cost; meanwhile, the volume of raw material can be guaranteed by the raw material supplier to dwindle the risk of shortage. Thus, the fuzzy set theory involves all fuzzy weight to identify the optimal ranking of sub-weight in the current scenario in the case study company.

Table 27 Sub-weight from thirteen respondents

	DF	**Rank**
C1	0.43	2
C2	0.47	1
C3	0.08	10
C4	0.06	12
C5	0.28	3
C6	0.17	6
C7	0.10	8
C8	0.09	9
C9	0.26	4
C10	0.21	5
C11	0.16	6
C12	0.08	10

4.5. New supplier selection

Each respondent has a different preference in scoring raw material suppliers, which the linguistic approximation is able to deal with this situation. The results (Fuzzy synthetic decision) are obtained in each raw material in Table 28 to 31. For instance, in the current supplier selection in Stainless steel and Phosphor bronze in the case study company, before switching to new raw material suppliers, the frequency of serious issues (e.g., flatness, the times of insertion/withdrawal, pin elasticity of height, etc.) that leads to being suspended in the assembly line in OEM, paid the penalty, reworked the issue or reduced orders from clients happens three times in two years. After switching to the new supplier (Stainless steel: Supplier 1 and Phosphor bronze: Supplier 2) in

Table 32 and 33, the similar issues and the frequency are decreased to be zero so far that the case study company dwindles the potential risks in the downstream supply chain, improves the value of quality of the connector, and maintains to be the first supplier. In this case, we can assume that the other two raw material parts (Plastic and Nickel) might have a possibility to cause a different issue that affects the OEM and the case study company's performance. Also, the breakeven point was reached in 2018, that the profitability is increased. The new supplier selection results in Table 34 and 35 we provided in Plastic and Nickel have a high possibility of reducing the potential risks to not only enhance further corporation but also maintain supplier status, first supplier to clients. Hence, the new supplier selection is able to maintain and improve both the quality and value of the nano sim-card connector and reduce the potential risks in the production line in the internal factory and assembly line in OEM.

Table 28 Raw material supplier in Plastic

	$\widetilde{\boldsymbol{R}}$			DF	Rank
Supplier 1	0.170	0.585	1.744	0.833	1
Supplier 2	0.162	0.566	1.692	0.807	2
Supplier 3	0.085	0.346	1.161	0.531	4
Supplier 4	0.132	0.475	1.473	0.693	3

Table 29 Raw material supplier in Nickel

	$\widetilde{\boldsymbol{R}}$			DF	Rank
Supplier 1	0.106	0.396	1.302	0.601	4
Supplier 2	0.166	0.581	1.737	0.828	2
Supplier 3	0.175	0.601	1.787	0.854	1
Supplier 4	0.137	0.480	1.499	0.705	3

Table 30 Raw material supplier in Phosphor bronze

	$\widetilde{\boldsymbol{R}}$			DF	Rank
Supplier 1	0.151	0.524	1.596	0.757	2

Supplier 2	0.167	0.574	1.730	0.824	1
Supplier 3	0.105	0.408	1.324	0.612	3

Table 31 Raw material supplier in Stainless steel

	$\widetilde{\boldsymbol{R}}$			DF	Rank
Supplier 1	0.172	0.589	1.743	0.835	1
Supplier 2	0.153	0.536	1.626	0.772	2
Supplier 3	0.123	0.453	1.431	0.669	3

Table 32 Nano sim-card connector result in Stainless steel

	Stainless Steel supplier selection	
	Current Decision	Proposed model
Supplier 1	3	1
Supplier 2	2	2
Supplier 3	1	3

Table 33 Nano sim-card connector result in Phosphor bronze

	Phosphor bronze supplier selection	
	Current Decision	Proposed model
Supplier 1	2	2
Supplier 2	3	1
Supplier 3	1	3

Table 34 Nano sim-card connector result in Plastic

	Plastic supplier selection	
	Current Decision	Proposed model
Supplier 1	3	1
Supplier 2	2	2
Supplier 3	4	4
Supplier 4	1	3

Table 35 Nano sim-card connector result in Nickel

	Nickel supplier selection	
	Current Decision	Proposed model
Supplier 1	4	4

Supplier 2	3	2
Supplier 3	2	1
Supplier 4	1	3

Chapter 5 Sensitivity analysis

In this chapter, the sensitivity analysis provides a new perspective in raw material supplier selection by changing each weight of synthetic value in the top five sub-criteria. Ultimately, based on the result, the relationship in each sub-criterion can be analyzed for the case study company to select the suitable raw material supplier for each raw material.

5.1. Results and discussion

Step 1: Based on the sub-weight, the weight is a fixed value that would not be changed in Table 36. Collecting the data from the medium in very high (VH) from linguistic approximation is to compute the maximum weight of synthetic value in each sub-criterion in Table 37. In Table 38, the maximum weight of synthetic decision would be a standard when adjusting the synthetic value.

Table 36 Top five sub-weight after defuzzification

Sub-criteria	Weight
C2	0.47
C1	0.43
C5	0.28
C9	0.26
C10	0.21

Table 37 The linguistic approximation from the medium in very high (VH)

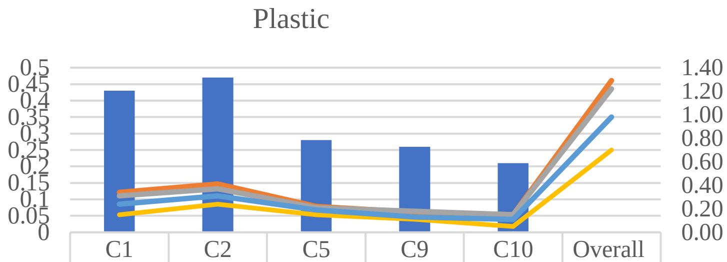
	VH
Respondent 1	88
Respondent 2	93

Respondent 3	95
Respondent 4	85
Respondent 5	85
Respondent 6	90
Respondent 7	85
Respondent 8	95
Respondent 9	90
Respondent 10	85
Respondent 11	89
Respondent 12	89
Respondent 13	89
Geometric Mean	89.01
Normalized	0.89

Table 38 The maximum weight of synthetic decision

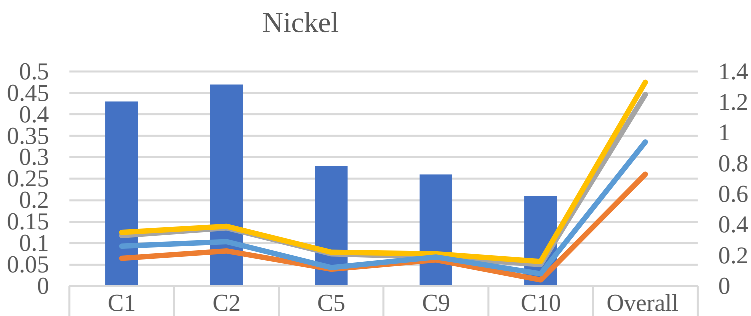
	Max weight
C1	0.38
C2	0.42
C5	0.25
C9	0.23
C10	0.19

Step 2: Based on the top five sub-criteria, adjusting the weight of sub-criteria from linguistic approximation is able to receive the new supplier selection ranking. Figure 18 to 21 shows the actual supplier selection results in four raw materials.



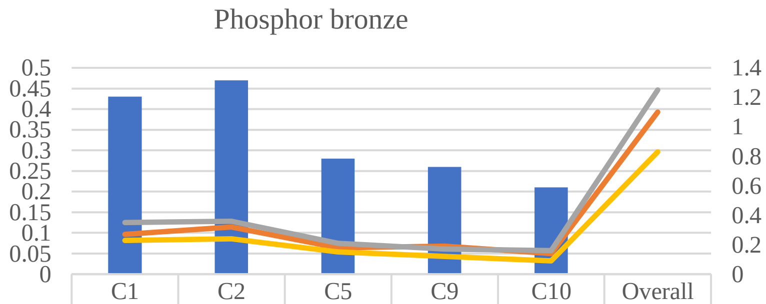
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.34	0.41	0.22	0.17	0.15	1.29
Supplier 2	0.31	0.37	0.21	0.18	0.15	1.22
Supplier 3	0.15	0.24	0.15	0.11	0.05	0.70
Supplier 4	0.24	0.31	0.19	0.13	0.11	0.98

Figure 18 The actual supplier selection in Plastic



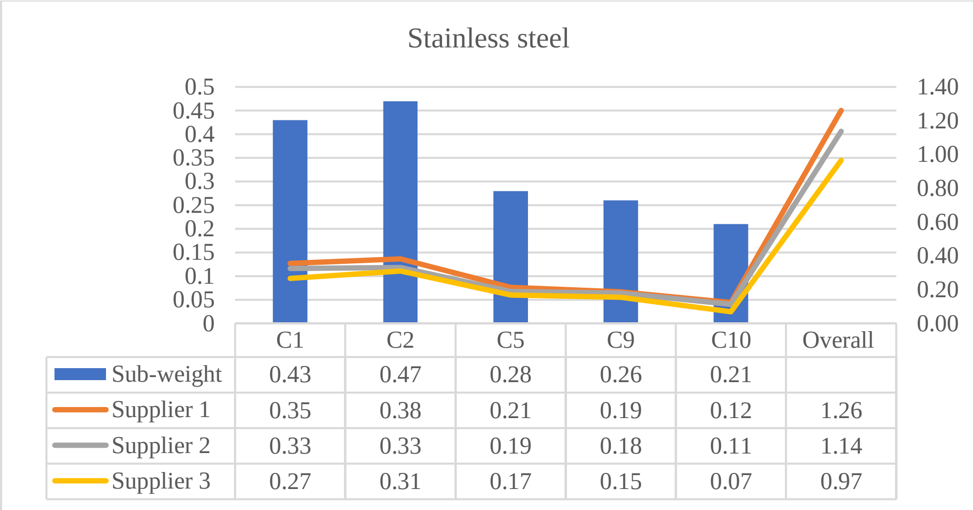
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.18	0.23	0.11	0.17	0.04	0.73
Supplier 2	0.33	0.38	0.21	0.19	0.14	1.25
Supplier 3	0.35	0.39	0.22	0.21	0.16	1.33
Supplier 4	0.26	0.29	0.12	0.19	0.08	0.94

Figure 19 The actual supplier selection in Nickel



	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.27	0.32	0.18	0.19	0.14	1.10
Supplier 2	0.35	0.36	0.21	0.17	0.16	1.25
Supplier 3	0.23	0.24	0.15	0.12	0.09	0.83

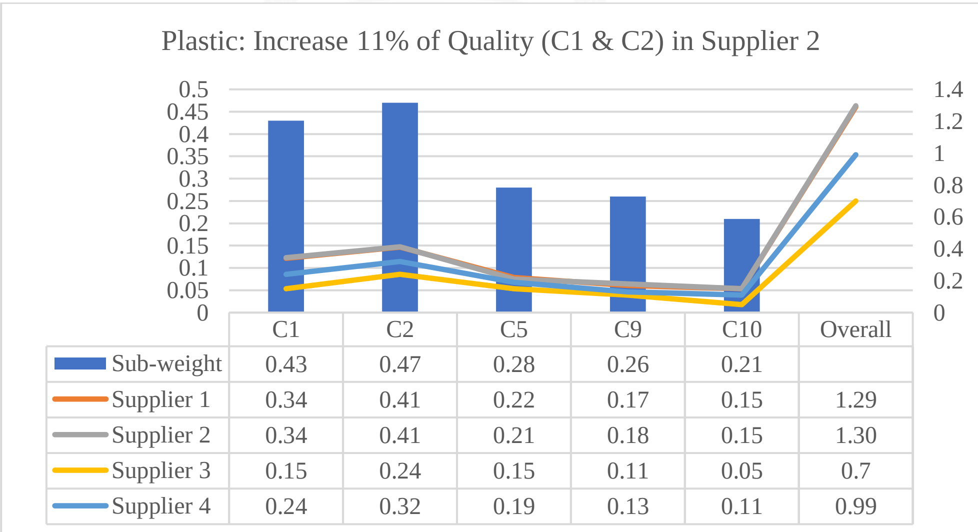
Figure 20 The actual supplier selection in Phosphor bronze



	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.35	0.38	0.21	0.19	0.12	1.26
Supplier 2	0.33	0.33	0.19	0.18	0.11	1.14
Supplier 3	0.27	0.31	0.17	0.15	0.07	0.97

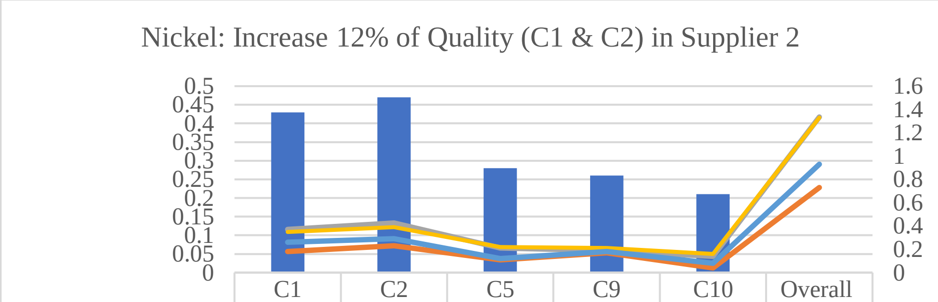
Figure 21 The actual supplier selection in Stainless steel

First, in Plastic in Supplier 2, when Quality (C1 & C2) increases 11%, Supplier 2 becomes the priority in supplier selection in Figure 22. In Supplier 2 of Nickel, when Quality (C1 & C2) increases 25%, Supplier 2 becomes the first priority in Figure 23. In Supplier 1 of Phosphor bronze, when Quality (C1 & C2) increases 27%, Supplier 1 becomes the first priority in Figure 24. In Supplier 2 of Stainless steel, when Quality (C1 & C2) increases 18%, Supplier 2 becomes the first priority in Figure 25.



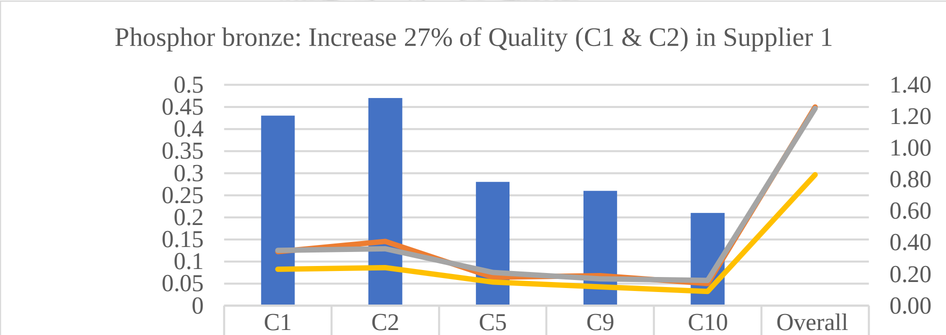
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.34	0.41	0.22	0.17	0.15	1.29
Supplier 2	0.34	0.41	0.21	0.18	0.15	1.30
Supplier 3	0.15	0.24	0.15	0.11	0.05	0.7
Supplier 4	0.24	0.32	0.19	0.13	0.11	0.99

Figure 22 Sensitivity analysis with respect to Quality in Plastic



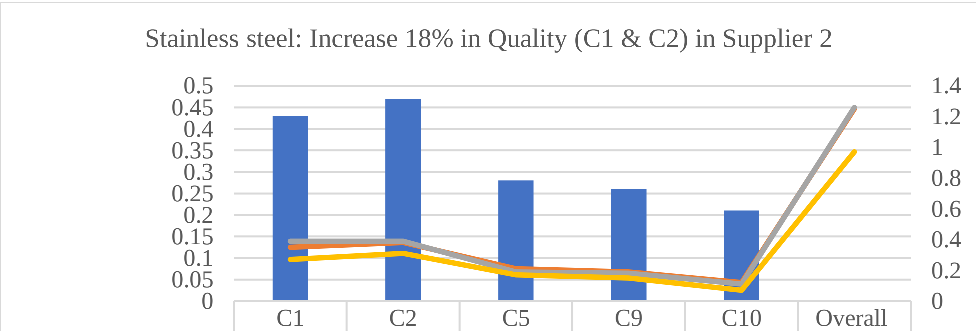
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.18	0.23	0.11	0.17	0.04	0.73
Supplier 2	0.37	0.43	0.21	0.19	0.14	1.34
Supplier 3	0.35	0.39	0.22	0.21	0.16	1.33
Supplier 4	0.26	0.29	0.12	0.18	0.08	0.93

Figure 23 Sensitivity analysis with respect to Quality in Nickel



	C1	C2	C5	C9	C10	Overall
sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.34	0.41	0.18	0.19	0.14	1.26
Supplier 2	0.35	0.36	0.21	0.17	0.16	1.25
Supplier 3	0.23	0.24	0.15	0.12	0.09	0.83

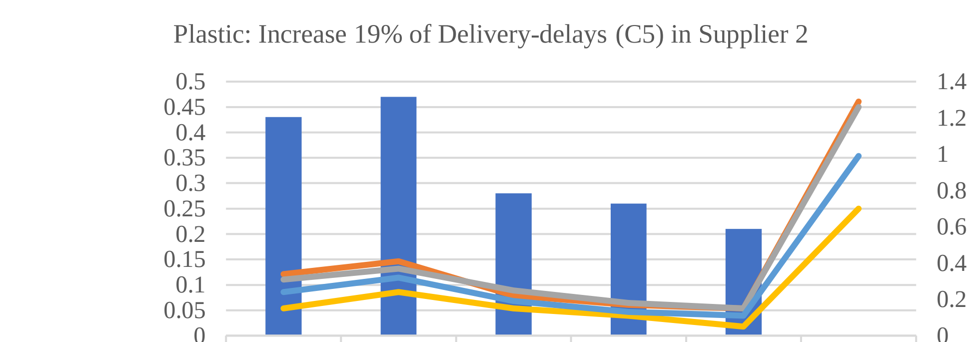
Figure 24 Sensitivity analysis with respect to Quality in Phosphor bronze



	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.35	0.38	0.21	0.19	0.12	1.25
Supplier 2	0.39	0.39	0.19	0.18	0.11	1.26
Supplier 3	0.27	0.31	0.17	0.15	0.07	0.97

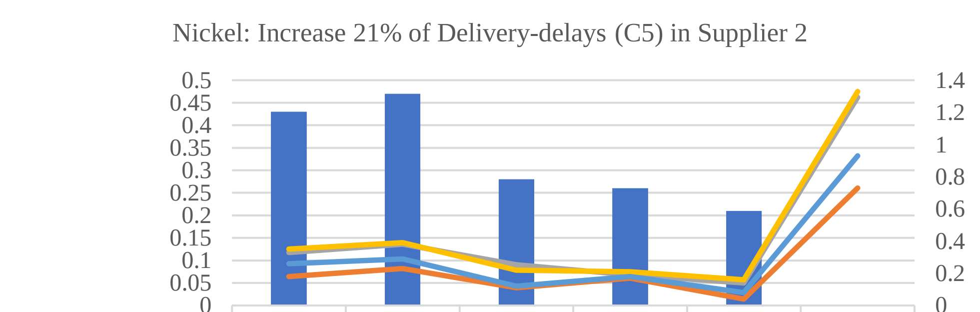
Figure 25 Sensitivity analysis with respect to Quality in Stainless steel

Second, in Plastic in Supplier 2, when Delivery-delays (C5) gains 19%, the result is not overthrown: Supplier 1 is still the first priority in Figure 26. Similar results show in Nickel, Phosphor bronze, and Stainless steel in Figure 27 to 29 that even though the weight of synthetic value in C5 reaches the maximum (0.25), the first supplier remains.



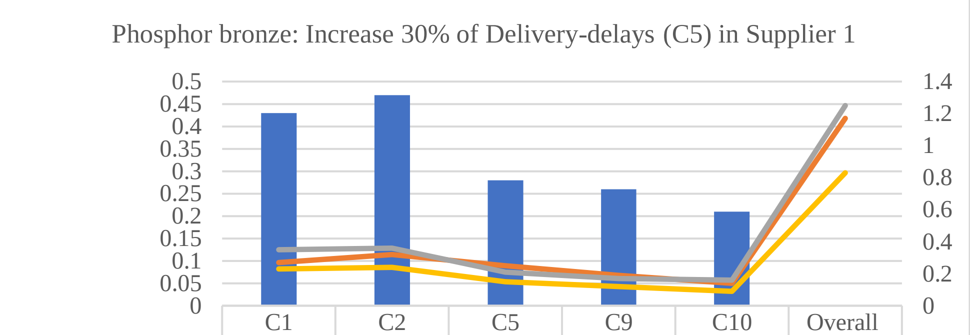
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.34	0.41	0.22	0.17	0.15	1.29
Supplier 2	0.31	0.37	0.25	0.18	0.15	1.26
Supplier 3	0.15	0.24	0.15	0.11	0.05	0.7
Supplier 4	0.24	0.32	0.19	0.13	0.11	0.99

Figure 26 Sensitivity analysis with respect to Delivery-delays in Plastic



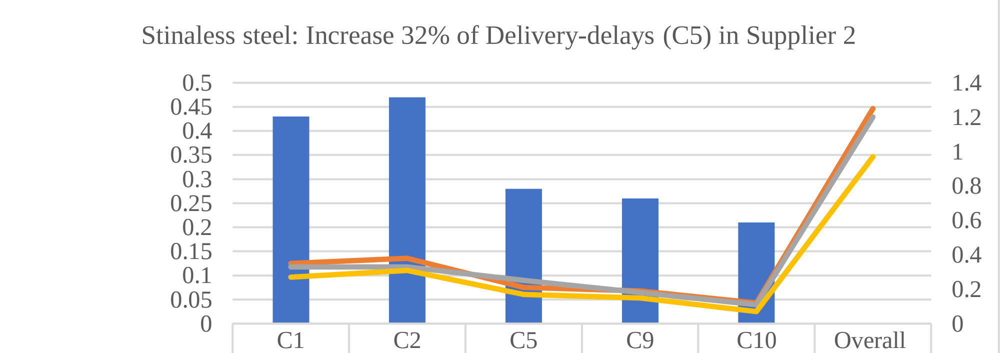
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.18	0.23	0.11	0.17	0.04	0.73
Supplier 2	0.33	0.38	0.25	0.19	0.14	1.29
Supplier 3	0.35	0.39	0.22	0.21	0.16	1.33
Supplier 4	0.26	0.29	0.12	0.18	0.08	0.93

Figure 27 Sensitivity analysis with respect to Delivery-delays in Nickel



	C1	C2	C5	C9	C10	Overall
sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.27	0.32	0.25	0.19	0.14	1.17
Supplier 2	0.35	0.36	0.21	0.17	0.16	1.25
Supplier 3	0.23	0.24	0.15	0.12	0.09	0.83

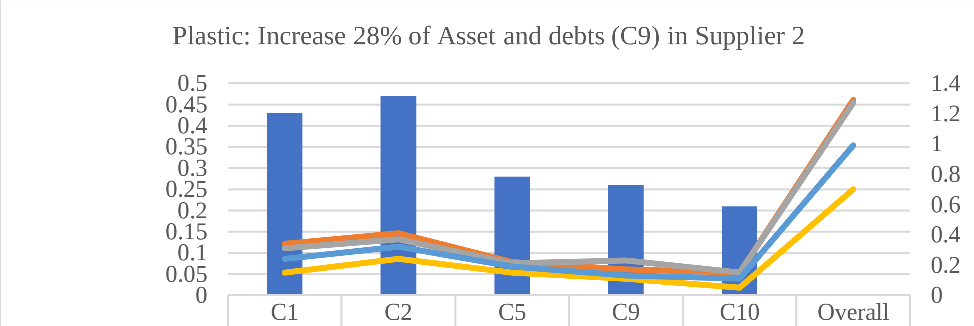
Figure 28 Sensitivity analysis with respect to Delivery-delays in Phosphor bronze



	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.35	0.38	0.21	0.19	0.12	1.25
Supplier 2	0.33	0.33	0.25	0.18	0.11	1.20
Supplier 3	0.27	0.31	0.17	0.15	0.07	0.97

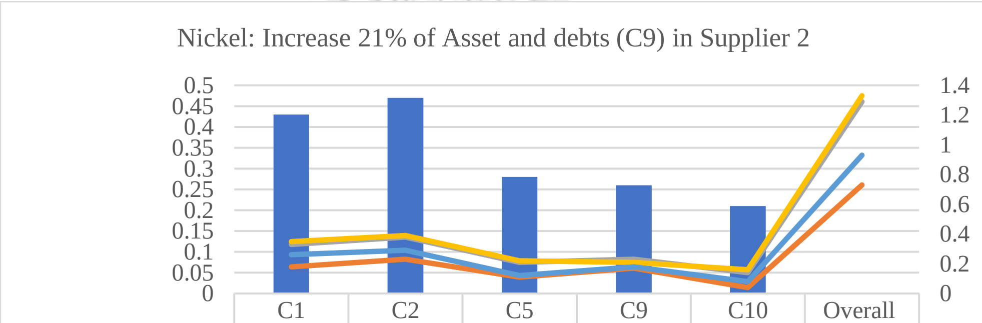
Figure 29 Sensitivity analysis with respect to Delivery-delays in Stainless steel

Third, in Asset and debts (C9) in four raw materials, they achieve the maximum weight of synthetic value, which Supplier 2 in Plastic increases 28%, Supplier 2 in Nickel increases 21%, Supplier 1 in Phosphor bronze increases 21%, and Supplier 2 in Stainless steel increases 28%. Nevertheless, the synthetic decision results show that C9 does not affect the rank in each raw material supplier selection in Figure 30 to 33.



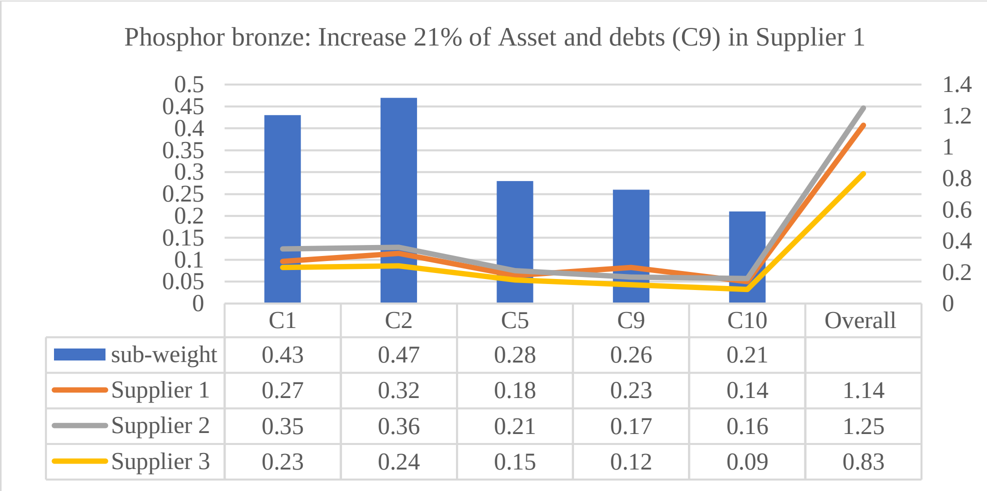
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.34	0.41	0.22	0.17	0.15	1.29
Supplier 2	0.31	0.37	0.21	0.23	0.15	1.27
Supplier 3	0.15	0.24	0.15	0.11	0.05	0.7
Supplier 4	0.24	0.32	0.19	0.13	0.11	0.99

Figure 30 Sensitivity analysis with respect to Asset and debts in Plastic



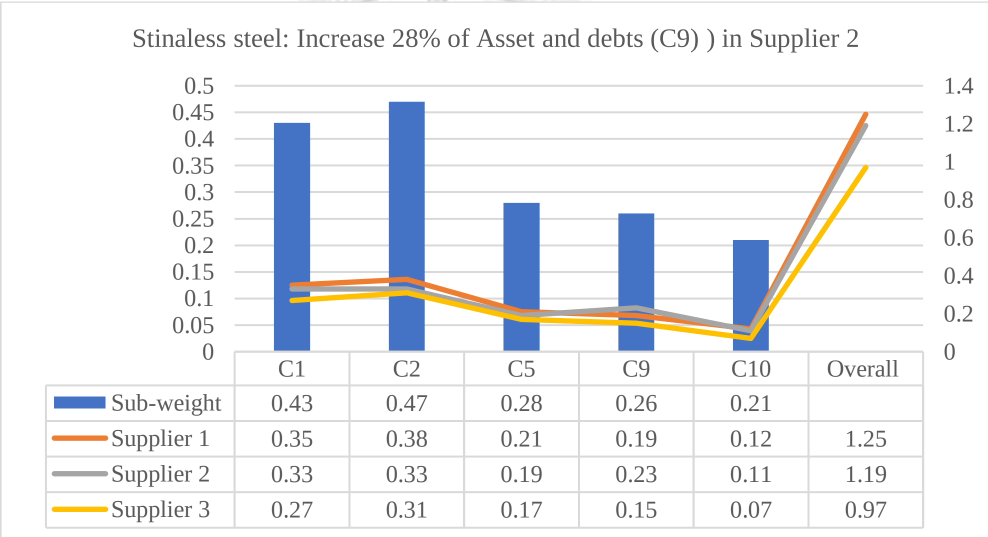
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.18	0.23	0.11	0.17	0.04	0.73
Supplier 2	0.33	0.38	0.21	0.23	0.14	1.29
Supplier 3	0.35	0.39	0.22	0.21	0.16	1.33
Supplier 4	0.26	0.29	0.12	0.18	0.08	0.93

Figure 31 Sensitivity analysis with respect to Asset and debts in Nickel



	C1	C2	C5	C9	C10	Overall
sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.27	0.32	0.18	0.23	0.14	1.14
Supplier 2	0.35	0.36	0.21	0.17	0.16	1.25
Supplier 3	0.23	0.24	0.15	0.12	0.09	0.83

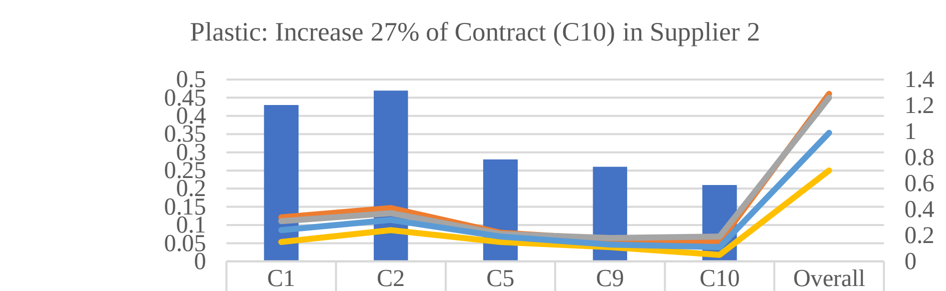
Figure 32 Sensitivity analysis with respect to Asset and debts in Phosphor bronze



	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.35	0.38	0.21	0.19	0.12	1.25
Supplier 2	0.33	0.33	0.19	0.23	0.11	1.19
Supplier 3	0.27	0.31	0.17	0.15	0.07	0.97

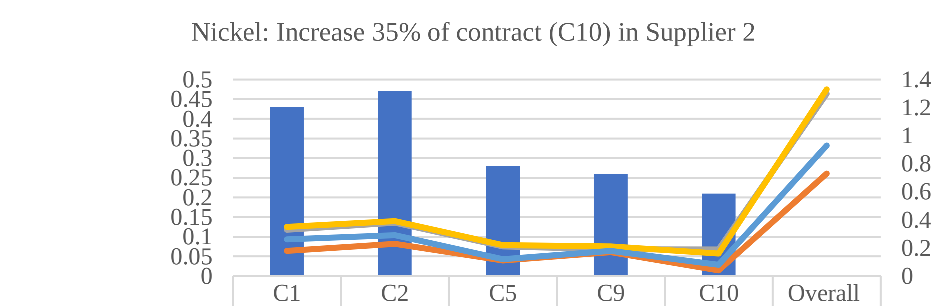
Figure 33 Sensitivity analysis with respect to Asset and debts in Stainless steel

Ultimately, in the Supplier contract (C10) in four raw materials, although the maximum weight of synthetic value is reached (Plastic: 27%, Nickel: 35%, Phosphor bronze: 35%, and Stainless steel: 72%), the synthetic decision results show that C10 does not affect the rank in each material supplier selection in Figure 34 to 37.



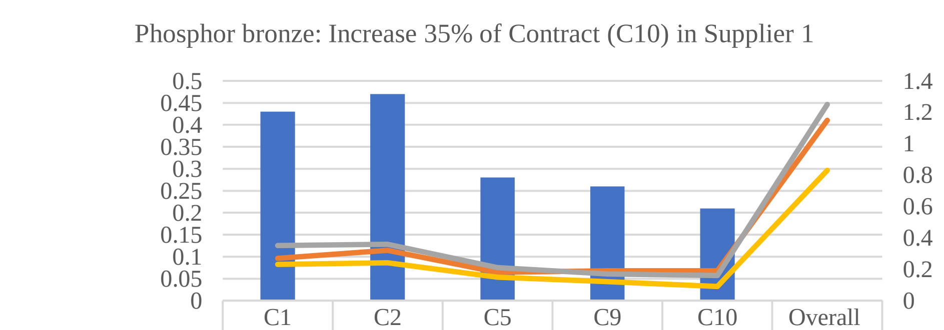
	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.34	0.41	0.22	0.17	0.15	1.29
Supplier 2	0.31	0.37	0.21	0.18	0.19	1.26
Supplier 3	0.15	0.24	0.15	0.11	0.05	0.7
Supplier 4	0.24	0.32	0.19	0.13	0.11	0.99

Figure 34 Sensitivity analysis with respect to Supplier contract in Plastic



	C1	C2	C5	C9	C10	Overall
Sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.18	0.23	0.11	0.17	0.04	0.73
Supplier 2	0.33	0.38	0.21	0.19	0.19	1.30
Supplier 3	0.35	0.39	0.22	0.21	0.16	1.33
Supplier 4	0.26	0.29	0.12	0.18	0.08	0.93

Figure 35 Sensitivity analysis with respect to Supplier contract in Plastic



	C1	C2	C5	C9	C10	Overall
sub-weight	0.43	0.47	0.28	0.26	0.21	
Supplier 1	0.27	0.32	0.18	0.19	0.19	1.15
Supplier 2	0.35	0.36	0.21	0.17	0.16	1.25
Supplier 3	0.23	0.24	0.15	0.12	0.09	0.83

Figure 36 Sensitivity analysis with respect to Supplier contract in Phosphor bronze

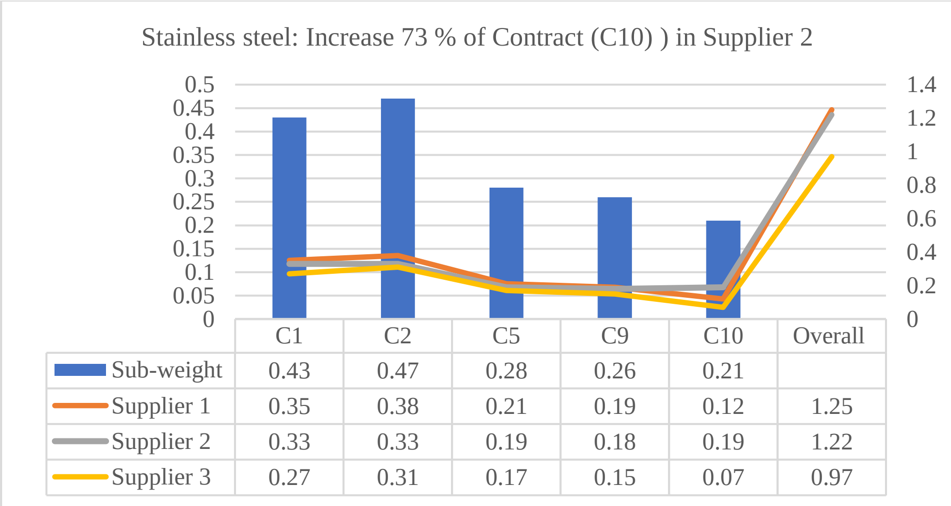


Figure 37 Sensitivity analysis with respect to Supplier contract in Stainless steel

5.2. Analysis

Traditionally, the sensitivity analysis is to understand the influence of changing the weight of main and sub-criteria on suppliers' ranking. Min (1994) and Dweiri et al. (2016) manage the criterion in different levels to adjust the main criteria weight to explore the relationship between each factor that affects the supplier selection. Nevertheless, those research focus on the large size and general components (e.g., wheel caps and door trim.) which compared to the nano sim-card connector, it is not appropriate to adjust the weight of main and sub-criteria, for it can be categorized as one of the high value-added components in the smartphone. Quality has direct effects on the user experience in the smartphone industry. Changing the weight of quality has high potential risks to affect the entire supply chain, leading to rework to fix the issue in OEM, pay the penalty, reduce orders, and even reduce to be a second source. In this thesis, the sub-weight is a fixed value after defuzzification, for the main and sub-criteria are selected by the respondents (Department of Procurement and Engineering and client) as a standard to examine the performance of the raw material suppliers in the four primary materials.

The sensitivity analysis is for changing the weight of linguistic approximation in the top five sub-criteria compared to each raw material supplier. When the raw material suppliers improve their performance (e.g., quality improvement, delay reduction, etc.), the judgment from the respondents will dynamically adjust the synthetic value to understand the relationship between each criterion and rank the suitable raw material supplier. Based on the actual results in four raw materials, the rank of supplier 1 and 2 is slightly different. It can be assumed that the supplier 2 might improve performance in the future, leading to a new supplier selection.

In Quality (C1 and C2) in Figure 5.1.5 to 5.1.8, when a second supplier improves their quality performance (Plastic: 11%, Nickel: 12%, Phosphor bronze: 27%, Stainless steel: 18%), the second supplier becomes the first supplier in each raw material. Nevertheless, in Reliability (C5), Financial status (C9), and Partnership (C10), although the second supplier achieves the maximum weight of synthetic value in each sub-criterion, the results in each material still remain the same. In this case, it indicates that in the smartphone supply chain, the quality is the priority to be considered first because of the size of components in millimeters or micrometers. When the second supplier surpasses the first supplier in quality, which reduces the defect rate in the factory, improves the quality consistency, and diminishes rework times in OEM, a new supplier selection will be created to replace the existing one. Indeed, other sub-criteria are essential, which the case study company must monitor. Nevertheless, in the competitive market in the electronic industry, the second raw material supplier has continued to improve those criteria to gain more orders from clients; meanwhile, the first raw material supplier remains or improves the performance to appeal to more clients. Hence, it can be assumed that the other three sub-criteria are essential for all raw material suppliers to reach a high level of performance. Quality (C1 and C2) becomes a determinant of whether to be the first raw material supplier in raw material supplier selection.

Chapter 6 Conclusion and possible future research

In the smartphone supply chain, each chain was relatively tied to each other. Specifically, the collaboration between manufacturers and raw material suppliers was an essential link that had a high potential risks to affect the entire supply chain performance in the market. The suitable raw material supplier strengthened the manufacturer to reduce the failure of coordination in defect rate, delays, and penalties from clients; the final products were also launched smoothly. This thesis aimed to identify the suitable raw material supplier in four primary raw materials (Plastic, Nickel, Phosphor bronze, and Stainless steel) in the nano sim-card connector. In order to achieve the objective, Fuzzy AHP was utilized to recognize the critical main and sub-criteria and select the appropriate raw material supplier in two parts. Sensitivity analysis provided a different perspective supplier selection to understand by changing the weight of synthetic value in the top five sub-criteria.

Firstly, the DM in the case study company was able to assess data to recognize the importance of main criteria (Material quality, Reliability, Partnership, and Financial status) and top five sub-criteria (Quality consistent, Defect rate, Delays, Asset and debts, and Supplier contract), which were considered the business scenarios in the case study company, collected several studies in a relative field, and selected by two departments and client.

Secondly, the vagueness of human consideration in personal preference and judgement was captured by utilizing Fuzzy AHP from collecting linguistics approximation surveys to select the suitable raw material supplier. The proposed model contributed to the DM in the case study company to identify the right raw material supplier in four primary materials (Plastic, Nickel, Phosphor bronze, and Stainless steel) to improve the value and quality of connectors and reduce the potential risks (e.g., component quality, delays, penalty, rework, etc.) in the supply chain. The new supplier selection in Phosphor bronze and Stainless steel improved the quality of the nano sim-card connecter and eliminated the serious issues, e.g., flatness, times of insertion and withdrawal, and frangibility, in the OEM. Hence, the other two raw materials (Plastic and Nickel) in the new supplier selection were able to be assumed to reduce the potential risks in the production line in the case study company and OEM.

Thirdly, sensitivity analysis provided several answers in different scenarios when the linguistic approximation in the top five sub-criteria was adjusted. The results in each sub-criterion offered new details and information in raw material supplier selection. On the one hand, in the smartphone supply chain, the quality in defect rate and consistency directly affected the performance of the raw material supplier. In a new result from the four raw materials, when quality increased 11% in Plastic, 12% in Nickel, 27% in Phosphor bronze, and 18% in Stainless steel, the first supplier was replaced by the second supplier. On the other hand, although each sub-criterion (Delays, Asset and debts, and Supplier contract) achieved the maximum weight in synthetic value, the results remained the same that the first supplier did not be replaced. In this case, those three sub-criteria were defined as fundamental elements that all raw material suppliers were crucial toward maintaining in high performance.

For future research, first, this research work can be extended to similar components produced in millimeters or micrometers and assembled in several material parts by obtaining new main criteria and sub-criteria to manufacturers. In addition, this thesis can be extended that when the total volume orders from clients are reached to a single raw material supplier that cannot satisfy demands from a manufacturer, more than one supplier in each material can be selected in supplier selection. Third, this thesis can be extended in different departments when employees and employers are less experienced in the same field, a product, defined as fast-moving consumer goods can be measured by different main criteria and sub-criteria. Each department is able to select an appropriate supplier in reasonable price and acceptable quality without involving different departments. Ultimately, by adjusting the parameter in sub-criteria or other elements, this thesis can be expanded to provide alternative information in different scenarios to select the suitable suppliers in supplier selection.

Appendix

Appendix I: Appraisal record for supplier survey of the case study company

Cat	Check list	Standard score	The standard of grading	Review department	Score	Assessor
A	Quality	40	Raw material、manufacturing process、percent of pass and defect score: (30) □ Percent of pass＞99~100%, score: 40 □ Percent of pass＞97~99% , score: 35 □ Percent of pass＞95~97% , score: 30 □ Percent of pass＞90~95% , score: 25 □ Percent of pass＞80~90% , score 20 □ Percent of pass＞70-80% , score: 15 □ Percent of pass＜70% , score: 0	QC		
B	Price	20	□ Price in peers is in top 1/3, score: 10 □ Price in peers is in the middle, score: 15 □ Price in peers is in bottom 1/3, score: 20	Procurement		
C	Delivery-on time	20	1. C＝{1 - (delay times/total times) }*20 2. One delay time to cause extra charge: -5 分 3. Cause product delay between our company and clients, score: 0	Procurement		
D	Customer service	10	□ service and corporation (very high), score: 10 □ service and corporation (high), score: 8 □ service and corporation(medium), score: 5 □service and corporation(low), score: 0	QC & Procurement		
E	Response instantly and effectively	10	□instant and effective response (high), score:10 □instant and effective response (medium), score: 5 □instant and effective response (low), score: 0	QC & Procurement		

Total score		Level		Result	□ Passed, listed in supplier roster □ Failed, reason： File：□Supplier information □Sample evaluation □ Other

Note：Level of performance, reward and punishment (If quality is lower than 20, a vendor must submit the improvement report; if lower than 10, reducing to purchase; if it's 0, removing from the supplier roster)

Level	Total score	Reward and punishment regulations
A	85>	Best supplier, being bulk purchase
B	70 ~ 84	Qualified supplier, being regular purchase
C	60 ~ 69	Still qualified supplier, but less purchase
D	60 <	Not qualified supplier, removing from the supplier roster

Appendix II: Selection for the main criteria and sub-criteria

WARWICK
THE UNIVERSITY OF WARWICK

Ethical Approval Confirmation

Dear Mr Tsai,

Warwick ID Number: 1839172

Thank you for submitting your Supervisor's Delegated Approval form to the Overseas Programmes Course Office for the project: Fuzzy AHP for supplier selection: a case study in an electronic component manufacturer.

Your reference number is REGO-2020-WMGOS-0176.

You now have the appropriate approval in place to begin your study.

Please ensure you insert a copy of this email into the appendices of your project.

Best Wishes

Mengjiao Han

WMG Overseas Programmes Course Office

wmg-overseas@warwick.ac.uk

warwick.ac.uk/fac/sci/wmg/overseas/

Dear Mr./Ms.

Please find attached a questionnaire form to collect information on selecting main criteria and sub-criteria that are essential in the nano sim-card connector.

Before filling in the questionnaire, I would briefly introduce my background.

My name is Chia Ken Tsai, a Master student in Chulalongkorn University, Thailand, and University of Warwick, England. The provisional title of my project is Fuzzy AHP for supplier selection: a case study in an electronic component manufacturer.

The definition of Fuzzy AHP for this survey is "AHP was coined by Saaty (1980) to classify multi-criteria in both quality and quantity, aiming to rank the optimal supplier. Nevertheless, in globalization and technology, more criteria need to be involved; also, uncertainty and personal judgement need to be adjusted. A triangular fuzzy number (TFN) in the fuzzy set theory (Buckley, 1985) can deal with uncertainly and preference. Hence, Fuzzy AHP is able to provide information precisely."

This questionnaire is to "be a first step for hierarchy structure to identify which main criteria and sub-criteria are necessary to be selected in the nano sim-card connector."

The questionnaire provided by you will be used for this research purposed only; also, personal information is kept confidential and not used for another research.

I appreciate that you would spend some time to answer this questionnaire, and I look forward to your participation.

Yours respectfully,

Chia Ken Tsai
Department of Regional Centre for Manufacturing Systems Engineering
Chulalongkorn University, Thailand, and University of Warwick, England

Questionnaire for survey description

A. <u>In the following sheet, we would like to elicit your point of view to identify the main criteria and sub-criteria that are essential to be selected in the nano sim-card connector.</u>

For example, in the **main criteria**, you can select more than one as follows:

If purchasing cost, material quality, risks are the three essential criteria, you can click "✓" in the column.

If you have another essential criterion that is not listed in the survey, you can fill in to No.7 and 8 in the column.

1.	Purchasing Cost	✓	**5.**	Financial status	
2.	Material Quality	✓	**6.**	Service/Partnership	
3.	Reliability		**7.**		
4.	Risks	✓	**8.**		

After the main criteria, in **sub-criteria**, you can select more than one based on the main criteria you select as follows:

If in the main criteria, purchasing cost, material quality, and risks are the three essential criteria, you can select sub-criteria based on the three criteria and click "✓"

Also, if you have another important sub-criteria that is not listed in the survey, you can fill in in the blank column based on the same main criteria that you select.

1.	Cost	i	Material cost	✓	2. Material quality	i	Quality consistency	✓
		ii	Credit time			ii	Defect rate	
		iii	Ordering cost	✓		iii		✓

B. The following questionnaire is to identify essential main criteria and sub-criteria in the nano sim-card connector in the electronic company.

Main criteria:

1.	Purchasing Cost		**5.**	Financial status	
2.	Material Quality		**6.**	Service/Partnership	
3.	Reliability		**7.**		
4.	Risks		**8.**		

Sub-criteria:

1.	Material Quality	i	Quality consistency		**5.**	Financial status	i	Cash flow	
		ii	Defect rate				ii	Assets and debts	
		iii	Packaging quality				iii	Income	
2.	Cost	i	Material cost		**6.**	Service/ Partnership	i	Contract	
		ii	Credit time				ii	Proactive information	
		iii	Ordering cost				iii	Lead time to order	
		iv	Transportation cost				iv	Response after defect	
							v	Flexibility	
3.	Reliability	i	Delivery-delay		**7.**		i		
		ii	Delivery-shortage				ii		
		iii	Minimum order requirement				iii		
4.	Risks	i	Distance		**8.**		i		
		ii	Legal environment				ii		
		iii	Political stability				iii		

□ Department of Engineering

□ Department of Procurement

Signature:__________ Date:

Appendix III: Pairwise questionnaire for Fuzzy AHP approach

WARWICK
THE UNIVERSITY OF WARWICK

Ethical Approval Confirmation

Dear Mr Tsai,

Warwick ID Number: 1839172

Thank you for submitting your Supervisor's Delegated Approval form to the Overseas Programmes Course Office for the project: Fuzzy AHP for supplier selection: a case study in an electronic component manufacturer.

Your reference number is REGO-2020-WMGOS-0176.

You now have the appropriate approval in place to begin your study.

Please ensure you insert a copy of this email into the appendices of your project.

Best Wishes

Mengjiao Han

WMG Overseas Programmes Course Office

wmg-overseas@warwick.ac.uk

warwick.ac.uk/fac/sci/wmg/overseas/

Dear Mr./Ms.

Please find attached a questionnaire form to collect information on how the level of importance in each criterion influences the selection of the raw material suppliers.

Before filling in the questionnaire, I would briefly introduce my background.

My name is Chia Ken Tsai, a Master student in Chulalongkorn University, Thailand, and University of Warwick, England. The provisional title of my project is Fuzzy AHP for supplier selection: a case study in an electronic component manufacturer.

The definition of Fuzzy AHP for this survey is "AHP was coined by Saaty (1980) to classify multi-criteria in both quality and quantity, aiming to rank the optimal supplier. Nevertheless, in globalization and technology, more criteria need to be involved; also, uncertainty and personal judgement need to be adjusted. A triangular fuzzy number (TFN) in the fuzzy set theory (Buckley, 1985) can deal with uncertainly and preference. Hence, Fuzzy AHP is able to provide information precisely."

This questionnaire is to "evaluate and compare the level of importance between each criterion in a different category."

The questionnaire provided by you will be used for this research purposed only; also, personal information is kept confidential and not used for another research.

I appreciate that you would spend some time to answer this questionnaire, and I look forward to your participation.

Yours respectfully,

Chia Ken Tsai
Department of Regional Centre for Manufacturing Systems Engineering
Chulalongkorn University, Thailand, and University of Warwick, England

Questionnaire for survey description

A. <u>In the following sheet, we would like to elicit your point of view to identify the level of importance between elements in the pairwise comparison.</u>

Fuzzy evaluation criterion	Meaning
$\tilde{1} = (1,1,1)$	Equal importance
$\tilde{2} = (1,2,3)$	Intermediate values
$\tilde{3} = (2,3,4)$	Weak importance
$\tilde{4} = (3,4,5)$	Intermediate values
$\tilde{5} = (4,5,6)$	Essential importance
$\tilde{6} = (5,6,7)$	Intermediate values
$\tilde{7} = (6,7,8)$	Very strong importance
$\tilde{8} = (7,8,9)$	Intermediate values
$\tilde{9} = (9,9,9)$	Absolute importance

For example, Compared B1 and B2, you could select their relative importance as follow:

If B1 is very strong importance than B2, you can click "✓" in the column below 7:1.

If B2 is essential importance than B1, you can click "✓" in the column below 1:5.

B. <u>The following questionnaire is to evaluate the level of importance for Fuzzy AHP to compute the weight of each criteria in the nano sim-card connector in the electronic company.</u>

Questionnaire

Paired-comparison value / Item	Identify how important between each criterion ***(9: Absolute importance, 7: Very strong importance, 5: Essential Importance, 3: Weak importance, 1: Equal) (2, 4, 6, and 8: Intermediate values)***																	Paired-comparison value / Item
	9:1	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	
Material Quality(B1)																		**Purchasing Cost (B2)**
Material Quality(B1)																		**Reliability (B3)**
Material Quality(B1)																		**Financial Status (B4)**
Material Quality(B1)																		**Partnership (B5)**
Purchasing Cost (B2)																		**Reliability (B3)**
Purchasing Cost (B2)																		**Financial Status (B4)**
Purchasing Cost (B2)																		**Partnership (B5)**
Reliability (B3)																		**Financial Status (B4)**
Reliability (B3)																		**Partnership (B5)**
Financial Status (B4)																		**Partnership (B5)**

Paired-comparison value / Item	**B1: Material Quality** Identify how important between each criterion ***(9: Absolute importance, 7: Very strong importance, 5: Essential Importance, 3: Weak importance, 1: Equal) (2, 4, 6, and 8: Intermediate values)***																	Paired-comparison value / Item
	9:1	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	
Defeat rate (C1)																		**Quality consistency (C2)**

Paired-comparison value / Item	**B2: Purchasing Cost** Identify how important between each criterion ***(9: Absolute importance, 7: Very strong importance, 5: Essential Importance, 3: Weak importance, 1: Equal) (2, 4, 6, and 8: Intermediate values)***																	Paired-comparison value / Item
	9:1	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	
Material Cost (C3)																		**Credit Time (C4)**

Paired-comparison value / Item	B3: Reliability Identify how important between each criterion ***(9: Absolute importance, 7: Very strong importance, 5: Essential Importance, 3: Weak importance, 1: Equal) (2, 4, 6, and 8: Intermediate values)***																	Paired-comparison value / Item
	9:1	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	
Delivery-Delays (C5)																		**Delivery-shortages (C6)**
Delivery-Delays (C5)																		**Minimum order requirement (C7)**
Delivery-shortages (C6)																		**Minimum order requirement (C7)**

Paired-comparison value / Item	B4: Financial Status Identify how important between each criterion ***(9: Absolute importance, 7: Very strong importance, 5: Essential Importance, 3: Weak importance, 1: Equal) (2, 4, 6, and 8: Intermediate values)***	Paired-comparison value / Item

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Cash flow (C8)																		**Asset and debts (C9)**

Paired-comparison value / Item	**B5: Partnership** Identify how important between each criterion ***(9: Absolute importance, 7: Very strong importance, 5: Essential Importance, 3: Weak importance, 1: Equal) (2, 4, 6, and 8: Intermediate values)***																	Paired-comparison value / Item
	9:1	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	
Supplier contract (C10)																		**Informing the price fluctuation proactively (C11)**
Supplier contract (C10)																		**Lead time to order (C12)**
Informing the price fluctuation proactively (C11)																		**Lead time to order (C12)**

□Department of Engineering
□Department of Procurement
□Client
Signature:_______ Date:

Appendix IV: Questionnaire of Linguistic Approximation

WARWICK
THE UNIVERSITY OF WARWICK

Ethical Approval Confirmation

Dear Mr Tsai,

Warwick ID Number: 1839172

Thank you for submitting your Supervisor's Delegated Approval form to the Overseas Programmes Course Office for the project: Fuzzy AHP for supplier selection: a case study in an electronic component manufacturer.

Your reference number is REGO-2020-WMGOS-0176.

You now have the appropriate approval in place to begin your study.

Please ensure you insert a copy of this email into the appendices of your project.

Best Wishes

Mengjiao Han

WMG Overseas Programmes Course Office

wmg-overseas@warwick.ac.uk

warwick.ac.uk/fac/sci/wmg/overseas/

Dear Mr./Ms.

Please find attached a questionnaire form to collect information on how the level of importance in each criterion would influence on selecting the raw material suppliers.

Before filling in the questionnaire, I would briefly introduce my background.

My name is Chia Ken Tsai, a Master student in Chulalongkorn University, Thailand, and University of Warwick, England. The provisional title of my project is Fuzzy AHP for supplier selection: a case study in an electronic component manufacturer.

The definition of Fuzzy AHP for this survey is "AHP was coined by Saaty (1980) to classify multi-criteria in both quality and quantity, which aims to rank the optimal supplier. Nevertheless, in globalization and technology, more criteria need to be involved; also, uncertainty and personal judgement need to be adjusted. A triangular fuzzy number (TFN) in the fuzzy set theory (Buckley, 1985) can deal with uncertainly and preference. Hence, Fuzzy AHP is able to provide information precisely."

This questionnaire is for "Linguistic Approximation is between 0 to 100 percent. Each respondent has a different range of linguistic approximation to judge different suppliers."

The questionnaire provided by you will be used for this research purposed only; also, personal information is kept confidential and not used for another research.

I appreciate that you would spend some time to answer this questionnaire, and I look forward to your participation.

Yours respectfully,

Chia Ken Tsai

Department of Regional Centre for Manufacturing Systems Engineering

Chulalongkorn University, Thailand, and University of Warwick, England

Questionnaire for survey description

A. **<u>In the following sheet, we would like to elicit your point of view to identify a different rang of linguistic approximation to judge different suppliers.</u>**

For example, you could fill in the range between 0 to 100 percent as follow:

If very low (VL) is 5, 15, and 20, you can insert your number in the column below VL.

Very low (VL)
5,15,20

After all the range is completed, you can move to the next step to compare sub-criteria and suppliers in different rang of linguistic approximation.

If supplier 1 in C1 is VL, you can click "✓" in the column below VL.

If supplier 2 in C1 is VH, you can click "✓" in the column below VH.

B. **<u>The following questionnaire is to evaluate the linguistic approximation for Fuzzy AHP to compute the weight of suppliers in the nano sim-card connector in the electronic company.</u>**

Respondent	**Very Low (VL)**	**Low (L)**	**Medium (M)**
	(VL_L, VL_M, VL_U)	(L_L, L_M, L_U)	(M_L, M_M, M_U)
	High (H)	**Very high (VH)**	
	(H_L, H_M, H_U)	(VH_L, VH_M, VH_U)	

1. Raw material supplier (Nickel)

C1. Defect rate					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C2. Quality consistency					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

4					

C3. Material Cost					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C4. Credit Time					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					

C5. Delivery-delays					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C6. Delivery-shortage					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C7. Minimum order requirement					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					

C8. Cash Flow					
Supplier	**VL**	**L**	**M**	**H**	**VH**

1					
2					
3					
4					
C9. Asset and Debts					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					

C10. Supplier contracts					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C11. Informing the price fluctuation proactively					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C12. Lead time to order					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					

2. Raw material supplier (Stainless Steel)

C1. Defect rate

Supplier	VL	L	M	H	VH
1					
2					
3					
C2. Quality consistency					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

C3. Material Cost					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C4. Credit Time					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

C5. Delivery-delays					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C6. Delivery-shortage					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C7. Minimum order requirement					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

C8. Cash Flow					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C9. Asset and Debts					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

C10. Supplier contracts					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C11. Informing the price fluctuation proactively					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C12. Lead time to order					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

3. Raw material supplier (Phosphor Bronze)

C1. Defect rate					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C2. Quality consistency					
Supplier	**VL**	**L**	**M**	**H**	**VH**

1					
2					
3					

C3. Material Cost					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C4. Credit Time					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

C5. Delivery-delays					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C6. Delivery-shortage					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C7. Minimum order requirement					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

C8. Cash Flow					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

C9. Asset and Debts					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

C10. Supplier contracts					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C11. Informing the price fluctuation proactively					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
C12. Lead time to order					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					

4. Raw material supplier (Plastic)

C1. Defect rate					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C2. Quality consistency					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					

C3. Material Cost

Supplier	VL	L	M	H	VH
1					
2					
3					
4					

C4. Credit Time

Supplier	VL	L	M	H	VH
1					
2					
3					
4					

C5. Delivery-delays

Supplier	VL	L	M	H	VH
1					
2					
3					
4					

C6. Delivery-shortage

Supplier	VL	L	M	H	VH
1					
2					
3					
4					

C7. Minimum order requirement

Supplier	VL	L	M	H	VH
1					
2					
3					
4					

C8. Cash Flow

Supplier	VL	L	M	H	VH
1					
2					

3					
4					
C9. Asset and Debts					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					

C10. Supplier contracts					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C11. Informing the price fluctuation proactively					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					
C12. Lead time to order					
Supplier	**VL**	**L**	**M**	**H**	**VH**
1					
2					
3					
4					

Appendix V: The pairwise comparison matrix in sub-criteria

1.	C1			C2		
C1	1	1	1	1	1	1
C2	1	1	1	1	1	1
2.	C1			C2		
C1	1	1	1	1/4	1/3	1/2
C2	2	3	4	1	1	1
3.	C1			C2		
C1	1	1	1	1/6	1/5	1/4
C2	4	5	6	1	1	1
4.	C1			C2		
C1	1	1	1	1	1	1
C2	1	1	1	1	1	1
5.	C1			C2		
C1	1	1	1	2	3	4
C2	1/4	1/3	1/2	1	1	1
6.	C1			C2		
C1	1	1	1	1	1	1
C2	1	1	1	1	1	1
7.	C1			C2		
C1	1	1	1	1/8	1/7	1/6
C2	6	7	8	1	1	1

8.	C1			C2		
C1	1	1	1	1/4	1/3	1/2
C2	2	3	4	1	1	1
9.	C1			C2		
C1	1	1	1	1/6	1/5	1/4
C2	4	5	6	1	1	1
10.	C1			C2		
C1	1	1	1	2	3	4
C2	1/4	1/3	1/2	1	1	1
11.	C1			C2		
C1	1	1	1	4	3	5
C2	1/5	1/3	1/4	1	1	1
12.	C1			C2		
C1	1	1	1	6	7	8
C2	1/8	1/7	1/6	1	1	1
13.	C1			C2		
C1	1	1	1	6	7	8
C2	1/8	1/7	1/6	1	1	1

(Source: Developed for this study)

1.	C3			C4		
C3	1	1	1	1/4	1/3	1/2
C4	2	3	4	1	1	1
2.	C3			C4		
C3	1	1	1	1/4	1/3	1/2
C4	2	3	4	1	1	1
3.	C3			C4		
C3	1	1	1	1	1	1
C4	1	1	1	1	1	1
4.	C3			C4		
C3	1	1	1	1	1	1
C4	1	1	1	1	1	1
5.	C3			C4		
C3	1	1	1	2	3	4
C4	1/4	1/3	1/2	1	1	1
6.	C3			C4		

8.	C3			C4		
C3	1	1	1	1/4	1/3	1/2
C4	2	3	4	1	1	1
9.	C3			C4		
C3	1	1	1	2	3	4
C4	1/4	1/3	1/2	1	1	1
10.	C3			C4		
C3	1	1	1	4	5	6
C4	1/6	1/5	1/4	1	1	1
11.	C3			C4		
C3	1	1	1	2	3	4
C4	1/4	1/3	1/2	1	1	1
12.	C3			C4		
C3	1	1	1	1	1	1
C4	1	1	1	1	1	1
13.	C3			C4		

C3	1	1	1	**1/4**	**1/3**	**1/2**
C4	**2**	**3**	**4**	1	1	1
7.	C3			C4		
C3	1	1	1	**1**	**1**	**1**
C4	**1**	**1**	**1**	1	1	1

C3	1	1	1	**1/6**	**1/5**	**1/4**
C4	**4**	**5**	**6**	1	1	1

(Source: Developed for this study)

1.	C5			C6			C7		
C5	1	1	1	**4**	**5**	**6**	**6**	**7**	**8**
C6	**1/6**	**1/5**	**1/4**	1	1	1	**2**	**3**	**4**
C7	**1/8**	**1/7**	**1/6**	**1/4**	**1/3**	**1/2**	1	1	1
2.	C5			C6			C7		
C5	1	1	1	**6**	**7**	**8**	**6**	**7**	**8**
C6	**1/8**	**1/7**	**1/6**	1	1	1	**1**	**1**	**1**
C7	**1/8**	**1/7**	**1/6**	**1**	**1**	**1**	1	1	1
3.	C5			C6			C7		
C5	1	1	1	**2**	**3**	**4**	**9**	**9**	**9**
C6	**1/4**	**1/3**	**1/2**	1	1	1	**1**	**1**	**1**
C7	**1/9**	**1/9**	**1/9**	**1**	**1**	**1**	1	1	1
4.	C5			C6			C7		
C5	1	1	1	**1**	**1**	**1**	**2**	**3**	**4**
C6	**1**	**1**	**1**	1	1	1	**2**	**3**	**4**
C7	**1/4**	**1/3**	**1/2**	**1/4**	**1/3**	**1/2**	1	1	1
5.	C5			C6			C7		
C5	1	1	1	**1**	**1**	**1**	**1**	**1**	**1**
C6	**1**	**1**	**1**	1	1	1	**1**	**1**	**1**
C7	**1**	**1**	**1**	**1**	**1**	**1**	1	1	1
6.	C5			C6			C7		
C5	1	1	1	**3**	**4**	**5**	**3**	**4**	**5**
C6	**1/5**	**1/4**	**1/3**	1	1	1	**1/3**	**1/2**	**1**
C7	**1/5**	**1/4**	**1/3**	**1**	**2**	**3**	1	1	1
7.	C5			C6			C7		
C5	1	1	1	**2**	**3**	**4**	**4**	**5**	**6**
C6	**1/4**	**1/3**	**1/2**	1	1	1	**6**	**7**	**8**
C7	**1/6**	**1/5**	**1/4**	**1/8**	**1/7**	**1/6**	1	1	1

8.	C5			C6			C7		
C5	1	1	1	**1/4**	**1/3**	**1/2**	**2**	**3**	**4**
C6	**2**	**3**	**4**	1	1	1	**9**	**9**	**9**
C7	**1/4**	**1/3**	**1/2**	**1/9**	**1/9**	**1/9**	1	1	1
9.	C5			C6			C7		
C5	1	1	1	**9**	**9**	**9**	**6**	**7**	**8**
C6	**1/9**	**1/9**	**1/9**	1	1	1	**2**	**3**	**4**
C7	**1/8**	**1/7**	**1/6**	**1/4**	**1/3**	**1/2**	1	1	1
10.	C5			C6			C7		
C5	1	1	1	**1**	**1**	**1**	**4**	**5**	**6**
C6	**1**	**1**	**1**	1	1	1	**4**	**5**	**6**
C7	**1/6**	**1/5**	**1/4**	**1/6**	**1/5**	**1/4**	1	1	1
11.	C5			C6			C7		
C5	1	1	1	**2**	**3**	**4**	**6**	**7**	**8**
C6	**1/4**	**1/3**	**1/2**	1	1	1	**9**	**9**	**9**
C7	**1/8**	**1/7**	**1/6**	**1/9**	**1/9**	**1/9**	1	1	1
12.	C5			C6			C7		
C5	1	1	1	**6**	**7**	**8**	**9**	**9**	**9**
C6	**1/8**	**1/7**	**1/6**	1	1	1	**6**	**7**	**8**
C7	**1/9**	**1/9**	**1/9**	**1/8**	**1/7**	**1/6**	1	1	1
13.	C5			C6			C7		
C5	1	1	1	**1**	**1**	**1**	**9**	**9**	**9**
C6	**1**	**1**	**1**	1	1	1	**9**	**9**	**9**
C7	**1/9**	**1/9**	**1/9**	**1/9**	**1/9**	**1/9**	1	1	1

(Source: Developed for this study)

1.	C8			C9		
C8	1	1	1	**1**	**1**	**1**
C9	**1**	**1**	**1**	1	1	1
2.	C8			C9		

8.	C8			C9		
C8	1	1	1	**2**	**3**	**4**
C9	**1/4**	**1/3**	**1/2**	1	1	1
9.	C8			C9		

C8	1	1	1	**1/6**	**1/5**	**1/4**
C9	**4**	**5**	**6**	1	1	1
3.	C8			C9		
C8	1	1	1	**2**	**3**	**4**
C9	**1/4**	**1/3**	**1/2**	1	1	1
4.	C8			C9		
C8	1	1	1	**4**	**5**	**6**
C9	**1/6**	**1/5**	**1/4**	1	1	1
5.	C8			C9		
C8	1	1	1	**1/4**	**1/3**	**1/2**
C9	**2**	**3**	**4**	1	1	1
6.	C8			C9		
C8	1	1	1	**1/6**	**1/5**	**1/4**
C9	**4**	**5**	**6**	1	1	1
7.	C8			C9		
C8	1	1	1	**1/4**	**1/3**	**1/2**
C9	**2**	**3**	**4**	1	1	1

C8	1	1	1	**1/4**	**1/3**	**1/2**
C9	**2**	**3**	**4**	1	1	1
10.	C8			C9		
C8	1	1	1	**1**	**1**	**1**
C9	**1**	**1**	**1**	1	1	1
11.	C8			C9		
C8	1	1	1	**1/9**	**1/9**	**1/9**
C9	**9**	**9**	**9**	1	1	1
12.	C8			C9		
C8	1	1	1	**1/8**	**1/7**	**1/6**
C9	**6**	**7**	**8**	1	1	1
13.	C8			C9		
C8	1	1	1	**1/6**	**1/5**	**1/4**
C9	**4**	**5**	**6**	1	1	1

(Source: Developed for this study)

1.	C10			C11			C12		
C10	1	1	1	**1/4**	**1/3**	**1/2**	**2**	**3**	**4**
C11	**2**	**3**	**4**	1	1	1	**4**	**5**	**6**
C12	**1/4**	**1/3**	**1/2**	**1/6**	**1/5**	**1/4**	1	1	1
2.	C10			C11			C12		
C10	1	1	1	**1/6**	**1/5**	**1/4**	**1**	**1**	**1**
C11	**4**	**5**	**6**	1	1	1	**4**	**5**	**6**
C12	**1**	**1**	**1**	**1/6**	**1/5**	**1/4**	1	1	1
3.	C10			C11			C12		
C10	1	1	1	**1**	**1**	**1**	**1**	**1**	**1**
C11	**1**	**1**	**1**	1	1	1	**1**	**2**	**3**
C12	**1**	**1**	**1**	**1/3**	**1/2**	**1**	1	1	1
4.	C10			C11			C12		
C10	1	1	1	**1/4**	**1/3**	**1/2**	**1/3**	**1/2**	**1**
C11	**2**	**3**	**4**	1	1	1	**2**	**3**	**4**
C12	**1**	**2**	**3**	**1/4**	**1/3**	**1/2**	1	1	1
5.	C10			C11			C12		
C10	1	1	1	**1/8**	**1/7**	**1/6**	**1/4**	**1/3**	**1/2**
C11	**6**	**7**	**8**	1	1	1	**4**	**5**	**6**
C12	**2**	**3**	**4**	**1/6**	**1/5**	**1/4**	1	1	1
6.	C10			C11			C12		
C10	1	1	1	**1/9**	**1/9**	**1/9**	**1**	**1**	**1**

8.	C10			C11			C12		
C10	1	1	1	**6**	**7**	**8**	**2**	**3**	**4**
C11	**1/8**	**1/7**	**1/6**	1	1	1	**1/4**	**1/3**	**1/2**
C12	**1/4**	**1/3**	**1/2**	**2**	**3**	**4**	1	1	1
9.	C10			C11			C12		
C10	1	1	1	**4**	**5**	**6**	**4**	**5**	**6**
C11	**1/6**	**1/5**	**1/4**	1	1	1	**2**	**3**	**4**
C12	**1/6**	**1/5**	**1/4**	**1/4**	**1/3**	**1/2**	1	1	1
10.	C10			C11			C12		
C10	1	1	1	**1/8**	**1/7**	**1/6**	**4**	**5**	**6**
C11	**6**	**7**	**8**	1	1	1	**6**	**7**	**8**
C12	**1/6**	**1/5**	**1/4**	**1/8**	**1/7**	**1/6**	1	1	1
11.	C10			C11			C12		
C10	1	1	1	**1/4**	**1/3**	**1/2**	**2**	**3**	**4**
C11	**2**	**3**	**4**	1	1	1	**2**	**3**	**4**
C12	**1/4**	**1/3**	**1/2**	**1/4**	**1/3**	1/2	1	1	1
12.	C10			C11			C12		
C10	1	1	1	**1**	**1**	**1**	**1/4**	**1/3**	**1/2**
C11	**1**	**1**	**1**	1	1	1	**1**	**1**	**1**
C12	**2**	**3**	**4**	**1**	**1**	**1**	1	1	1
13.	C10			C11			C12		
C10	1	1	1	**6**	**7**	**8**	**2**	**3**	**4**

C11	**9**	**9**	**9**	1	1	1	**6**	**7**	**8**
C12	**1**	**1**	**1**	**1/8**	**1/7**	**1/6**	1	1	1
7.	C10			C11			C12		
C10	1	1	1	**1/8**	**1/7**	**1/6**	**1/4**	**1/2**	**1**
C11	**6**	**7**	**8**	1	1	1	**4**	**5**	**6**
C12	**1**	**2**	**4**	**1/6**	**1/5**	**1/4**	1	1	1

C11	**1/8**	**1/7**	**1/6**	1	1	1	**1/4**	**1/3**	**1/2**
C12	**1/4**	**1/3**	**1/2**	**2**	**3**	**4**	1	1	1

(Source: Developed for this study)

Appendix VI: Test consistency in sub-criteria

1. Test consistency in sub-criteria (C1 to C2)

1.	Test Consistency		**8.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
2.	Test Consistency		**9.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
3.	Test Consistency		**10.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
4.	Test Consistency		**11.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
5.	Test Consistency		**12.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
6.	Test Consistency		**13.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
7.	Test Consistency				
λM	2.00				
C.I.	0.00	**Accepted**			
C.R.	0.00	**Accepted**			

(Source: Developed for this study)

2. Test consistency in sub-criteria (C3 to C4)

1.	Test Consistency		**8.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
2.	Test Consistency		**9.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
3.	Test Consistency		**10.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**

C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
4.	Test Consistency		**11.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
5.	Test Consistency		**12.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
6.	Test Consistency		**13.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
7.	Test Consistency				
λM	2.00				
C.I.	0.00	**Accepted**			
C.R.	0.00	**Accepted**			

(Source: Developed for this study)

3. Test consistency in sub-criteria (C5 to C7)

1.	Test Consistency		**8.**	Test Consistency	
λM	3.06		λM	3.00	
C.I.	0.03	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.06	**Accepted**	C.R.	0.00	**Accepted**
2.	Test Consistency		**9.**	Test Consistency	
λM	3.00		λM	3.21	
C.I.	0.00	**Accepted**	C.I.	0.10	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.20	**Accepted**
3.	Test Consistency		**10.**	Test Consistency	
λM	3.14		λM	3.00	
C.I.	0.07	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.13	**Accepted**	C.R.	0.00	**Accepted**
4.	Test Consistency		**11.**	Test Consistency	
λM	3.00		λM	3.21	
C.I.	0.00	**Accepted**	C.I.	0.10	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.20	**Accepted**
5.	Test Consistency		**12.**	Test Consistency	
λM	3.00		λM	3.33	
C.I.	0.00	**Accepted**	C.I.	0.16	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.32	**Rejected**
6.	Test Consistency		**13.**	Test Consistency	
λM	3.05		λM	3.00	
C.I.	0.03	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.05	**Accepted**	C.R.	0.00	**Accepted**
7.	Test Consistency				
λM	3.23				
C.I.	0.12	**Accepted**			
C.R.	0.22	**Rejected**			

(Source: Developed for this study)

4. Test consistency in sub-criteria (C8 to C9)

1.	Test Consistency		**8.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
2.	Test Consistency		**9.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
3.	Test Consistency		**10.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
4.	Test Consistency		**11.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
5.	Test Consistency		**12.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
6.	Test Consistency		**13.**	Test Consistency	
λM	2.00		λM	2.00	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.00	**Accepted**
7.	Test Consistency				
λM	2.00				
C.I.	0.00	**Accepted**			
C.R.	0.00	**Accepted**			

(Source: Developed for this study)

5. Test consistency in sub-criteria (C10 to C12)

1.	Test Consistency		**8.**	Test Consistency	
λM	3.04		λM	3.01	
C.I.	0.02	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.04	**Accepted**	C.R.	0.01	**Accepted**
2.	Test Consistency		**9.**	Test Consistency	
λM	3.00		λM	3.14	
C.I.	0.00	**Accepted**	C.I.	0.07	**Accepted**
C.R.	0.00	**Accepted**	C.R.	0.13	**Accepted**
3.	Test Consistency		**10.**	Test Consistency	
λM	3.05		λM	3.29	
C.I.	0.03	**Accepted**	C.I.	0.15	**Accepted**
C.R.	0.05	**Accepted**	C.R.	0.28	**Rejected**
4.	Test Consistency		**11.**	Test Consistency	
λM	3.05		λM	3.14	
C.I.	0.03	**Accepted**	C.I.	0.07	**Accepted**
C.R.	0.05	**Accepted**	C.R.	0.13	**Accepted**

5.	Test Consistency		**12.**	Test Consistency	
λM	3.06		λM	3.14	
C.I.	0.03	**Accepted**	C.I.	0.07	**Accepted**
C.R.	0.06	**Accepted**	C.R.	0.13	**Rejected**
6.	Test Consistency		**13.**	Test Consistency	
λM	3.01		λM	3.01	
C.I.	0.00	**Accepted**	C.I.	0.00	**Accepted**
C.R.	0.01	**Accepted**	C.R.	0.01	**Accepted**
7.	Test Consistency				
λM	3.01				
C.I.	0.01	**Accepted**			
C.R.	0.01	**Rejected**			

(Source: Developed for this study)

Appendix VII: The result of Fuzzy synthetic value

1. Fuzzy synthetic value in Plastic

C1	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	75	82	89	70	75	79	10	15	20	60	75	85
Respondent 2	82	93	97	65	77	80	25	40	50	50	55	65
Respondent 3	65	75	83	83	95	100	55	60	70	55	60	70
Respondent 4	76	85	94	60	69	75	24	35	43	60	69	75
Respondent 5	66	76	81	49	56	65	35	46	49	35	46	49
Respondent 6	70	75	80	70	75	80	50	60	70	50	60	70
Respondent 7	82	85	90	66	75	80	31	45	50	51	60	65
Respondent 8	65	70	80	45	50	60	5	10	15	20	30	40
Respondent 9	85	90	95	65	75	85	50	60	65	50	60	65
Respondent 10	60	65	75	75	85	90	16	30	39	60	65	75
Respondent 11	82	89	93	65	69	74	20	37	47	52	58	63
Respondent 12	64	72	83	64	72	83	28	32	41	45	50	57
Respondent 13	84	89	98	62	75	79	23	33	38	40	49	59
Geometric Mean	73.034	80.004	87.233	63.801	72.074	78.630	24.094	34.807	42.414	46.655	55.465	63.396
Normalized	**0.730**	**0.800**	**0.872**	**0.638**	**0.721**	**0.786**	**0.241**	**0.348**	**0.424**	**0.467**	**0.555**	**0.634**
C2	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	85	88	92	85	88	92	45	55	60	60	75	85
Respondent 2	82	93	97	65	77	80	50	55	65	65	77	80
Respondent 3	83	95	100	83	95	100	55	60	70	65	75	83
Respondent 4	76	85	94	60	69	75	60	69	75	60	69	75
Respondent 5	81	95	95	66	76	81	49	56	65	49	56	65
Respondent 6	80	90	95	70	75	80	50	60	70	70	75	80
Respondent 7	82	85	90	82	85	90	51	60	65	66	75	80
Respondent 8	85	95	100	65	70	80	20	30	40	45	50	60
Respondent 9	85	90	95	85	90	95	50	60	65	65	75	85
Respondent 10	60	65	75	60	65	75	40	50	60	40	50	60
Respondent 11	82	89	93	65	69	74	52	58	63	65	69	74
Respondent 12	64	72	83	86	89	96	28	32	41	64	72	83
Respondent 13	84	89	98	84	89	98	40	49	59	62	75	79
Geometric Mean	78.729	86.520	92.584	72.832	79.190	85.361	43.765	52.066	60.451	58.954	67.945	75.555
Normalized	**0.787**	**0.865**	**0.926**	**0.728**	**0.792**	**0.854**	**0.438**	**0.521**	**0.605**	**0.590**	**0.679**	**0.756**
C3	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	45	55	60	60	75	85	85	88	92	85	88	92

Respondent 2	25	40	50	50	55	65	65	77	80	82	93	97
Respondent 3	10	18	30	55	60	70	65	75	83	55	60	70
Respondent 4	24	35	43	44	50	59	76	85	94	60	69	75
Respondent 5	49	56	65	49	56	65	81	95	95	66	76	81
Respondent 6	25	40	55	25	40	55	70	75	80	50	60	70
Respondent 7	31	45	50	51	60	65	66	75	80	51	60	65
Respondent 8	20	30	40	45	50	60	85	95	100	65	70	80
Respondent 9	25	40	50	50	60	65	65	75	85	65	75	85
Respondent 10	16	30	39	40	50	60	75	85	90	60	65	75
Respondent 11	20	37	47	52	58	63	82	89	93	65	69	74
Respondent 12	1	1	27	28	32	41	64	72	83	45	50	57
Respondent 13	40	49	59	40	49	59	62	75	79	62	75	79
Geometric Mean	19.662	28.738	45.923	44.088	52.442	61.732	71.919	81.244	86.971	61.445	69.098	76.228
Normalized	**0.197**	**0.287**	**0.459**	**0.441**	**0.524**	**0.617**	**0.719**	**0.812**	**0.870**	**0.614**	**0.691**	**0.762**
C4	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	60	75	85	45	55	60	45	55	60
Respondent 2	50	55	65	65	77	80	25	40	50	50	55	65
Respondent 3	65	75	83	55	60	70	25	40	55	55	60	70
Respondent 4	44	50	59	60	69	75	2	6	24	24	35	43
Respondent 5	66	76	81	35	46	49	35	46	49	49	56	65
Respondent 6	70	75	80	50	60	70	25	40	55	25	40	55
Respondent 7	51	60	65	66	75	80	1	15	30	31	45	50
Respondent 8	65	70	80	45	50	60	20	30	40	45	50	60
Respondent 9	65	75	85	65	75	85	25	40	50	25	40	50
Respondent 10	60	65	75	40	50	60	16	30	39	60	65	75
Respondent 11	65	69	74	52	58	63	20	37	47	20	37	47
Respondent 12	64	72	83	45	50	57	28	32	41	64	72	83
Respondent 13	62	75	79	62	75	79	40	49	59	62	75	79
Geometric Mean	60.055	68.062	75.996	52.872	62.043	69.301	16.849	31.530	44.694	39.678	51.204	60.500
Normalized	**0.601**	**0.681**	**0.760**	**0.529**	**0.620**	**0.693**	**0.168**	**0.315**	**0.447**	**0.397**	**0.512**	**0.605**
C5	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	60	75	85	60	75	85	60	75	85
Respondent 2	82	93	97	82	93	97	65	77	80	65	77	80
Respondent 3	65	75	83	55	60	70	25	40	55	55	60	70
Respondent 4	60	69	75	76	85	94	44	50	59	44	50	59
Respondent 5	66	76	81	66	76	81	35	46	49	49	56	65
Respondent 6	70	75	80	50	60	70	25	40	55	50	60	70

Respondent 7	66	75	80	51	60	65	31	45	50	51	60	65
Respondent 8	65	70	80	85	95	100	45	50	60	65	70	80
Respondent 9	85	90	95	85	90	95	50	60	65	85	90	95
Respondent 10	75	85	90	60	65	75	40	50	60	60	65	75
Respondent 11	65	69	74	82	89	93	52	58	63	52	58	63
Respondent 12	86	89	96	64	72	83	45	50	57	64	72	83
Respondent 13	84	89	98	84	89	98	62	75	79	84	89	98
Geometric Mean	70.874	78.799	85.307	67.974	76.522	84.251	42.595	53.743	61.937	59.183	66.841	75.121
Normalized	**0.709**	**0.788**	**0.853**	**0.680**	**0.765**	**0.843**	**0.426**	**0.537**	**0.619**	**0.592**	**0.668**	**0.751**
C6	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	60	75	85	20	30	45	45	55	60
Respondent 2	50	55	65	65	77	80	5	20	25	25	40	50
Respondent 3	83	95	100	65	75	83	25	40	55	65	75	83
Respondent 4	76	85	94	44	50	59	24	35	43	60	69	75
Respondent 5	66	76	81	81	95	95	1	20	35	49	56	65
Respondent 6	80	90	95	70	75	80	50	60	70	70	75	80
Respondent 7	66	75	80	66	75	80	31	45	50	51	60	65
Respondent 8	45	50	60	65	70	80	20	30	40	45	50	60
Respondent 9	85	90	95	65	75	85	50	60	65	50	60	65
Respondent 10	60	65	75	75	85	90	16	30	39	40	50	60
Respondent 11	52	58	63	65	69	74	2	10	18	52	58	63
Respondent 12	64	72	83	45	50	57	28	32	41	28	32	41
Respondent 13	84	89	98	84	89	98	40	49	59	62	75	79
Geometric Mean	65.678	73.594	81.504	64.358	72.703	79.566	15.634	32.099	42.417	47.482	56.508	63.986
Normalized	**0.657**	**0.736**	**0.815**	**0.644**	**0.727**	**0.796**	**0.156**	**0.321**	**0.424**	**0.475**	**0.565**	**0.640**
C7	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	20	30	45	45	55	60	60	75	85	45	55	60
Respondent 2	25	40	50	50	55	65	65	77	80	65	77	80
Respondent 3	25	40	55	25	40	55	65	75	83	55	60	70
Respondent 4	24	35	43	2	6	24	60	69	75	44	50	59
Respondent 5	35	46	49	49	56	65	81	95	95	66	76	81
Respondent 6	25	40	55	50	60	70	70	75	80	70	75	80
Respondent 7	31	45	50	51	60	65	66	75	80	51	60	65
Respondent 8	45	50	60	20	30	40	65	70	80	65	70	80
Respondent 9	25	40	50	50	60	65	85	90	95	65	75	85
Respondent 10	40	50	60	40	50	60	75	85	90	60	65	75
Respondent 11	20	37	47	52	58	63	82	89	93	65	69	74

Respondent 12	28	32	41	45	50	57	64	72	83	45	50	57
Respondent 13	23	33	38	23	33	38	62	75	79	40	49	59
Geometric Mean	27.317	39.356	49.025	31.516	41.988	53.900	68.756	78.230	84.226	55.682	63.086	70.484
Normalized	**0.273**	**0.394**	**0.490**	**0.315**	**0.420**	**0.539**	**0.688**	**0.782**	**0.842**	**0.557**	**0.631**	**0.705**
C8	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	85	88	92	60	75	85	60	75	85	85	88	92
Respondent 2	65	77	80	50	55	65	50	55	65	50	55	65
Respondent 3	55	60	70	65	75	83	55	60	70	65	75	83
Respondent 4	44	50	59	60	69	75	60	69	75	24	35	43
Respondent 5	49	56	65	49	56	65	66	76	81	66	76	81
Respondent 6	70	75	80	25	40	55	50	60	70	50	60	70
Respondent 7	66	75	80	82	85	90	51	60	65	82	85	90
Respondent 8	45	50	60	65	70	80	65	70	80	45	50	60
Respondent 9	65	75	85	25	40	50	50	60	65	85	90	95
Respondent 10	40	50	60	60	65	75	75	85	90	40	50	60
Respondent 11	52	58	63	52	58	63	20	37	47	65	69	74
Respondent 12	64	72	83	86	89	96	45	50	57	45	50	57
Respondent 13	62	75	79	62	75	79	62	75	79	84	89	98
Geometric Mean	57.379	65.085	72.748	53.818	63.735	72.705	52.437	62.700	70.480	57.026	64.585	72.539
Normalized	**0.574**	**0.651**	**0.727**	**0.538**	**0.637**	**0.727**	**0.524**	**0.627**	**0.705**	**0.570**	**0.646**	**0.725**
C9	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	85	88	92	45	55	60	20	30	45
Respondent 2	65	77	80	50	55	65	50	55	65	25	40	50
Respondent 3	55	60	70	65	75	83	25	40	55	55	60	70
Respondent 4	76	85	94	60	69	75	44	50	59	44	50	59
Respondent 5	66	76	81	66	76	81	35	46	49	49	56	65
Respondent 6	50	60	70	70	75	80	25	40	55	70	75	80
Respondent 7	82	85	90	66	75	80	51	60	65	51	60	65
Respondent 8	65	70	80	65	70	80	20	30	40	20	30	40
Respondent 9	50	60	65	65	75	85	25	40	50	50	60	65
Respondent 10	16	30	39	60	65	75	16	30	39	40	50	60
Respondent 11	52	58	63	65	69	74	20	37	47	52	58	63
Respondent 12	64	72	83	45	50	57	28	32	41	45	50	57
Respondent 13	84	89	98	62	75	79	40	49	59	40	49	59
Geometric Mean	56.805	66.870	74.993	62.718	69.868	76.883	30.503	42.316	51.867	40.515	49.805	58.949
Normalized	**0.568**	**0.669**	**0.750**	**0.627**	**0.699**	**0.769**	**0.305**	**0.423**	**0.519**	**0.405**	**0.498**	**0.589**
C10	Supplier 1			Supplier 2			Supplier 3			Supplier 4		

Respondent 1	85	88	45	85	88	45	20	30	45	60	75	85
Respondent 2	65	77	80	50	55	65	25	40	50	82	93	97
Respondent 3	83	95	100	65	75	83	25	40	55	55	60	70
Respondent 4	44	50	59	60	69	75	2	6	24	24	35	43
Respondent 5	66	76	81	81	95	95	35	46	49	49	56	65
Respondent 6	50	60	70	70	75	80	25	40	55	25	40	55
Respondent 7	82	85	90	82	85	90	31	45	50	51	60	65
Respondent 8	45	50	60	45	50	60	5	10	15	65	70	80
Respondent 9	65	75	85	85	90	95	25	40	50	50	60	65
Respondent 10	75	85	90	60	65	75	16	30	39	40	50	60
Respondent 11	65	69	74	65	69	74	20	37	47	52	58	63
Respondent 12	64	72	83	45	50	57	1	1	27	28	32	41
Respondent 13	84	89	98	62	75	79	23	33	38	40	49	59
Geometric Mean	65.623	73.283	76.347	64.293	70.920	73.334	13.743	22.361	39.471	44.965	54.519	63.523
Normalized	**0.656**	**0.733**	**0.763**	**0.643**	**0.709**	**0.733**	**0.137**	**0.224**	**0.395**	**0.450**	**0.545**	**0.635**
C11	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	20	30	45	20	30	45	10	15	20	45	55	60
Respondent 2	25	40	50	50	55	65	25	40	50	5	20	25
Respondent 3	25	40	55	55	60	70	10	18	30	25	40	55
Respondent 4	44	50	59	24	35	43	2	6	24	24	35	43
Respondent 5	35	46	49	1	20	35	1	20	35	49	56	65
Respondent 6	50	60	70	25	40	55	10	10	30	25	40	55
Respondent 7	51	60	65	31	45	50	1	15	30	51	60	65
Respondent 8	20	30	40	45	50	60	5	10	15	5	10	15
Respondent 9	25	40	50	65	75	85	10	15	30	50	60	65
Respondent 10	40	50	60	40	50	60	16	30	39	60	65	75
Respondent 11	52	58	63	20	37	47	2	10	18	20	37	47
Respondent 12	28	32	41	45	50	57	28	32	41	28	32	41
Respondent 13	40	49	59	62	75	79	23	33	38	62	75	79
Geometric Mean	33.097	43.777	53.549	28.058	45.156	56.129	6.668	16.909	29.189	27.168	40.203	48.914
Normalized	**0.331**	**0.438**	**0.535**	**0.281**	**0.452**	**0.561**	**0.067**	**0.169**	**0.292**	**0.272**	**0.402**	**0.489**
C12	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
Respondent 1	60	75	85	85	88	92	20	30	45	45	55	60
Respondent 2	65	77	80	65	77	80	25	40	50	50	55	65
Respondent 3	65	75	83	55	60	70	25	40	55	25	40	55
Respondent 4	44	50	59	60	69	75	24	35	43	44	50	59
Respondent 5	66	76	81	66	76	81	1	20	35	35	46	49

Respondent 6	50	60	70	80	90	95	25	40	55	70	75	80
Respondent 7	66	75	80	51	60	65	31	45	50	51	60	65
Respondent 8	65	70	80	85	95	100	20	30	40	45	50	60
Respondent 9	50	60	65	65	75	85	25	40	50	50	60	65
Respondent 10	60	65	75	75	85	90	16	30	39	40	50	60
Respondent 11	52	58	63	65	69	74	20	37	47	65	69	74
Respondent 12	86	89	96	64	72	83	28	32	41	45	50	57
Respondent 13	62	75	79	62	75	79	23	33	38	40	49	59
Geometric Mean	60.026	68.861	75.984	66.774	75.518	81.655	18.195	34.124	44.797	45.168	53.816	61.699
Normalized	**0.600**	**0.689**	**0.760**	**0.668**	**0.755**	**0.817**	**0.182**	**0.341**	**0.448**	**0.452**	**0.538**	**0.617**

(Source: Developed for this study)

2. Fuzzy synthetic value in Stainless steel

C1	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	85	88	92	60	75	85	60	75	85
Respondent 2	65	77	80	65	77	80	50	55	65
Respondent 3	83	95	100	65	75	83	55	60	70
Respondent 4	76	85	94	76	85	94	60	69	75
Respondent 5	66	76	81	81	95	95	66	76	81
Respondent 6	70	75	80	70	75	80	50	60	70
Respondent 7	82	85	90	66	75	80	51	60	65
Respondent 8	65	70	80	65	70	80	45	50	60
Respondent 9	85	90	95	85	90	95	65	75	85
Respondent 10	75	85	90	60	65	75	60	65	75
Respondent 11	82	89	93	82	89	93	65	69	74
Respondent 12	64	72	83	45	50	57	45	50	57
Respondent 13	84	89	98	62	75	79	40	49	59
Geometric Mean	75.087	82.418	88.648	66.986	75.718	82.100	54.125	61.818	70.265
Normalized	**0.751**	**0.824**	**0.886**	**0.670**	**0.757**	**0.821**	**0.541**	**0.618**	**0.703**
C2	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	85	88	92	85	88	92	60	75	85
Respondent 2	65	77	80	65	77	90	65	77	80
Respondent 3	83	95	100	65	75	83	65	75	83
Respondent 4	60	69	75	44	50	59	44	50	59
Respondent 5	81	95	95	66	76	81	66	76	81
Respondent 6	80	90	95	50	60	70	70	75	80
Respondent 7	66	75	80	82	85	90	66	75	80

Respondent 8	65	70	80	65	70	80	65	70	80
Respondent 9	65	75	85	85	90	95	50	60	65
Respondent 10	75	85	90	60	65	75	60	65	75
Respondent 11	82	89	93	65	59	74	52	58	63
Respondent 12	64	72	83	64	72	83	64	72	83
Respondent 13	84	89	98	62	75	79	40	49	59
Geometric Mean	71.978	81.217	87.469	63.504	70.313	79.339	58.074	66.051	73.395
Normalized	**0.720**	**0.812**	**0.875**	**0.635**	**0.703**	**0.793**	**0.581**	**0.661**	**0.734**
C3	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	45	55	60	60	75	85	85	88	92
Respondent 2	50	55	65	50	55	65	82	93	97
Respondent 3	55	60	70	65	75	83	83	95	100
Respondent 4	24	35	43	44	50	59	60	69	75
Respondent 5	35	46	49	49	56	65	66	76	81
Respondent 6	50	60	70	70	75	80	70	75	80
Respondent 7	51	60	65	82	85	90	82	85	90
Respondent 8	45	50	60	65	70	80	85	95	100
Respondent 9	25	40	50	50	60	65	65	75	85
Respondent 10	40	50	60	60	65	75	60	65	75
Respondent 11	20	37	47	52	58	63	65	69	74
Respondent 12	45	50	57	64	72	83	86	89	96
Respondent 13	40	49	59	62	75	79	84	89	98
Geometric Mean	38.163	48.594	57.255	58.536	65.552	73.285	73.306	80.564	87.010
Normalized	**0.382**	**0.486**	**0.573**	**0.585**	**0.656**	**0.733**	**0.733**	**0.806**	**0.870**
C4	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	60	75	85	20	30	45
Respondent 2	82	93	97	65	77	80	50	55	65
Respondent 3	65	75	83	25	40	55	25	40	55
Respondent 4	60	69	75	76	85	94	24	35	43
Respondent 5	66	76	81	49	56	65	1	20	35
Respondent 6	70	75	80	50	60	70	10	10	30
Respondent 7	82	85	90	66	75	80	51	60	65
Respondent 8	65	70	80	65	70	80	45	50	60
Respondent 9	65	75	85	85	90	95	50	60	65
Respondent 10	60	65	75	60	65	75	16	30	39
Respondent 11	82	89	93	82	89	93	52	58	63
Respondent 12	64	72	83	45	50	57	28	32	41

Respondent 13	62	75	79	62	75	79	62	75	79
Geometric Mean	68.125	76.187	83.168	58.213	67.544	75.793	24.625	38.782	51.215
Normalized	**0.681**	**0.762**	**0.832**	**0.582**	**0.675**	**0.758**	**0.246**	**0.388**	**0.512**
C5	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	85	88	92	60	75	85	60	75	85
Respondent 2	65	77	80	82	93	97	65	77	80
Respondent 3	65	75	83	65	75	83	65	75	83
Respondent 4	76	85	94	60	69	75	44	50	59
Respondent 5	66	76	81	49	56	65	49	56	65
Respondent 6	70	75	80	50	60	70	50	60	70
Respondent 7	82	85	90	82	85	90	66	75	80
Respondent 8	65	70	80	45	50	60	45	50	60
Respondent 9	50	60	65	65	75	85	50	60	65
Respondent 10	75	85	90	75	85	90	60	65	75
Respondent 11	65	69	74	52	58	63	52	58	63
Respondent 12	86	89	96	64	72	83	45	50	57
Respondent 13	62	75	79	40	49	59	40	49	59
Geometric Mean	68.284	76.328	82.232	59.262	67.512	75.629	51.876	59.618	67.431
Normalized	**0.683**	**0.763**	**0.822**	**0.593**	**0.675**	**0.756**	**0.519**	**0.596**	**0.674**
C6	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	44	55	60	60	75	85
Respondent 2	82	93	97	65	77	80	50	55	65
Respondent 3	65	75	83	83	95	100	65	75	83
Respondent 4	44	50	59	60	69	75	24	35	43
Respondent 5	81	95	95	81	95	95	66	76	81
Respondent 6	70	75	80	50	60	70	50	60	70
Respondent 7	82	85	90	66	75	80	51	60	65
Respondent 8	65	70	80	45	50	60	20	30	40
Respondent 9	65	75	85	85	90	95	65	75	85
Respondent 10	60	65	75	40	50	60	16	30	39
Respondent 11	82	89	93	65	69	74	65	69	74
Respondent 12	64	72	83	45	50	57	28	32	41
Respondent 13	62	75	79	62	75	79	62	75	79
Geometric Mean	67.530	75.561	82.612	60.492	69.437	75.870	42.078	52.531	61.119
Normalized	**0.675**	**0.756**	**0.826**	**0.605**	**0.694**	**0.759**	**0.421**	**0.525**	**0.611**
C7	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	20	30	45	20	30	45	60	75	85

Respondent 2	50	55	65	25	40	50	65	77	80
Respondent 3	55	60	70	65	75	83	83	95	100
Respondent 4	24	35	43	44	50	59	60	69	75
Respondent 5	49	56	65	49	56	65	66	76	81
Respondent 6	50	60	70	70	75	80	80	90	95
Respondent 7	51	60	65	51	60	65	66	75	80
Respondent 8	20	30	40	20	30	40	85	95	100
Respondent 9	50	60	65	25	40	50	65	75	85
Respondent 10	16	30	39	40	50	60	75	85	90
Respondent 11	52	58	63	65	69	74	65	69	74
Respondent 12	45	50	57	64	72	83	86	89	96
Respondent 13	40	49	59	40	49	59	62	75	79
Geometric Mean	38.992	48.716	57.263	43.147	53.518	62.567	70.924	80.332	85.774
Normalized	**0.390**	**0.487**	**0.573**	**0.431**	**0.535**	**0.626**	**0.709**	**0.803**	**0.858**
C8	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	85	88	92	60	75	85	85	88	92
Respondent 2	65	77	80	50	55	65	50	55	65
Respondent 3	65	75	83	25	40	55	55	60	70
Respondent 4	60	69	75	44	50	59	76	85	94
Respondent 5	66	76	81	35	46	49	49	56	65
Respondent 6	70	75	80	50	60	70	70	75	80
Respondent 7	66	75	80	51	60	65	82	85	90
Respondent 8	65	70	80	20	30	40	45	50	60
Respondent 9	85	90	95	50	60	65	65	75	85
Respondent 10	75	85	90	60	65	75	75	85	90
Respondent 11	65	69	74	65	69	74	82	89	93
Respondent 12	64	72	83	64	72	83	86	89	96
Respondent 13	84	89	98	40	49	59	62	75	79
Geometric Mean	68.772	76.525	82.961	43.738	53.242	62.153	64.952	71.861	79.610
Normalized	**0.688**	**0.765**	**0.830**	**0.437**	**0.532**	**0.622**	**0.650**	**0.719**	**0.796**
C9	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	60	75	85	60	75	85
Respondent 2	82	93	97	50	55	65	65	77	80
Respondent 3	65	75	83	83	95	100	65	75	83
Respondent 4	60	69	75	44	50	59	44	50	59
Respondent 5	49	56	65	66	76	81	66	76	81
Respondent 6	80	90	95	70	75	80	50	60	70

Respondent 7	66	75	80	51	60	65	31	45	50
Respondent 8	45	50	60	65	70	80	45	50	60
Respondent 9	85	90	95	65	75	85	50	60	65
Respondent 10	60	65	75	60	65	75	40	50	60
Respondent 11	65	69	74	52	58	63	52	58	63
Respondent 12	64	72	83	86	89	96	64	72	83
Respondent 13	62	75	79	62	75	79	40	49	59
Geometric Mean	64.195	72.128	79.304	61.666	69.077	76.370	49.713	59.108	66.886
Normalized	**0.642**	**0.721**	**0.793**	**0.617**	**0.691**	**0.764**	**0.497**	**0.591**	**0.669**
C10	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	45	55	60	45	55	60	20	30	45
Respondent 2	50	55	65	25	40	50	5	20	25
Respondent 3	25	40	55	55	60	70	10	18	30
Respondent 4	60	69	75	44	50	59	24	35	43
Respondent 5	49	56	65	35	46	49	1	20	35
Respondent 6	25	40	55	50	60	70	25	40	55
Respondent 7	66	75	80	51	60	65	31	45	50
Respondent 8	45	50	60	45	50	60	20	30	40
Respondent 9	50	60	65	25	40	50	25	40	50
Respondent 10	40	50	60	60	65	75	16	30	39
Respondent 11	65	69	74	52	58	63	20	37	47
Respondent 12	64	72	83	45	50	57	45	50	57
Respondent 13	84	89	98	62	75	79	40	49	59
Geometric Mean	48.981	58.752	68.568	44.016	53.597	61.519	15.934	32.673	42.845
Normalized	**0.490**	**0.588**	**0.686**	**0.440**	**0.536**	**0.615**	**0.159**	**0.327**	**0.428**
C11	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	45	55	60	20	30	45	10	15	20
Respondent 2	25	40	50	25	40	50	5	20	25
Respondent 3	25	40	55	55	60	70	25	40	55
Respondent 4	44	50	59	2	6	24	24	35	43
Respondent 5	49	56	65	35	46	49	35	46	49
Respondent 6	25	40	55	50	60	70	10	10	30
Respondent 7	31	45	50	31	45	50	1	15	30
Respondent 8	20	30	40	45	50	60	5	10	15
Respondent 9	25	40	50	50	60	65	25	40	50
Respondent 10	40	50	60	40	50	60	16	30	39
Respondent 11	20	37	47	52	58	63	2	10	18

Respondent 12	28	32	41	28	32	41	1	1	27
Respondent 13	62	75	79	40	49	59	40	49	59
Geometric Mean	30.787	43.261	53.335	30.981	41.268	53.198	8.619	17.973	33.753
Normalized	**0.308**	**0.433**	**0.533**	**0.310**	**0.413**	**0.532**	**0.086**	**0.180**	**0.338**
C12	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	60	75	85	45	55	60
Respondent 2	50	55	65	65	77	80	25	40	50
Respondent 3	83	95	100	65	75	83	55	60	70
Respondent 4	44	50	59	60	69	75	2	6	24
Respondent 5	49	56	65	49	56	65	35	46	49
Respondent 6	70	75	80	50	60	70	25	40	55
Respondent 7	51	60	65	51	60	65	31	45	50
Respondent 8	85	95	100	45	50	60	20	30	40
Respondent 9	65	75	85	50	60	65	25	40	50
Respondent 10	40	50	60	40	50	60	16	30	39
Respondent 11	52	58	63	82	89	93	2	10	18
Respondent 12	64	72	83	86	89	96	45	50	57
Respondent 13	84	89	98	62	75	79	40	49	59
Geometric Mean	59.512	67.354	75.421	57.276	66.258	73.363	18.953	31.756	44.055
Normalized	**0.595**	**0.674**	**0.754**	**0.573**	**0.663**	**0.734**	**0.190**	**0.318**	**0.441**

(Source: Developed for this study)

3. Fuzzy synthetic value in Phosphor bronze

C1	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	85	88	92	60	75	85	60	75	85
Respondent 2	50	55	65	65	77	80	50	55	65
Respondent 3	65	75	83	65	75	83	55	60	70
Respondent 4	44	50	59	76	85	94	60	69	75
Respondent 5	66	76	81	81	95	95	49	56	65
Respondent 6	80	90	95	80	90	95	70	75	80
Respondent 7	66	75	80	82	85	90	66	75	80
Respondent 8	45	50	60	65	70	80	20	30	40
Respondent 9	50	60	65	85	90	95	25	40	50
Respondent 10	40	50	60	60	65	75	40	50	60
Respondent 11	52	58	63	82	89	93	20	37	47
Respondent 12	28	32	41	64	72	83	45	50	57
Respondent 13	62	75	79	84	89	98	40	49	59

Geometric Mean	54.150	61.864	69.366	72.379	80.792	87.857	42.793	53.478	62.646
Normalized	**0.541**	**0.619**	**0.694**	**0.724**	**0.808**	**0.879**	**0.428**	**0.535**	**0.626**
C2	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	45	55	60	85	88	92	60	75	85
Respondent 2	65	77	80	50	55	65	25	40	50
Respondent 3	65	75	83	83	95	100	55	60	70
Respondent 4	60	69	75	76	85	94	44	50	59
Respondent 5	66	76	81	66	76	81	35	46	49
Respondent 6	50	60	70	50	60	70	25	40	55
Respondent 7	51	60	65	82	85	90	31	45	50
Respondent 8	65	70	80	85	95	100	45	50	60
Respondent 9	65	75	85	65	75	85	50	60	65
Respondent 10	40	50	60	60	65	75	40	50	60
Respondent 11	65	69	74	82	89	93	52	58	63
Respondent 12	64	72	83	64	72	83	45	50	57
Respondent 13	62	75	79	84	89	98	62	75	79
Geometric Mean	59.218	68.495	75.862	69.395	77.293	85.394	40.824	51.195	59.185
Normalized	**0.592**	**0.685**	**0.759**	**0.694**	**0.773**	**0.854**	**0.408**	**0.512**	**0.592**
C3	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	45	55	60	20	30	45	60	75	85
Respondent 2	65	77	80	50	55	65	82	93	97
Respondent 3	65	75	83	55	60	70	65	75	83
Respondent 4	60	69	75	24	35	43	44	50	59
Respondent 5	49	56	65	35	46	49	66	76	81
Respondent 6	70	75	80	25	40	55	80	90	95
Respondent 7	66	75	80	31	45	50	66	75	80
Respondent 8	65	70	80	45	50	60	85	95	100
Respondent 9	50	60	65	25	40	50	65	75	85
Respondent 10	40	50	60	16	30	39	75	85	90
Respondent 11	65	69	74	20	37	47	82	89	93
Respondent 12	45	50	57	28	32	41	86	89	96
Respondent 13	40	49	59	23	33	38	62	75	79
Geometric Mean	55.601	63.691	70.882	29.388	40.978	49.677	70.394	79.565	85.737
Normalized	**0.556**	**0.637**	**0.709**	**0.294**	**0.410**	**0.497**	**0.704**	**0.796**	**0.857**
C4	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	45	55	60	10	15	20
Respondent 2	65	77	80	82	93	97	25	40	50

Respondent 3	65	75	83	83	95	100	55	60	70
Respondent 4	44	50	59	44	50	59	76	85	94
Respondent 5	49	56	65	66	76	81	35	46	49
Respondent 6	70	75	80	70	75	80	50	60	70
Respondent 7	51	60	65	82	85	90	31	45	50
Respondent 8	65	70	80	85	95	100	20	30	40
Respondent 9	65	75	85	50	60	65	10	15	30
Respondent 10	40	50	60	60	65	75	16	30	39
Respondent 11	52	58	63	82	89	93	20	37	47
Respondent 12	45	50	57	64	72	83	28	32	41
Respondent 13	40	49	59	62	75	79	23	33	38
Geometric Mean	53.204	61.114	68.900	67.787	76.165	82.487	28.014	39.249	49.038
Normalized	**0.532**	**0.611**	**0.689**	**0.678**	**0.762**	**0.825**	**0.280**	**0.392**	**0.490**
C5	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	85	88	92	60	75	85	60	75	85
Respondent 2	25	40	50	65	77	80	50	55	65
Respondent 3	55	60	70	83	95	100	65	75	83
Respondent 4	44	50	59	60	69	75	24	35	43
Respondent 5	66	76	81	66	76	81	49	56	65
Respondent 6	80	90	95	50	60	70	70	75	80
Respondent 7	82	85	90	82	85	90	51	60	65
Respondent 8	65	70	80	45	50	60	20	30	40
Respondent 9	65	75	85	85	90	95	50	60	65
Respondent 10	40	50	60	60	65	75	16	30	39
Respondent 11	82	89	93	82	89	93	52	58	63
Respondent 12	45	50	57	64	72	83	64	72	83
Respondent 13	62	75	79	84	89	98	40	49	59
Geometric Mean	56.294	65.391	73.395	67.447	75.187	82.472	41.874	52.122	60.600
Normalized	**0.563**	**0.654**	**0.734**	**0.674**	**0.752**	**0.825**	**0.419**	**0.521**	**0.606**
C6	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	60	75	85	45	55	60
Respondent 2	65	77	80	50	55	65	50	55	65
Respondent 3	65	75	83	83	95	100	55	60	70
Respondent 4	44	50	59	60	69	75	60	69	75
Respondent 5	81	95	95	66	76	81	49	56	65
Respondent 6	50	60	70	70	75	80	25	40	55
Respondent 7	82	85	90	66	75	80	51	60	65

Respondent 8	65	70	80	85	95	100	45	50	60
Respondent 9	50	60	65	65	75	85	25	40	50
Respondent 10	60	65	75	40	50	60	40	50	60
Respondent 11	52	58	63	65	69	74	20	37	47
Respondent 12	86	89	96	86	89	96	64	72	83
Respondent 13	62	75	79	84	89	98	62	75	79
Geometric Mean	62.176	70.386	77.037	66.789	74.663	81.798	42.707	53.975	63.623
Normalized	**0.622**	**0.704**	**0.770**	**0.668**	**0.747**	**0.818**	**0.427**	**0.540**	**0.636**
C7	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	45	55	60	20	30	45	85	88	92
Respondent 2	50	55	65	50	55	65	82	93	97
Respondent 3	25	40	55	55	60	70	65	75	83
Respondent 4	60	69	75	44	50	59	76	85	94
Respondent 5	49	56	65	35	46	49	81	95	95
Respondent 6	50	60	70	70	75	80	80	90	95
Respondent 7	51	60	65	31	45	50	66	75	80
Respondent 8	20	30	40	5	10	15	65	70	80
Respondent 9	50	60	65	10	15	30	85	90	95
Respondent 10	16	30	39	16	30	39	60	65	75
Respondent 11	52	58	63	20	37	47	65	69	74
Respondent 12	45	50	57	45	50	57	86	89	96
Respondent 13	62	75	79	23	33	38	84	89	98
Geometric Mean	40.875	51.638	60.234	27.031	37.206	46.177	74.001	81.437	88.039
Normalized	**0.409**	**0.516**	**0.602**	**0.270**	**0.372**	**0.462**	**0.740**	**0.814**	**0.880**
C8	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	60	75	85	85	88	92
Respondent 2	50	55	65	65	77	80	65	77	80
Respondent 3	65	75	83	55	60	70	83	95	100
Respondent 4	60	69	75	76	85	94	60	69	75
Respondent 5	66	76	81	49	56	65	35	46	49
Respondent 6	80	90	95	70	75	80	50	60	70
Respondent 7	66	75	80	66	75	80	51	60	65
Respondent 8	45	50	60	85	95	100	65	70	80
Respondent 9	50	60	65	25	40	50	65	75	85
Respondent 10	60	65	75	40	50	60	60	65	75
Respondent 11	82	89	93	65	69	74	52	58	63
Respondent 12	45	50	57	45	50	57	64	72	83

Respondent 13	84	89	98	40	49	59	62	75	79
Geometric Mean	61.351	68.815	76.121	53.977	63.085	70.978	58.203	67.492	74.273
Normalized	**0.614**	**0.688**	**0.761**	**0.540**	**0.631**	**0.710**	**0.582**	**0.675**	**0.743**
C9	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	60	75	85	45	55	60
Respondent 2	82	93	97	50	55	65	65	77	80
Respondent 3	55	60	70	65	75	83	25	40	55
Respondent 4	60	69	75	44	50	59	24	35	43
Respondent 5	81	95	95	66	76	81	49	56	65
Respondent 6	70	75	80	70	75	80	50	60	70
Respondent 7	66	75	80	51	60	65	66	75	80
Respondent 8	65	70	80	45	50	60	20	30	40
Respondent 9	50	60	65	65	75	85	25	40	50
Respondent 10	60	65	75	40	50	60	40	50	60
Respondent 11	52	58	63	65	69	74	20	37	47
Respondent 12	64	72	83	64	72	83	45	50	57
Respondent 13	62	75	79	84	89	98	40	49	59
Geometric Mean	63.218	71.413	77.892	57.755	65.150	73.460	35.872	47.951	57.500
Normalized	**0.632**	**0.714**	**0.779**	**0.578**	**0.652**	**0.735**	**0.359**	**0.480**	**0.575**
C10	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	45	55	60	60	75	85	20	30	45
Respondent 2	50	55	65	65	77	80	5	20	25
Respondent 3	55	60	70	65	75	83	55	60	70
Respondent 4	60	69	75	76	85	94	44	50	59
Respondent 5	66	76	81	66	76	81	35	46	49
Respondent 6	70	75	80	50	60	70	25	40	55
Respondent 7	66	75	80	82	85	90	51	60	65
Respondent 8	45	50	60	65	70	80	20	30	40
Respondent 9	50	60	65	65	75	85	25	40	50
Respondent 10	60	65	75	60	65	75	40	50	60
Respondent 11	65	69	74	82	89	93	52	58	63
Respondent 12	86	89	96	64	72	83	45	50	57
Respondent 13	62	75	79	84	89	98	40	49	59
Geometric Mean	60.393	67.370	74.459	67.962	75.982	83.970	31.651	44.258	52.709
Normalized	**0.604**	**0.674**	**0.745**	**0.680**	**0.760**	**0.840**	**0.317**	**0.443**	**0.527**
C11	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	45	55	60	45	55	60	20	30	45

Respondent 2	50	55	65	65	77	80	25	40	50
Respondent 3	10	18	30	25	40	55	10	18	30
Respondent 4	24	35	43	2	6	24	2	6	24
Respondent 5	66	76	81	49	56	65	35	46	49
Respondent 6	50	60	70	25	40	55	25	40	55
Respondent 7	31	45	50	66	75	80	1	15	30
Respondent 8	20	30	40	45	50	60	5	10	15
Respondent 9	50	60	65	50	60	65	25	40	50
Respondent 10	40	50	60	60	65	75	40	50	60
Respondent 11	20	37	47	52	58	63	2	10	18
Respondent 12	28	32	41	45	50	57	28	32	41
Respondent 13	40	49	59	62	75	79	23	33	38
Geometric Mean	31.875	42.737	52.329	36.249	47.493	60.709	10.902	23.268	35.244
Normalized	**0.319**	**0.427**	**0.523**	**0.362**	**0.475**	**0.607**	**0.109**	**0.233**	**0.352**
C12	Supplier 1			Supplier 2			Supplier 3		
Respondent 1	60	75	85	60	75	85	45	55	60
Respondent 2	65	77	80	25	40	50	50	55	65
Respondent 3	25	40	55	55	60	70	10	18	30
Respondent 4	60	69	75	44	50	59	24	35	43
Respondent 5	81	95	95	66	76	81	49	56	65
Respondent 6	70	75	80	50	60	70	50	60	70
Respondent 7	31	45	50	66	75	80	1	15	30
Respondent 8	45	50	60	65	70	80	20	30	40
Respondent 9	50	60	65	65	75	85	25	40	50
Respondent 10	40	50	60	60	65	75	40	50	60
Respondent 11	65	69	74	52	58	63	20	37	47
Respondent 12	45	50	57	64	72	83	28	32	41
Respondent 13	62	75	79	84	89	98	40	49	59
Geometric Mean	50.570	60.981	68.002	55.914	64.521	73.406	22.045	36.755	48.172
Normalized	**0.506**	**0.610**	**0.680**	**0.559**	**0.645**	**0.734**	**0.220**	**0.368**	**0.482**

(Source: Developed for this study)

Appendix VIII: The results of fuzzy synthetic decision

1. The result of fuzzy synthetic decision in Nickel

Supplier1	$\widetilde{W_j}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.296	0.415	0.505	0.014	0.069	0.198
C2	0.038	0.167	0.430	0.385	0.484	0.571	0.015	0.081	0.246
C3	0.007	0.026	0.070	0.720	0.809	0.877	0.005	0.021	0.061
C4	0.022	0.029	0.053	0.280	0.392	0.524	0.006	0.011	0.028
C5	0.054	0.101	0.262	0.561	0.645	0.728	0.030	0.065	0.191
C6	0.013	0.048	0.155	0.295	0.453	0.563	0.004	0.022	0.087
C7	0.006	0.018	0.092	0.761	0.840	0.897	0.005	0.015	0.083
C8	0.014	0.038	0.087	0.590	0.675	0.763	0.009	0.026	0.066
C9	0.022	0.077	0.245	0.549	0.636	0.700	0.012	0.049	0.172
C10	0.015	0.041	0.202	0.110	0.201	0.360	0.002	0.008	0.073
C11	0.021	0.074	0.145	0.083	0.190	0.363	0.002	0.014	0.053
C12	0.008	0.030	0.075	0.403	0.510	0.598	0.003	0.015	0.045
						Total	**0.106**	**0.396**	**1.302**
Supplier 2	$\widetilde{W_j}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.688	0.771	0.845	0.033	0.127	0.331
C2	0.038	0.167	0.430	0.733	0.810	0.877	0.028	0.135	0.377
C3	0.007	0.026	0.070	0.310	0.430	0.518	0.002	0.011	0.036
C4	0.022	0.029	0.053	0.613	0.701	0.764	0.013	0.020	0.041
C5	0.054	0.101	0.262	0.647	0.741	0.809	0.035	0.075	0.212
C6	0.013	0.048	0.155	0.689	0.780	0.844	0.009	0.038	0.131
C7	0.006	0.018	0.092	0.404	0.513	0.597	0.003	0.009	0.055
C8	0.014	0.038	0.087	0.619	0.701	0.786	0.009	0.027	0.068
C9	0.022	0.077	0.245	0.649	0.728	0.803	0.014	0.056	0.197
C10	0.015	0.041	0.202	0.578	0.682	0.760	0.009	0.028	0.153
C11	0.021	0.074	0.145	0.329	0.450	0.534	0.007	0.033	0.077
C12	0.008	0.030	0.075	0.617	0.699	0.768	0.005	0.021	0.058
						Total	**0.166**	**0.581**	**1.737**
Supplier 3	$\widetilde{W_j}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.738	0.815	0.875	0.036	0.135	0.343
C2	0.038	0.167	0.430	0.754	0.824	0.887	0.029	0.138	0.382
C3	0.007	0.026	0.070	0.162	0.312	0.418	0.001	0.008	0.029
C4	0.022	0.029	0.053	0.645	0.726	0.799	0.014	0.021	0.043
C5	0.054	0.101	0.262	0.703	0.782	0.854	0.038	0.079	0.224

C6	0.013	0.048	0.155	0.718	0.815	0.874	0.009	0.039	0.135
C7	0.006	0.018	0.092	0.315	0.442	0.544	0.002	0.008	0.050
C8	0.014	0.038	0.087	0.630	0.726	0.795	0.009	0.028	0.069
C9	0.022	0.077	0.245	0.714	0.800	0.868	0.016	0.062	0.213
C10	0.015	0.041	0.202	0.642	0.745	0.806	0.009	0.031	0.162
C11	0.021	0.074	0.145	0.317	0.437	0.526	0.007	0.032	0.076
C12	0.008	0.030	0.075	0.653	0.727	0.795	0.005	0.022	0.060
						Total	**0.175**	**0.601**	**1.787**
Supplier 4	$\widetilde{W_J}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.508	0.606	0.693	0.025	0.100	0.272
C2	0.038	0.167	0.430	0.531	0.609	0.694	0.020	0.102	0.299
C3	0.007	0.026	0.070	0.525	0.601	0.679	0.004	0.015	0.047
C4	0.022	0.029	0.053	0.506	0.596	0.682	0.011	0.017	0.036
C5	0.054	0.101	0.262	0.614	0.695	0.772	0.033	0.070	0.202
C6	0.013	0.048	0.155	0.563	0.650	0.724	0.007	0.031	0.112
C7	0.006	0.018	0.092	0.612	0.701	0.775	0.004	0.012	0.071
C8	0.014	0.038	0.087	0.601	0.688	0.774	0.009	0.026	0.067
C9	0.022	0.077	0.245	0.598	0.682	0.753	0.013	0.053	0.185
C10	0.015	0.041	0.202	0.282	0.359	0.487	0.004	0.015	0.098
C11	0.021	0.074	0.145	0.177	0.308	0.432	0.004	0.023	0.062
C12	0.008	0.030	0.075	0.452	0.527	0.610	0.004	0.016	0.046
						Total	**0.137**	**0.480**	**1.499**

(Source: Developed for this study)

2. The result of fuzzy synthetic decision in Phosphor bronze

Supplier1	$\widetilde{W_J}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.541	0.619	0.694	0.026	0.102	0.272
C2	0.038	0.167	0.430	0.592	0.685	0.759	0.023	0.114	0.326
C3	0.007	0.026	0.070	0.556	0.637	0.709	0.004	0.016	0.049
C4	0.022	0.029	0.053	0.532	0.611	0.689	0.011	0.018	0.037
C5	0.054	0.101	0.262	0.622	0.704	0.770	0.033	0.071	0.202
C6	0.013	0.048	0.155	0.622	0.704	0.770	0.008	0.034	0.119
C7	0.006	0.018	0.092	0.409	0.516	0.602	0.003	0.009	0.055
C8	0.014	0.038	0.087	0.614	0.688	0.761	0.009	0.026	0.066
C9	0.022	0.077	0.245	0.632	0.714	0.779	0.014	0.055	0.191
C10	0.015	0.041	0.202	0.604	0.674	0.745	0.009	0.028	0.150
C11	0.021	0.074	0.145	0.319	0.427	0.523	0.007	0.031	0.076

C12	0.008	0.030	0.075	0.506	0.610	0.680	0.004	0.018	0.051
						Total	**0.151**	**0.524**	**1.596**
Supplier 2	$\widetilde{W_J}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.724	0.808	0.879	0.035	0.133	0.344
C2	0.038	0.167	0.430	0.694	0.773	0.854	0.026	0.129	0.367
C3	0.007	0.026	0.070	0.294	0.410	0.497	0.002	0.011	0.035
C4	0.022	0.029	0.053	0.678	0.762	0.825	0.015	0.022	0.044
C5	0.054	0.101	0.262	0.674	0.752	0.825	0.036	0.076	0.216
C6	0.013	0.048	0.155	0.668	0.747	0.818	0.009	0.036	0.127
C7	0.006	0.018	0.092	0.270	0.372	0.462	0.002	0.007	0.042
C8	0.014	0.038	0.087	0.540	0.631	0.710	0.008	0.024	0.062
C9	0.022	0.077	0.245	0.578	0.652	0.735	0.013	0.050	0.180
C10	0.015	0.041	0.202	0.680	0.760	0.840	0.010	0.032	0.169
C11	0.021	0.074	0.145	0.362	0.475	0.607	0.008	0.035	0.088
C12	0.008	0.030	0.075	0.559	0.645	0.734	0.005	0.020	0.055
						Total	**0.167**	**0.574**	**1.730**
Supplier 3	$\widetilde{W_J}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.428	0.535	0.626	0.021	0.088	0.246
C2	0.038	0.167	0.430	0.408	0.512	0.592	0.016	0.085	0.255
C3	0.007	0.026	0.070	0.704	0.796	0.857	0.005	0.020	0.060
C4	0.022	0.029	0.053	0.280	0.392	0.490	0.006	0.011	0.026
C5	0.054	0.101	0.262	0.419	0.521	0.606	0.022	0.053	0.159
C6	0.013	0.048	0.155	0.427	0.540	0.636	0.005	0.026	0.099
C7	0.006	0.018	0.092	0.740	0.814	0.880	0.005	0.014	0.081
C8	0.014	0.038	0.087	0.582	0.675	0.743	0.008	0.026	0.065
C9	0.022	0.077	0.245	0.359	0.480	0.575	0.008	0.037	0.141
C10	0.015	0.041	0.202	0.317	0.443	0.527	0.005	0.018	0.106
C11	0.021	0.074	0.145	0.109	0.233	0.352	0.002	0.017	0.051
C12	0.008	0.030	0.075	0.220	0.368	0.482	0.002	0.011	0.036
						Total	**0.105**	**0.408**	**1.324**

(Source: Developed for this study)

3. The result of fuzzy synthetic decision in Stainless steel

Supplier1	$\widetilde{W_J}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.751	0.824	0.886	0.036	0.136	0.347
C2	0.038	0.167	0.430	0.720	0.812	0.875	0.027	0.136	0.376

C3	0.007	0.026	0.070	0.382	0.486	0.573	0.003	0.012	0.040
C4	0.022	0.029	0.053	0.681	0.762	0.832	0.015	0.022	0.044
C5	0.054	0.101	0.262	0.683	0.763	0.822	0.037	0.077	0.216
C6	0.013	0.048	0.155	0.675	0.756	0.826	0.009	0.037	0.128
C7	0.006	0.018	0.092	0.390	0.487	0.573	0.002	0.009	0.053
C8	0.014	0.038	0.087	0.688	0.765	0.830	0.010	0.029	0.072
C9	0.022	0.077	0.245	0.642	0.721	0.793	0.014	0.056	0.195
C10	0.015	0.041	0.202	0.490	0.588	0.686	0.007	0.024	0.138
C11	0.021	0.074	0.145	0.308	0.433	0.533	0.007	0.032	0.077
C12	0.008	0.030	0.075	0.595	0.674	0.754	0.005	0.020	0.057
						Total	**0.172**	**0.589**	**1.743**
Supplier 2	$\widetilde{W_j}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.670	0.757	0.821	0.032	0.125	0.322
C2	0.038	0.167	0.430	0.635	0.703	0.793	0.024	0.117	0.341
C3	0.007	0.026	0.070	0.585	0.656	0.733	0.004	0.017	0.051
C4	0.022	0.029	0.053	0.582	0.675	0.758	0.013	0.020	0.040
C5	0.054	0.101	0.262	0.593	0.675	0.756	0.032	0.068	0.198
C6	0.013	0.048	0.155	0.605	0.694	0.759	0.008	0.034	0.118
C7	0.006	0.018	0.092	0.431	0.535	0.626	0.003	0.009	0.058
C8	0.014	0.038	0.087	0.437	0.532	0.622	0.006	0.020	0.054
C9	0.022	0.077	0.245	0.617	0.691	0.764	0.013	0.053	0.187
C10	0.015	0.041	0.202	0.440	0.536	0.615	0.006	0.022	0.124
C11	0.021	0.074	0.145	0.310	0.413	0.532	0.007	0.030	0.077
C12	0.008	0.030	0.075	0.573	0.663	0.734	0.005	0.020	0.055
						Total	**0.153**	**0.536**	**1.626**
Supplier 3	$\widetilde{W_j}$			E^s			$\tilde{R}$		
C1	0.048	0.165	0.392	0.541	0.618	0.703	0.026	0.102	0.275
C2	0.038	0.167	0.430	0.581	0.661	0.734	0.022	0.110	0.316
C3	0.007	0.026	0.070	0.733	0.806	0.870	0.005	0.021	0.061
C4	0.022	0.029	0.053	0.246	0.388	0.512	0.005	0.011	0.027
C5	0.054	0.101	0.262	0.519	0.596	0.674	0.028	0.060	0.177
C6	0.013	0.048	0.155	0.421	0.525	0.611	0.005	0.025	0.095
C7	0.006	0.018	0.092	0.709	0.803	0.858	0.004	0.014	0.079
C8	0.014	0.038	0.087	0.650	0.719	0.796	0.009	0.027	0.069
C9	0.022	0.077	0.245	0.497	0.591	0.669	0.011	0.046	0.164
C10	0.015	0.041	0.202	0.159	0.327	0.428	0.002	0.014	0.086
C11	0.021	0.074	0.145	0.086	0.180	0.338	0.002	0.013	0.049

C12	0.008	0.030	0.075	0.190	0.318	0.441	0.002	0.010	0.033
						Total	**0.123**	**0.453**	**1.431**

(Source: Developed for this study)

Appendix IX: Calculation of Fuzzy AHP in Excel

1. Example in Pairwise comparison and Consistency from Respondent 1

Q1	B1			B2			B3			B4			B5		
B1	1	1	1	9	9	9	2	3	4	2	3	4	4	5	6
B2	1/9	1/9	1/9	1	1	1	1/6	1/5	1/4	1	1	1	1/6	1/5	1/4
B3	1/4	1/3	1/2	4	5	6	1	1	1	1	1	1	1	1	1
B4	1/4	1/3	1/2	1	1	1	1	1	1	1	1	1	1	1	1
B5	1/6	1/5	1/4	4	5	6	1	1	1	1	1	1	1	1	1

	Geometric Mean			Fuzzy Weight Min	Avg	Max	De-Fuzzification Mi	Normalized
	2.70	3.32	3.87	0.36	0.51	0.68	0.61	0.52
	0.31	0.34	0.37	0.04	0.05	0.06	0.06	0.05
	1.00	1.11	1.25	0.13	0.17	0.22	0.20	0.17
	0.76	0.80	0.87	0.10	0.12	0.15	0.14	0.12
	0.92	1.00	1.08	0.12	0.15	0.19	0.17	0.15
Total	5.70	6.57	7.44				1.180	
Reverse	0.18	0.15	0.13					
Increasing	0.13	0.15	0.18					

Z	W'	Test Consistency		
1.713	4.715	λL	4.8623	
0.228	5.380	C.I. =	-0.03	Accepted
0.620	4.614	C.R. =	-0.03	Accepted
0.493	4.843			
0.590	4.760			
		Test Consistency		
2.602	5.15	λM	5.34	
0.294	5.71	C.I. =	0.09	Accepted
0.869	5.16	C.R. =	0.08	Accepted
0.663	5.43			
0.802	5.27			
		Test Consistency		
2.75	4.05	λU	5.330	
0.35	5.35	C.I. =	0.08	Accepted
1.10	5.03	C.R. =	0.07	Accepted
0.97	6.32			
1.12	5.89			

(Source: Developed for this study)

Q1	C1			C2		
C1	1	1	1	1	1	1
C2	1	1	1	1	1	1

	Geometric Mean			Min	Avg	Max	Mi	Normalized
	1.00	1.00	1.00	0.5	0.5	0.5	0.50	0.5
	1.00	1.00	1.00	0.5	0.5	0.5	0.50	0.5
Total	2.00	2.00	2.00				1.000	
Reverse	0.50	0.50	0.50					
Increasing	0.50	0.50	0.50					

Z	W'	Test Consistency		
1.00	2.00	λL	2	
1.00	2.00	C.I. =	0.00	Accepted
		C.R. =	0.00	Accepted
		Test Consistency		
1.00	2.00	λM	2.00	
1.00	2.00	C.I. =	0.00	Accepted
		C.R. =	0.00	Accepted
		Test Consistency		
1.00	2.00	λU	2	
1.00	2.00	C.I. =	0.00	Accepted
		C.R. =	0.00	Accepted

(Source: Developed for this study)

2. Example in Sub-weight calculation (Main criteria * sub-criteria)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Respondent 1	0.26	0.26	0.01	0.04	0.12	0.03	0.01	0.06	0.06	0.04	0.09	0.02
Respondent 2	0.12	0.37	0.01	0.04	0.10	0.01	0.01	0.02	0.11	0.03	0.14	0.03
Respondent 3	0.05	0.24	0.02	0.02	0.26	0.06	0.04	0.09	0.03	0.06	0.07	0.05
Respondent 4	0.14	0.14	0.04	0.04	0.13	0.13	0.05	0.08	0.04	0.04	0.13	0.06
Respondent 5	0.26	0.09	0.07	0.02	0.09	0.09	0.09	0.02	0.06	0.02	0.14	0.04
Respondent 6	0.20	0.20	0.02	0.05	0.06	0.01	0.02	0.05	0.24	0.01	0.12	0.02
Respondent 7	0.06	0.43	0.03	0.03	0.09	0.05	0.01	0.03	0.08	0.02	0.13	0.03
Respondent 8	0.10	0.29	0.02	0.05	0.05	0.16	0.02	0.06	0.02	0.16	0.02	0.06
Respondent 9	0.08	0.40	0.04	0.01	0.12	0.02	0.01	0.04	0.12	0.11	0.03	0.02
Respondent 10	0.39	0.13	0.07	0.01	0.07	0.07	0.01	0.06	0.06	0.02	0.10	0.01
Respondent 11	0.34	0.11	0.06	0.02	0.09	0.05	0.01	0.02	0.16	0.04	0.08	0.02
Respondent 12	0.34	0.05	0.03	0.03	0.10	0.02	0.01	0.04	0.25	0.03	0.04	0.06
Respondent 13	0.27	0.04	0.01	0.04	0.12	0.12	0.01	0.01	0.07	0.20	0.03	0.08

(Source: Developed for this study)

sub-weight						
	Min	Avg	Max		Error	Df
C1	0.05	0.16	0.39	Y	0.34	0.43
C2	0.04	0.17	0.43	Y	0.39	0.47
C3	0.01	0.03	0.07	Y	0.06	0.08
C4	0.02	0.03	0.05	Y	0.03	0.06
C5	0.05	0.10	0.26	Y	0.21	0.28
C6	0.01	0.05	0.16	Y	0.14	0.17
C7	0.01	0.02	0.09	Y	0.09	0.10
C8	0.01	0.04	0.09	Y	0.07	0.09
C9	0.02	0.08	0.25	Y	0.22	0.26
C10	0.01	0.04	0.20	Y	0.19	0.21
C11	0.02	0.07	0.14	Y	0.12	0.16
C12	0.01	0.03	0.08	Y	0.07	0.08

(Source: Developed for this study)

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