ENVIRONMENTAL IMPACT ON THE VENDOR SELECTION PROBLEM IN ELECTRONICS FIRMS - A SYSTEMATIC ANALYTIC NETWORK PROCESS WITH BOCR

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ABSTRACT

As environmental deterioration and global warming become issues that receive more attention, this study investigates the environmental impact on the vendor or supplier selection problem. After re-examining the existing selection process, the processes for qualification and final selection are highlighted by considering environmental (or green) and traditional criteria. Next, the Analytic Network Process (ANP) is adopted with the merits of benefits, opportunities, costs, and risks (BOCR) to assess all factors for ranking suppliers for the certain and uncertain effects as well as the dependences and feedback. In addition, this study integrates the content validity ratio and factor analysis into the solution procedure for the benefit of ANP analysis. Lastly, a case of selecting suppliers for an electronics firm in Taiwan is illustrated. The results show that the criteria of greatest concern are consistency delivery, flexibility, and cost, whereas environmental criteria are valued less.

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1. Introduction

As environmental deterioration and global warming become issues that receive more attention, business enterprises, especially in the electronics industry, have undertaken environmental plans inside and outside their corporate organizations. By way of infusing environmental awareness into corporate goals, firms can propagate the importance of environmental protection from the top down and combine green objectives with corporate functions, such as procurement, design, manufacturing, and marketing, so as to set forth comprehensive environmental activities for the making of true green enterprises (Chen et al., 2012; Chiou and Tzeng, 2002). Among various corporate mechanisms, procurement easily takes up more than half of a firm's total expenditures (Leenders et al., 2002), especially when it comes to original design/equipment manufacturing (ODM/OEM) or electronics manufacturing service (EMS) (Huang and Keskar, 2007). Companies with limited resources usually focus on their core business competitiveness, while handling their non-focused peripheral businesses through a variety of outsourcing. As a result, collaboration between buyers and suppliers is becoming greater (Green et al., 1996; Wadhwa and Ravindram, 2007; Lee et al., 2009). With cooperative activities of outsourcing and strategic alliances now more common, the relationship between companies and their suppliers has transformed from the traditional antagonistic one into a mutual commitment. Therefore, companies must be prudent in the selection of suppliers in order to formulate a win-win situation (Sonmez, 2006; Tahriri et al., 2008; Ting and Cho, 2008).

In response to environmental issues being taken more seriously, proposals on the selection of green suppliers have involved the use of environmental or green criteria (such as environmental certification and environmental management system) being appended to traditional evaluation criteria such as prices and quality (Handfield et al., 2002; Humphreys et al., 2003; Lee et al., 2009; Hsu and Hu, 2009; Tuzkaya et al., 2009). However, it seems that these studies over-estimate the effects of environmental issues by adding many environmental related criteria on supplier selection. In practice, traditional criteria may still dominate the choice of suppliers as supported by a recent survey (Genoverse et al., 2013). Therefore, a motivation of this study is to explore when and how to use environmental and traditional criteria in the supplier selection process. Upon further investigation we find that research into the process of supplier

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or vendor selection is limited. De Boer et al., (2001) classified the selection process as a problem definition, formulation of criteria, qualification, and final choice. In practice, it is very likely that environmental guidelines will be used for qualification, and those firms that cross the threshold can get into the final choice stage. It seems that these studies simplify the process.

After reviewing the environmental criteria, these criteria can be further grouped into two types: mandatory and voluntary. The former includes RoHS (Restriction of Hazardous Substances Directive), WEEE (Waste Electrical and Electronic Equipment Directive), etc., which firms are expected to obey through regulations and laws. The latter comprises EPEAT (Electronic Product Environmental Assessment Tool), ISO 14000 standards, etc., which demonstrate the efforts of suppliers. Thus, “deep green” enterprises are requesting more of such voluntary criteria than “light green” enterprises. These two types of environmental criteria – mandatory and voluntary – play a central part in the stages of qualification and final choice of the vendor selection process.

Due to the multi-dimensional aspects or criteria being evaluated, past studies generally view supplier selection as a MCDM problem (Ho et al., 2010), and many techniques can attack this problem, i.e., multi-attribute decision making, multi-objective decision making, statistical approaches, intelligent approaches, and others (Bruno et al., 2012; de Boer et al., 2001; Genoverse et al., 2013; Ho et al., 2010; Shyur and Shih, 2006; Wu and Barnes, 2011). Most recent approaches concentrate on a combination of different techniques for different solution procedures, e.g., ANP with data envelopment analysis (Kuo and Lin, 2012). Among these techniques, the Analytic Hierarchy/Network Process (AHP/ANP) is extensively used, because it is able to handle tangible and intangible factors. Moreover, the new concept from the merits of benefits, opportunities, costs, and risks (BOCR) assesses all factors and interests involving certain and uncertain effects (Saaty, 2005). These advantages make the ANP BOCR model a suitable tool for evaluation (Bottero and Ferretti, 2010) and are especially suitable for assessing intangible environmental criteria. In addition, the traditional ANP procedure relies on brainstorming to clarify some key issues and appears to be a loose structure to attack the problem. Thus, the content validity ratio and factor analysis from statistics are integrated into the procedure for the benefit of ANP analysis. We believe this integrated network model provides another option for selecting and ranking suppliers.

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This study is organized as follows. Section 2 reviews the related literature. Section 3 proposes our methodology. Section 4 exhibits a case through the systematic ANP BOCR model with sensitivity analyses. Finally, this study draws forth conclusions.

2. Literature Review

Vendor or supplier selection is a common dilemma when trying to obtain the necessary materials for operations. The problem involves a process of decision making along with some analytic methods. We now discuss the procedures, the criteria for supplier selection under an environmental impact, and the main methodology used in the study – the Analytical Network Process with BOCR model.

2.1 Purchasing procedures

Most previous research studies have directly analyzed the final choice of suppliers as a supplier selection problem. It is obvious that the purchasing decision should go through some steps prior to the final choice. Dobler and Burt (1996) listed a typical purchasing cycle as: (i) recognize, define, and describe the need; (ii) transmit the need; (iii) investigate, qualify, and select the supplier; (iv) prepare and issue the purchase order; (v) follow up on the order; (vi) receive and inspect the material; (vii) audit the invoice; and (viii) close the order. De Boer et al. (2001) also mentioned that a completed supplier selection should be divided into: problem definition, criteria formulation, supplier qualification and final choice. In the qualification stage, potential suppliers must equal or exceed the basic requirement for screening and become an acceptable supplier. An order winner is then chosen by some characterized selection criteria. Thus, supplier selection is not a single work of selection. Indeed, there should be various activities in the purchasing process (Chopra and Meindl, 2007).

After environmental issues were considered in selecting suppliers, most studies have concentrated on supplier assessment, e.g., Bai and Sarkis (2010). From their viewpoint, the evaluation is simultaneously based on traditional and environmental criteria as shown on path (a) in Figure 1. However, after examining most purchasing procedures of the electronics industry in Taiwan, environmental criteria is used for qualification, and the final choice of suppliers only depends on traditional criteria whose procedure is presented on path (b) of Figure 1. Humphreys et al. (2003) and Nicosia and Moore (2006) supported this viewpoint with some complex phases. It seems that the above two viewpoints, (a) and (b), are not the whole story of supplier selection. For instance, some environmental criteria could be utilized for the purpose

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of screening, e.g., RoHS with yes/no responses. Hence, we extend Noci's argument (1997) and propose a procedure for enhancing the environmental issues and allocating different types of the criteria as shown on path (c) of Figure 1. The difference among the mentioned paths is one concern of this study.

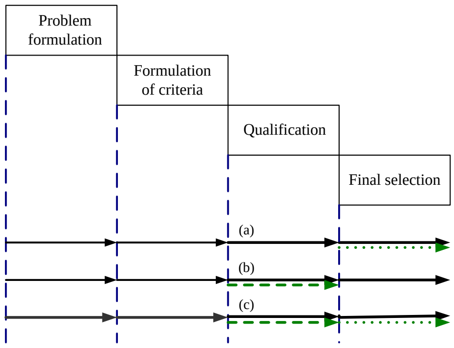

Figure 1. Different paths of supplier selection processes

Note:
(a) Most recent studies investigate the selection process by considering traditional and environmental criteria simultaneously at the final step.
(b) The current process in Taiwan's electronics industry takes environmental criteria for qualification and then uses traditional criteria for the final selection.
(c) The proposed process considers both traditional and environmental criteria for the steps of qualification and final selection.

2.2 Supplier selection criteria

Supplier selection criteria can be divided into two types: mandatory and voluntary. For environmentally concerned enterprises, mandatory environmental and traditional criteria are required and generally considered for the purpose of qualification. For instance, firms provide a checklist of specified items to make sure qualified suppliers meet them, and these suppliers are considered as candidate suppliers. These items, which are environment-related, industrial safe, or quality related, are presented in the forms of regulations or laws by the European Union and the United States, proving especially vital for Asian firms trying to export electronics merchandises to these countries. These environmental criteria, which are expected to be obeyed, include RoHS, WEEE, European Union's Ecodesign Directive, etc. These works are generally executed in the qualification step of Figure 1. Voluntary environmental criteria encompass EPEAT, EU Eco-label Flower, IECQ (International Electrotechnical Commission Quality Assessment System for Electronic Components) QC 080000, ISO 14000 standards, etc., which demonstrate efforts put forth by suppliers. These criteria can be seen as an achievement of the suppliers, and the more included the better. However, "deep green" enterprises may consider some of them as mandatory criteria that will be conducted in the qualification step, e.g., ISO 14000. In addition, Genovese et al. (2013) presented corporate social responsibility (CSR) criteria, which

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are generally at the strategic level for large enterprises and can be taken as an intangible factor for assessing suppliers.

The criteria of cost/price, delivery, and quality have been traditionally valued the highest in the past, whereas the criteria of service, responsiveness, and environmental considerations are more important now. Dickson first suggested 23 criteria for vendor selection (see Weber et al., 1991). Choi and Harley (1996) explored 26 evaluation criteria for the car manufacturing industry and focused on the different positions of suppliers in the supply chain, pointing out that quality and delivery are important. Barbarosoglu and Yazgac (1997) structured a four-level supplier performance assessment structure and emphasized the importance of quality and different costs. Leender et al. (2002) organized vendor performance by quality, price, delivery, and service. Gencer and Gürpinar (2007) considered business structure, manufacturing capability, and quality system as three clusters in a network for a case study on an electronics firm. Yang et al. (2008) selected quality, price and terms, supply chain support, and technology as the major criteria for analyzing vendor selection for the electronics industries in Taiwan.

Environmental criteria for assessing suppliers' performance have risen in demand. Noci (1997) suggested four major environmental criteria with corresponding indicators for supplier evaluation. Handfield et al. (2002) identified the top 10 criteria for environmental performance. Humphreys et al. (2003) proposed an almost full structure for the supplier selection process with a couple of stages on quantitative and qualitative as well as traditional and environmental criteria. Huang and Keskar (2007) appended safety and environmental metrics to the Supply Chain Council's SCOR (supply chain operations reference) model in practice. Kuo and Lin (2012) considered four criteria in the environment dimension for evaluation. Büyüközkan and Çifçi (2012) looked at green suppliers' evaluation criteria and organizational performance (traditional criteria) as two clusters in a network for evaluating green suppliers as a whole. We know that environment-related criteria are becoming more significant from these studies, and these mandatory and voluntary criteria are presented in the forms of qualified criteria, performance measures, or cooperation image, which can be evaluated during the steps of qualification and selection.

2.3 Analytical methods and ANP with BOCR

The ANP methodology is a special case of AHP, which deals with dependence and feedback among clusters and their elements in addition to a network structure (Saaty

2005). Traditionally, AHP/ANP is analyzed by using a single hierarchy/network, but such an approach is weaker at presenting a negative effect. Saaty (1980) directly considered a cost-benefit analysis by AHP, representing the analysis with two hierarchies. Focusing on the alternatives, we divide AHP's benefit priorities by AHP's cost priorities to get the benefit-cost ratios of the alternatives for the final choice. Saaty and Özdemir (2003) added the positive aspect of opportunities and the negative aspect of risks to shape the prototype of BOCR for a comprehensive analysis. Through the BOCR aspects we are able to understand the items of benefits associated with positive and certain contents, the items of opportunities with positive and uncertain contents, the items of costs with negative and certain contents, and the items of risks with negative and uncertain contents. For ranking and selection, our target is to obtain greater benefits and opportunities, while encountering smaller costs and risks. In addition, different decision makers may give varying degrees of importance to each BOCR aspect, depending on strategic issues or goals. Therefore, Saaty and Özdemir (2005) suggested that individuals or enterprises make pairwise comparisons under the goals in order to obtain BOCR's weights (i.e., b, o, c, and r, correspondingly). For synthesizing these four aspects, Saaty (2005) further recommended the formula $bB+oO–cC–rR$ for the BOCR calculation. Here, B, O, C, and R are the priorities of the respective aspects, and b, o, c, and r are their weights, respectively. If the resulting value is positive, then it indicates the positive value is higher than the negative value and the choice turns out to be appropriate. Bottero and Ferretti (2011) pointed out that the ANP BOCR model helps decision makers to venture deeper into the uncertainty of the problems. Hence, we choose this model for the analysis.

After examining the ANP BOCR model that has been used in the literature since 2003, we found that many studies only provided a simplified model that might not accommodate the complex environment effect. Table 1 collects some typical applications of the ANP BOCR model in the literature, in which full BOCR networks are preferred as in Bottero and Ferretti (2011). The contents of Table 1 illustrate the guide for researchers to use the model. In addition, the content validity ratio and factor analysis are adopted to support its solution procedure for a better coherence and rigorous process.

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Table 1
Some typical BOCR configurations in ANP

Application	BOCR configuration	Authors (year)	Remarks
Selection of a high-tech transaction system	Four alternatives–criteria–actors connections	Erdoğmuş et al. (2005)	Four criteria cluster in the BOCR aspects, respectively
Evaluation of alternative fuels for residential heating	1. Three alternatives–criteria–actors connections 2. Six clusters connected network in the benefits aspect	Erdoğmuş et al. (2006)	Different criteria in each criteria cluster of the OCR aspects
Supplier selection for the plastic parts of a refrigerator plant	1. Benefits: 3 clusters connected network 2. Opportunities: 2 clusters 3. Costs: 2 clusters 4. Risks: 2 clusters	Ustun and Demirtas (2008)	
Priority determination in strategic energy policies	Four criteria, participants, and policies connected networks	Dağdeviren and Eraslan (2008)	Different criteria in each criteria cluster in the BOCR aspects
Evaluation of buyer-supplier relationships in the high-tech industry	Single hierarchy including BOCR four aspects at one level with sub-criteria showing dependence	Lee et al. (2009)	Single hierarchy oriented
Project prioritization in higher education institutions	1. Benefits: 4 clusters connected network 2. Costs: 3 clusters connected network 3. Risks: 4 clusters connected network	Begičević et al. (2010)	In the BCR aspects only
Selection of dispatching rules in FMS	Sub-criteria connected sub-networks under the criteria of economy, strategy, and customer, respectively, at one level in BOCR's four hierarchies	Yazgan et al. (2010)	Four-hierarchy oriented
Location selection for a waste incinerator plant	1. Benefits Environment: 2 clusters; Socio-economy: 2 clusters 2. Opportunities Environment: 3 clusters connected network; Socio-economy: 2 clusters 3. Costs Environment: 5 clusters connected network; Socio-economy: 4 clusters connected network 4. Risks Environment: 4 clusters connected network; Socio-economy: 3 clusters connected network	Bottero and Ferretti (2011)	Different criteria in two clusters in the BOCR aspects
Site selection for coastal oil jetties	Single network including BOCR's four clusters and alternative	Hasanzadeh et al. (2013)	Single network oriented

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3. Research Methodologies

We mainly used the ANP BOCR model to simultaneously consider environmental and traditional elements for supplier selection and focused on the illustration of the last step due to a simple work on the yes/no questions in the qualification step. The suggested research framework involved two phases: obtaining a validated ANP with BOCR merits with four sub-networks, and designing the questionnaires of pairwise comparisons with calculation. Figure 2 illustrates the proposed systematic ANP BOCR process with seven steps.

3.1 Construction of the ANP BOCR network

For the evaluation stage, we checked all organized criteria by the content validity ratio (CVR) to fit the aspects of benefits, opportunities, costs, and risks, respectively. Next, we executed factor analysis to determine groups of the criteria and the clusters they belonged to. After identifying the relations between the dependence and feedback relations between clusters and criteria, we established four BOCR sub-networks.

To determine the selected criteria under the individual aspects of benefits, opportunities, costs, and risks, we adopted CVR as proposed by Lawshe (1975) to delete minor criteria in order to enhance the suitability of the concerned criteria in each aspect. The CVR formula quantifies the agreement on the questionnaire content from a professional perspective. The quantified value is between 1 and -1, and the larger the value is, the more important the topics are regarded to be.

$$\text{CVR} = (n_e - N/2) / (N/2), \qquad (1)$$

where n_e = number of experts who think the topics are important (or essential), and N = total number of experts who fill out the questionnaire. When there are 5 experts filling out the questionnaire (N=5), the content validity ratio (CVR) derived from the above equation is 0.99; when the number of experts is 30 (N=30), CVR is 0.33.

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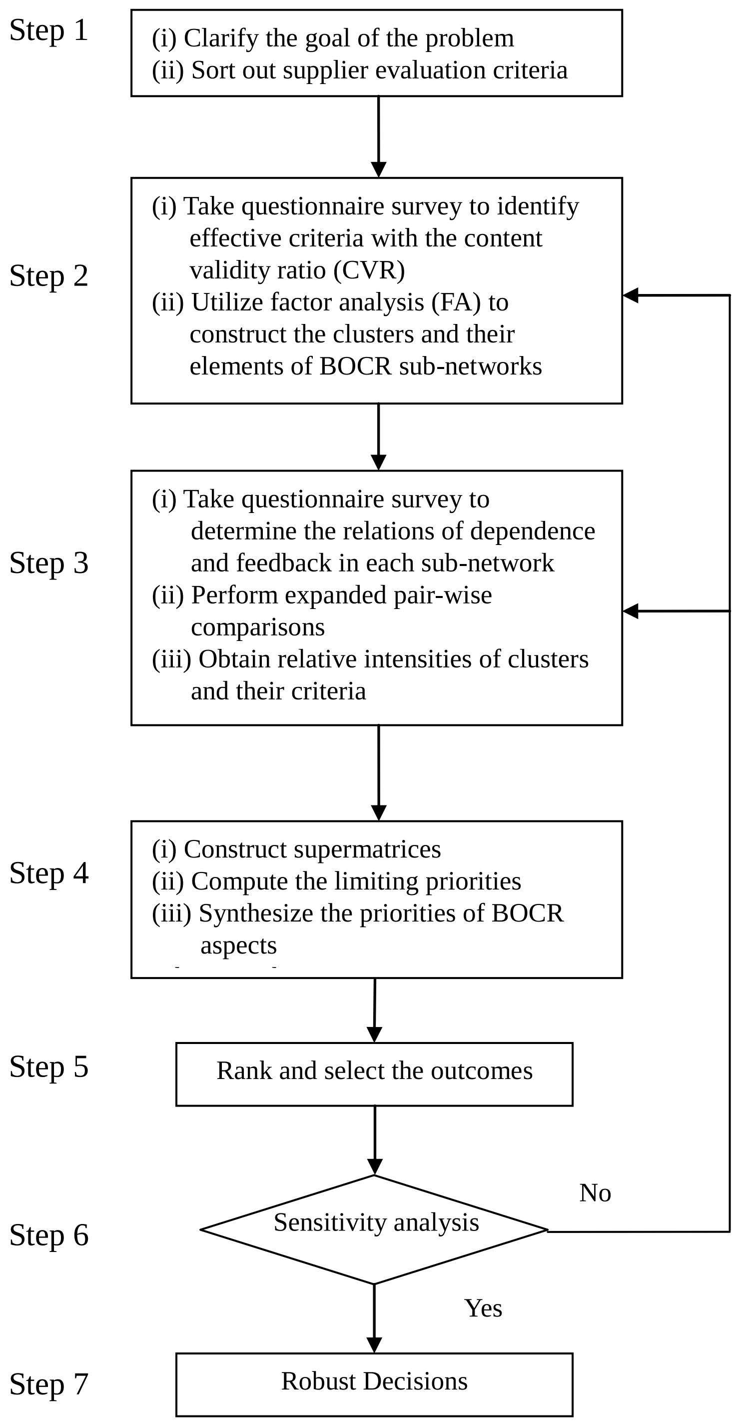

Figure 2. Proposed systematic ANP BOCR process

We used the five-level scale for the evaluation. In the effectiveness verification, we only picked items with 4 or 5 points for the new calculation. Moreover, the CVR value of one question higher than the specified CVR value determined by N (the number of

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experts filling out the questionnaire) was kept. Next, we executed factor analysis on the criteria of each aspect to obtain the corresponding clusters or dimensions that these criteria belong to for the ANP network. The questionnaires sent by both paper and email asked the respondents to evaluate the level of importance of each criterion in the aspect of benefits, opportunities, costs, and risks, respectively. Tabachnick and Fidell (2007) suggested that factor analysis should have a minimum number of samples that are five times the number of questions in a questionnaire as shown in the appendices.

Before factor analysis, we performed two tasks on the suitability for further analysis. First, we implemented the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and the Bartlett test of sphericity on the questionnaires to make sure the questionnaire items were appropriate for factor analysis. According to Kaiser (1970), the value of KMO is between 0 and 1, and the greater the value is, the more appropriate the data are. In addition, if the *P*-value resulting from the Bartlett test is less than the significant level, then the data variables are correlated and suitable for factor analysis. After reducing the criteria data, all the KMO values are greater than 0.6, and the *P*-values are less than 0.05, which supports the assumption that the data are appropriate for factor analysis. The clusters can then be determined from various criteria by factor analysis.

Following the clusters and their criteria being chosen in each aspect, the experts then decided upon the dependence and feedback relations between clusters and criteria. The results showed that more than half of the experts agreed that the factors influence one another, supporting the assumption that the factors are dependent. In our study we considered environmental and traditional criteria for the two phases as path (c) in Figure 1. A pairwise comparison was performed on these criteria under the merits of benefits, opportunities, costs, and risks. The BOCR-ANP network obtained from expert opinions is shown in Figure 3 for our case.

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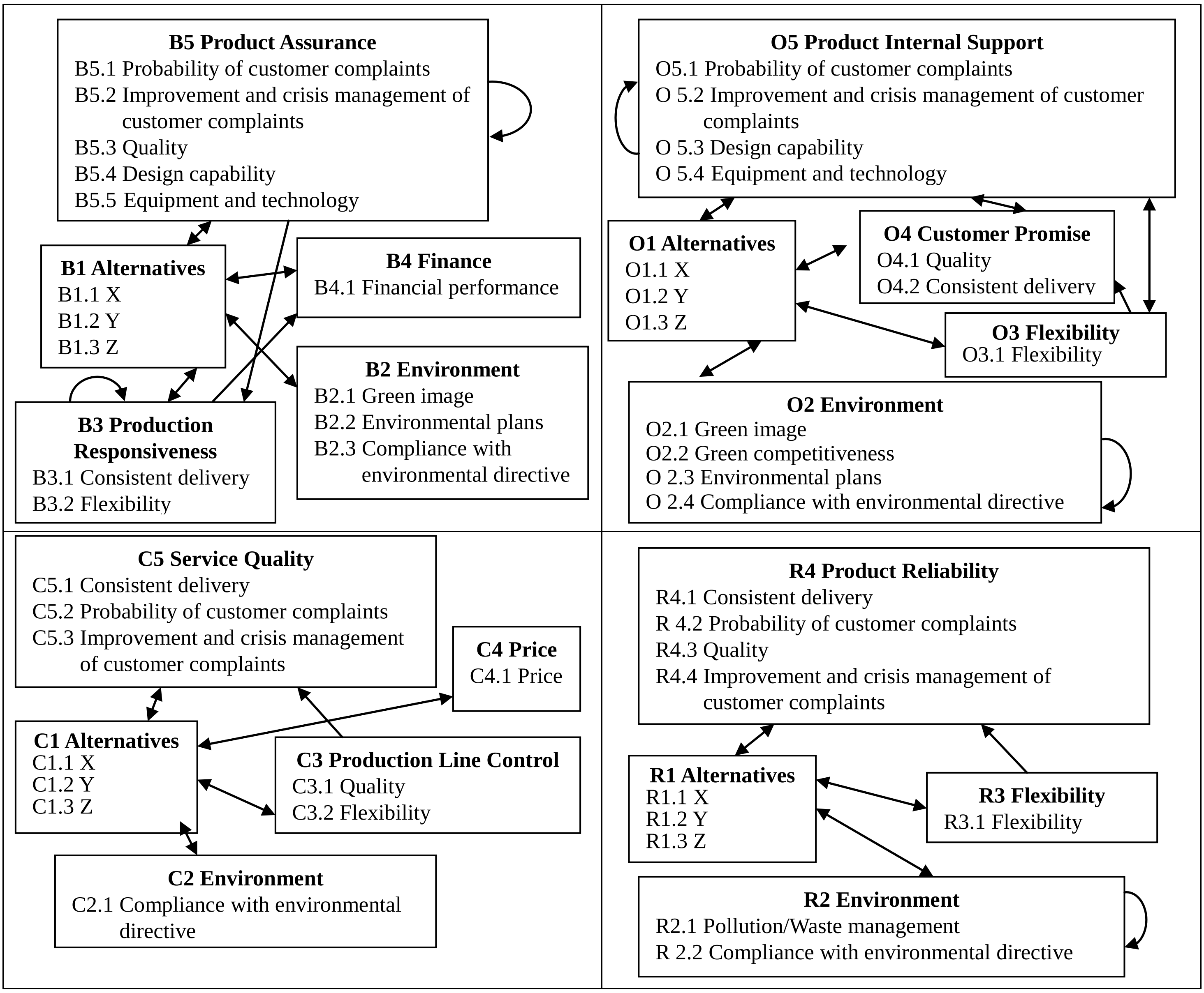

Figure 3. ANP BOCR's network

3.2 Expert questionnaires for the ANP BOCR model

The second phase was to design the pairwise comparison questionnaires to form the supermatrices and to execute their calculation.

3.2.1 Design of the questionnaires

We designed pairwise comparison questionnaires for four aspects of BOCR. There were two-stage questionnaires for the dependent relations among clusters and their elements, weights among clusters, and intensity of influence among elements.

3.2.2 Pairwise comparisons and group aggregation

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An analysis on the questionnaires filled out by the experts was first given, and we created a pairwise comparison matrix $\boldsymbol{A}$ by pairwise comparing the n elements of e_1, $e_2,\ldots, e_n$ and checking its consistency. After observing that different experts might give different answers to the questionnaire, a geometric mean operation is a commonly used method for the aggregation of experts' opinions (Saaty, 1989). In addition, a satisfaction index proposed by Huang et al. (2009) can be used for measuring the group opinion to improve the decision quality.

3.2.3 Construction of supermatrices and computation of the limiting priorities

The above priorities of each matrix were then arranged, representing the impact of a given set of elements in a cluster on another element in the network, as the sub-columns of the corresponding column of an unweighted supermatrix $\boldsymbol{W}$. We then normalized and synchronized each column of the unweighted supermatrix to record the overall clusters' influence by column, and this operation made the supermatrix's column stochastic, as a weighted supermatrix $\boldsymbol{W}^a$. We next obtained the limiting super- matrix $\boldsymbol{W}^{\boldsymbol{n}} = \lim_{a\to\infty} \boldsymbol{W}^{\boldsymbol{a}}$. The derived weights were then employed to weight the elements of the corresponding column blocks of the weighted supermatrix (Saaty, 2005).

3.2.4 Syntheses of the priorities of BOCR

Since there are four aspects to be considered, we synthesized the values from these four. The major concern was the supplier cluster, which meant we wanted to know which supplier (as the elements in the alternative cluster) is a better one. Each alternative obtains the priority values under the BOCR aspects to represent the importance of that aspect. We know that when $bB+oO-cC-rR > 1$, it means the target is preferred, and when $bB+oO-cC-rR \leq 1$, it means the target's benefits and opportunities are threatened by the costs and risks (Saaty, 2005).

4. Case Study

4.1 Background information

The company in this case study, Company P hereafter, provides professional EMS and has already participated in environmental projects and actions for many years. It sets up environmental policies and green standard procedures through clean production, green purchasing, and green manufacturing, which include product designs, components' procurements, production and manufacturing, and final customer services. Having received many international environmental certifications, including Green Partner, OHSAS (Occupational Health and Safety Advisory Services) 18001, ISO 14001, and IECQ QC 080000, Company P has put forth much effort to reach the goal of "zero pollution, zero accidents" via greenhouse gas emissions and the setting up of reduction targets, environmental monitoring, waste, wastewater, hazardous chemicals, energy-efficiency management, and environmental requirements upon its suppliers. Adhering to the Electronic Industry Code of Conduct (EICC), Company P actively attends EICC gatherings in order to understand sustainability-related issues and the latest development trends and to respond to corporate social responsibility (CSR) projects, such as supply chain CSR management, voluntary carbon reduction action, and so on. For its manufacturing process, Company P has instituted suppliers/contractors management, which asks suppliers to conform to its green purchasing polices and environmental requirements' approval-related information on a supplier relation management website and eGreen management platform. Furthermore, it executes a quarterly business review to evaluate potential suppliers that qualify under its own environmental standards.

The case study involved the purchasing of laptop power adapters. Since environmental criteria are rather diverse for different purposes, we organized the criteria from the above works (Sections 2.1 and 2.2) after the qualification step on the "deep green" aspect. We then sent these criteria to domain experts in the purchasing departments of electronics firms in Taiwan. There are 18 criteria, 6 environmental-related criteria and 12 traditional criteria, for future development. Table 2 lists these criteria. Moreover, after screening the potential suppliers through traditional and environmental criteria, three suppliers - denoted by X, Y, and Z - were left in the qualified vendor list, and further analysis was conducted to choose a better supplier.

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Table 2
Supplier selection criteria used in the study

Traditional Criteria	Environmental Criteria
1. Consistent delivery	1. Green image
2. Probability of customer complaints	2. Green competitiveness
3. Improvement and crisis management of customer complaints	3. Environmental plans
4. Quality	4. Pollution/Waste management
5. Design capability	5. Compliance with environmental directives
6. Equipment and technology	6. Green design capability
7. Flexibility	
8. Price	
9. Relationship with buyers	
10. Image	
11. Organisational management and size	
12. Financial performance	

4.2 Construction of the analytical network

To make sure the criteria listed in Table 2 are valid for our study, we checked their CVR. The questionnaires were sent out to 12 experts in the departments of purchasing, research and development, marketing, and quality assurance in Company P. All of them were returned, for a response rate of 100%. When N=12, only questions with CVR values higher than 0.56 were kept, with the rest deleted. Table 3 shows the valid criteria under BOCR.

Table 3
Validated supplier selection criteria under BOCR merits

	Benefits	Opportunities	Costs	Risks
Traditional Criteria	1. Consistent delivery 2. Probability of customer complaints 3. Improvement and crisis management of customer complaints 4. Quality 5. Design capability 6. Equipment and technology 7. Flexibility 12. Financial performance	1. Consistent delivery 2. Probability of customer complaints 3. Improvement and crisis management of customer complaints 4. Quality 5. Design capability 6. Equipment and technology 7. Flexibility	1. Consistent delivery 2. Probability of customer complaints 3. Improvement and crisis management of customer complaints 4. Quality 7. Flexibility 8. Price	1. Consistent delivery 2. Probability of customer complaints 3. Improvement and crisis management of customer complaints 4. Quality 7. Flexibility 8. Price
Environmental Criteria	1. Green image 3. Environmental plans 5. Compliance with environmental directives	1. Green image 2. Green competitiveness 5. Compliance with environmental directives 6. Green design capability	5. Compliance with environmental directives	4. Pollution/Waste management 5. Compliance with environmental directives

Next, questionnaires used for factor analysis were sent to employees in the electronics

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industry in Taiwan for them to evaluate the level of importance of each criterion in the BOCR aspects. This study received 93 copies of the questionnaire back, with 81 effective copies, i.e., an 87.1% effective response rate. The results derived from the analysis encompass several clusters with various criteria in each aspect (Figure 2). The dependence and feedback relations between clusters and their elements have been decided by five experts. Figure 3 below shows the resulting four sub-networks.

4.3 Integration and analysis of the expert questionnaires

We chose three experts from purchasing, research and development, and sales and marketing of Company P for the study. Because the paired comparisons in ANP are not as common as the five-level scale questionnaire, we provided an example posited before the pair comparisons in order to clarify any possible misunderstanding in response to the following paired comparison. The experts' responses were aggregated by geometric mean to obtain the group information with a satisfactory level. The priorities of all compared matrices form the unweighted supermatrices in the BOCR aspects. After normalizing and synthesizing to record the overall clusters' influence by column (in Table 4), the weighted supermatrices in the BOCR were established respectively. The weighted supermatrix was then multiplied by itself over and over until the elements in the matrix reached a stable convergence condition, which are the limiting supermatrices as shown in Table 5 under benefits.

Table 4
The weight of each cluster under the aspect of benefits

	Alternatives	Environment	Production responsiveness	Finance	Product assurance
Alternatives	0.0000	0.5000	0.4000	1.0000	0.5816
Environment	0.0884	0.5000	0.0000	0.0000	0.0000
Production responsiveness	0.4871	0.0000	0.2000	0.0000	0.3090
Finance	0.0912	0.0000	0.4000	0.0000	0.0000
Product assurance	0.3333	0.0000	0.0000	0.0000	0.1095

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Table 5
Limiting supermatrix under the aspect of benefits

			Alternatives			Environment			Production responsiveness		Finance	Product assurance				
			X	Y	Z	B2.1	B2.2	B2.3	B3.1	B3.2	B4.1	B5.1	B5.2	B5.3	B5.4	B5.5
Alternatives	**X**		0.0754	0.0754	0.0754	0.0754	0.0754	0.0754	0.0754	0.0754	0.0754	0.0754	0.0754	0.0754	0.0754	0.0754
	Y		0.2975	0.2975	0.2975	0.2975	0.2975	0.2975	0.2975	0.2975	0.2975	0.2975	0.2975	0.2975	0.2975	0.2975
	Z		0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495	0.0495
Environment	B2.1	Green image	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213	0.0213
	B2.2	Environmental plans	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065	0.0065
	B2.3	Compliance with environmental directives	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255
Production responsiveness	B3.1	Consistent delivery	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132	0.1132
	B3.2	Flexibility	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585	0.1585
Finance	B4.1	Financial performance	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951	0.0951
Product assurance	B5.1	Probability of customer complaints	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220	0.0220
	B5.2	Improvement and crisis management of customer complaints	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170	0.0170
	B5.3	Quality	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227
	B5.4	Design capability	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530	0.0530
	B5.5	Equipment and technology	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427	0.0427

4.4 Syntheses of the priorities of BOCR to supplier selection

Table 6 presents the final priorities or weights synthesized from BOCR. This study adopted the $bB+oO-cC-rR$ equation to synthesize the priorities of the suppliers. The resulting sequence in descending order is Supplier X, Supplier Y, and then Supplier Z. A radar chart shows the performance of criteria in each aspect in Figure 4 so that we can visually check the importance of the specific criterion under all aspects. Here, consistent delivery and flexibility were the major criteria in the BOR aspects, and price was the major criterion in the cost aspect.

4.5 Sensitivity analysis

Sensitivity analysis is a technique for systematically changing the elements to see if the final selection is affected. The target analyses are the changes in the priorities of the criteria of flexibility in the benefits aspect, the environment cluster in the benefits aspect, and the priority of the benefits aspect, respectively, with ±50% of their original values. The results of the analysis showed that the rank of the suppliers is kept the same. Figure 5 presents the result from a change in the priority on the selection of suppliers. Thus, we believe that the model is rather stable. Please refer to

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Step 6 in the flowchart of Figure 2.

Table 6
Synthesized priorities and the ranks of the suppliers

Weight / Suppliers	*b* 0.3629	*o* 0.1630	*c* 0.3261	*r* 0.1480	Synthesized priorities	Rank
X	0.1785	0.2195	0.3058	0.2888	-0.0419	2
Y	0.7043	0.6431	0.4052	0.1154	0.2112	1
Z	0.1172	0.1374	0.2890	0.5959	-0.1175	3

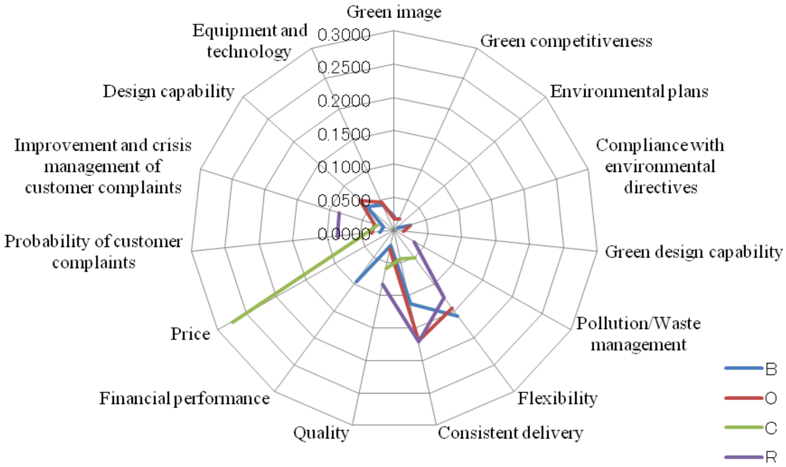

Figure 4. Radar chart of each criterion in BOCR

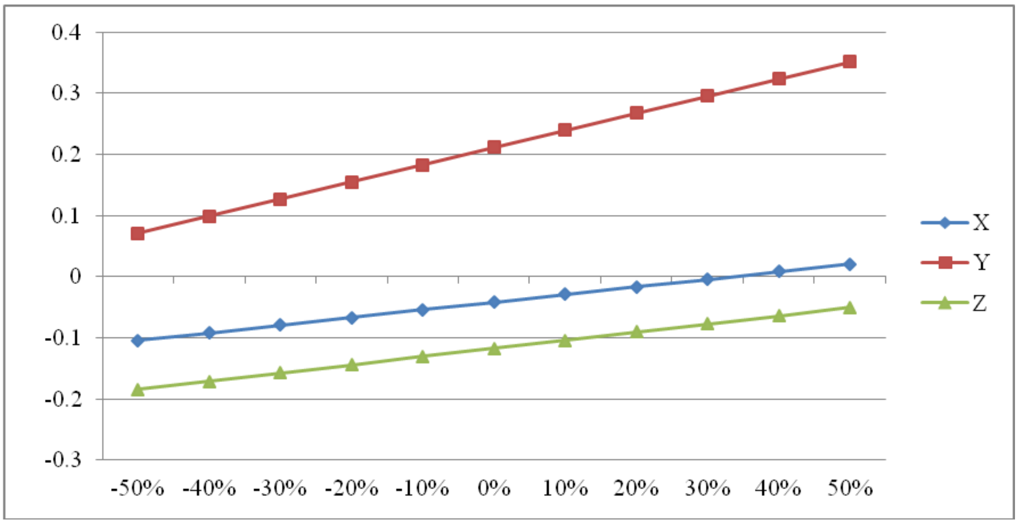

Figure 5. Sensitivity analysis on the change of the priority

4.6 Discussion

We discussed the analysis with the senior managers of the firm and received their responses. Three key issues were identified. First, Company P's final decision is to allocate 65% of its procurement of laptop adapters to Supplier Y and the rest to Supplier X. The decision is close to our analysis result, whose priority is Suppler Y $\succ$ Suppler X $\succ$ Supplier Z, with regard to the second source in its procurement process. In addition, based on the different situations of purchasing components for the laptops, the senior managers think the model can be used for their general procedure, but would not fit the procedure of rush purchasing. Second, Company P with "deep green" orientation has forced higher environmental standards of mandatory and voluntary types on its suppliers at the qualification step, which include environmental regulations, directives, and certifications, and this may cause the analysis results to not tell the whole story when less environmental criteria are the focus in the selection step. As the environmental requirements are attracting more attention, the mandatory or voluntary environmental criteria will become more and more significant in the supplier selection process. The rest of the study tried to simplify the process and shorten the purchasing cycle. Thus, the traditional criteria were the chief concerns for the firm's business operations, but there will be a gap that needs improvement in the future. Third, the past literature focuses on the importance of quality, providing a result not quite the same as the one from our study. It is not that Company P has given up on product quality, but rather its three suppliers provide products with similar high quality, demonstrating that product quality has become a basic threshold in the selection of suppliers, and thus the quality factor is not manifested in our result. Finally, theoretically, ANP is more flexible than AHP in structuring our problem, especially concerning the importance on the dependence and feedback relations between cluster and criteria. However, we make a trade-off between these relations and complexity. Some statistical tools are integrated into our solution procedure for reducing the complexity in using ANP.

5. Conclusions

This study deals with the environmental effect on the vendor selection problem for electronics firms in Taiwan through an ANP BOCR analysis. First, this study examined the different paths of supplier selection processes, finding that Taiwanese electronics firms concentrate on using environmental criteria in the qualification step. The results show that the traditional criteria are still the main concerns, revealing the reality that Taiwan's electronics industry for EMS is forced to take the traditional criteria into account for the final decision for market competition. This finding has

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also been confirmed by the recent survey in the aerospace and the railway industries in the UK (Genovese et al., 2013). However, this is not the right action for rewarding the environmental endeavors of suppliers. We recommend that business enterprises target more environmentally-relevant criteria in both the qualification step and the final choice step as better actions towards environmental protection. Second, the final decision of the firm was close to our result in selecting vendors of laptop adapters. We believe that the proposed model is applicable to many other choices of supply. Third and finally, ANP is well-known for processing tangible and intangible factors with dependences and feedbacks. With the ANP BOCR model, we can assess all aspects for ranking suppliers. Due to these BOCR aspects, we clearly settle upon the criteria and compare them with the criteria of the same constructive aspects without being affected by other different aspects. Furthermore, the content validity ratio and factor analysis are integrated into the procedure, making the model more accessible and the process more rigorous. Our study illustrates these advantages when looking at supplier selection.

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Appendix A

Questionnaire I

Benefit merit

Confirmation relationships between each cluster for Vendor selection

Cluster	**Y**	**N**
1-1 Products Assurance affects Suppliers	☐	☐
1-2 Products Assurance affects Finance	☐	☐
1-3 Products Assurance affects Environment	☐	☐
1-4 Products Assurance affects Production Responsiveness	☐	☐
2-1 Suppliers affects Finance	☐	☐
2-2 Suppliers affects Environment	☐	☐
2-3 Suppliers affects Production Responsiveness	☐	☐

Appendix B

Questionnaire II

Benefit merit

The importance of each criteria

Criteria	**Extremely Disagree** ⟷				**Extremely Agree**
	1	**2**	**3**	**4**	**5**
1. Consistent delivery: The ability of meeting delivery deadlines and arriving on time.	☐	☐	☐	☐	☐
2. Probability of customer complaints: The probability of the products providing to buyers didn't satisfy requirements.	☐	☐	☐	☐	☐
3. Improvement and crisis management of customer complaints: The responsiveness of product improvements and customers complaints.	☐	☐	☐	☐	☐

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Appendix C

Questionnaire III

Benefit merit
Part A

Please make pair-comparisons on clusters for choosing an appropriate supplier																		
Q1：In product assurance cluster, please make pair-comparisons on each cluster																		
Cluster	Intensity																	Cluster
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Product assurance	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Suppliers
Product assurance	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Production responsivenes s
Suppliers	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Production responsivenes s

Part B

Please make pair-comparisons on elements for choosing an appropriate supplier																		
Q1-1：In Probability of customer complaints factor, please make pair-comparisons on each criteria																		
Criteria	Intensity																	Criteria
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Probability of customer complaints	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Improvement and crisis management of customer complaints
Probability of customer complaints	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Quality
Probability of customer complaints	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	Design capability
Probability of customer complaints																		Equipment and technology

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