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Green Vendor Selection with Risk Analysis

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Abstract — Because the consciousness of environmental protection, many issues related to Green Supply Chains (GSC) are discussed. Different from traditional supply chains, GSC are concerned about environmental impacts and material utilization issues, which make the selection of the suppliers more complicated. The mindset of "prevention prior to cure" and the restrictions of the European Union render green materials and components critical issues from the beginning of production. According to the regulations of the EU and issues of supplier selection criteria, supplier selection is a type of multi-criteria problem. Thus, this research uses AHP and FMEA to construct a hierarchy structure for this purpose. By considering the minimal risk and costs, a complete analysis is conducted. Decision makers can follow rules to calibrate the results of decisions and establish a benchmark to identify suitable supplier; in the meantime to improve the alliance relation by the sensitivity analysis proposed in this study.

Keywords — AHP, green vendor ranking & selection, risk map, alliance development

1. INTRODUCTION

Traditional supply chain management faces rising environmental consciousness in recent decades, and the processes of traditional supply chain management require re-examination under considerations of green factors. There are various directives and regulations stipulated for green products, such as WEEE (2003), RoHS (http://www.rohs.gov.uk, 2010), EuP (http://www.eup-network.de, 2010), etc. In the past, the supply chain management focused on information flows, which allowed the chains to work effectively and efficiently; whereas, contemporary supply chains must also fulfil green factor regulations.

Purchasing is one of the most critical stages in a green supply chain. In a green supply chain, hazardous and harmful substances will accumulate throughout the processes, and purchasing activities of a green supply chain seek green suppliers to provide cleaning materials and components in order that the end-product could conform to green regulations. This paper proposes a method of risk estimation and selection for green suppliers as guidance for the manufacture so that a manufacture is not only able to select the qualified vendors; but also to improve the green quality of the vendors.

The paper is organized as follows. Literature of supplier selection and green supplier criteria are surveyed in Sec. 2. The methodology of this paper is proposed in Sec. 3, with the sensitivity analysis and its applications to the alliance development. The last section is the conclusion of this study.

2. LITERATURE REVIEW

Supplier selection is an issue under long-term discussion and development. Recently, Ho et al., (2010) reported a review of supplier evaluation and selection, indicated that the most popular evaluating criteria are quality, delivery, and price/cost. From the criteria of vendor selection, it can easily be realized that the selection of different suppliers is a typical multi-criteria decision making problem. Analytic Hierarchy Process (AHP) is a multiple criteria decision-making tool used in many applications related to decision-making (Satty, 1980; Vaidya *et al.*, 2006). AHP often applies to multi-criteria decision problem, but it is frequently the case that the DM is certain about the rank order of the criteria but uncertain about the precise numerical weights (Wang, 2004). However, Hurley (2001) has proposed a method to vary the weights by giving each element an exponential parameter α in the pairwise matrix. The resultant range of parameter α can give the DM some flexibility on the weights. Also, some researchers such as Chan *et al.* (2007) have applied Fuzzy approach to coping with such uncertainty.

Failure Modes and Effects Analysis (FMEA) first emerged from studies by NASA in 1963. It employs Risk Priority Numbers (RPN) to measure the risk and severity of failures. RPN consists of three indicators, namely, Occurrence (O), Severity (S), and Detection (D). This ability makes it appropriate to use FMEA to assess the risks associated with green components (Hu, et al., 2009). Utility function is a device that quantifies the attitude of a DM towards risk by assigning a

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numerical index for indifference level of comparison for criterion. Generally, decision makers are classified into three types, namely, risk aversion, neutral risks and risk prone, and the DM's risk attitude is reflected in the shape of the utility curve (Kainuma *et al.*, 2006).

Based on the past supplier selection criteria (Webber, 1991; Ho *et al.*, 2010) and the discussions with numerous experts, this paper will consider additional green criteria which relate to EU's regulations to evaluate a green supplier. Since AHP has been widely using in supplier selection problem to provide objective weights of criteria (Ho *et al.*, 2008), in the paper, we shall adopt it as our main frame of analysis. On the viewpoint of risk evaluation, FMEA will be integrated into the framework to represent the objective aspects of the risk measure; whereas the utility theory is adopted to measure DM's subjective level towards the risk. Finally, the sensitivity analysis of the exponential parameter in AHP and the parameters in utility functions will provide a DM some information of the critical factors in management; as well as the guideline of improvement of partnership with suppliers. The whole procedure will be introduced in next section.

3. RISK ANALYSIS OF VENDOR SELECTION

This section describes the framework of green supplier selection and the details of the evaluation method.

3.1 Construction of a Hierarchical Structure

When evaluating a supplier's green risk, there are four major criteria for measurement. The green improvement of this evaluation structure is the consideration of environmental impact and Life-Cycle Analysis (LCA), which are different from the traditional evaluation criteria. The first criterion is Income Quality Control (IQC), using the notation q to represent. The content of environmentally sensitive substances are controlled or forbidden, thus, this study aims at IQC, of green suppliers, in order to distinguish whether suppliers conform with RoHS. Secondly, the Disassembly Effort Index (DEI) is a criterion that measures the effects of a product's lifecycle, using the notation d to represent. DEI helps us to know the influence of the materials/components in the future, by ensuring that the materials/components are recyclable. The third criterion is the performance of vendor management and represent by the notation vm . This criterion can evaluate the performance of management in 5 dimensions. The first dimension is self-inspection reports, where each supplier is compelled to initiate basic improvements in management performance. The second dimension is actual inspection reports, where the objective point of view of experts specializing in inspections provides accurate results. The third dimension is warranty, where suppliers make a commitment, by vouching for their material/component contents as conformed to law. Moreover, the fourth and fifth dimensions are certifications that come from international certification organizations or well-known enterprises. Through such measures, authoritative organizations' certify, as proof of conformity, that the named suppliers have good management performance.

The fourth criterion is a logistic level, where all suppliers work cooperatively with all partners in a supply chain, the results of which are increased efficiency and profits for all members. This criterion uses the notation l to represent. The above mentioned criteria's relationships can be drawn as a hierarchical structure, as shown in Figure 1. The measurement method of each criterion is discussed in the next section.

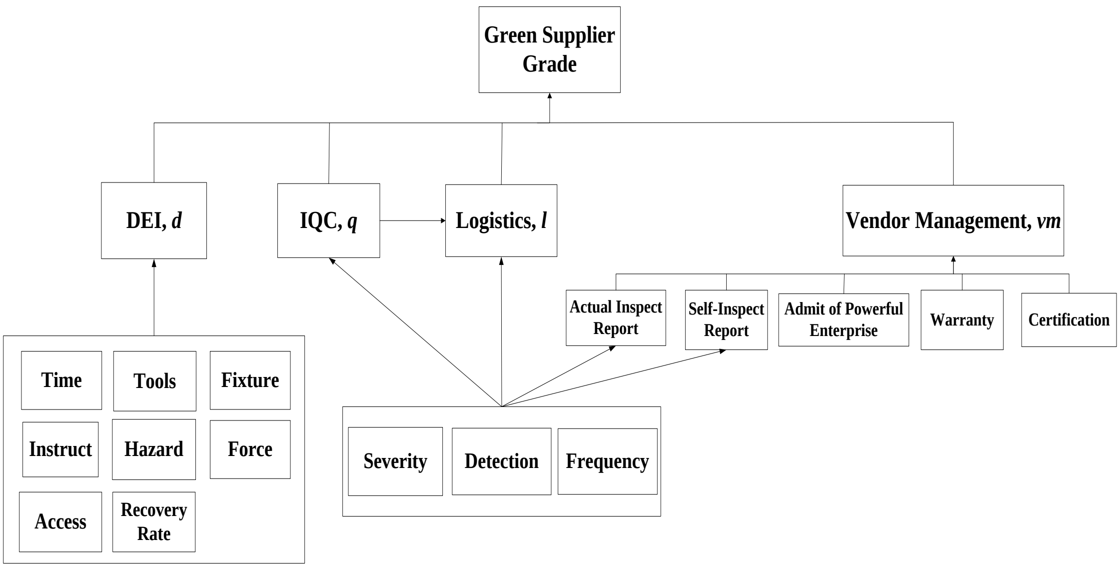

Figure 1. Hierarchical analysis structure of green supplier selection

3.2 Evaluation of the Weights of the Criteria

In order to measure the weights of importance of different criteria, in this section two different evaluation methods from different aspects are proposed as below:

3.2.1 Subjective Evaluation — Risk Utility Function

Since the consciousness of the risk is different from each one, utility function is adopted by articulating DM's risk attitude. First of all , this system will establish the best and worst scores of each criterion, then the best score's utility value is $U = 1$, and the worst score's utility value is $U = 0$. After deciding the best and worst scores, the mid-score C between these two scores is computed. According to the probability we can compute the expect value of mid-score C utility value, U_c. When three points is obtained for the utility function, the utility function can be computed. The exponent parameter a_v of each criterion will show the risk attitude of the DM. The utility function is shown as Equation (1):

$$f_v(x) = x^{a_v} \qquad v \in \{d, q, vm, l\} \tag{1}$$

3.2.2 Objective Evaluation — AHP

While the utility function shows the subjective measure of a DM's risk attitude towards each attributes, to the objective measure of the weights of each criterion, will be estimated by conducting AHP with sequential aggregation of pairwise evaluation of criteria in each hierarchy. The evaluation results a 9 level scale, which is recommended by Saaty (1980). Let A be the pairwise matrix, based on Equation (2), each pairwise matrix's eigenvalue is computed to obtain the eigenvector as the weights of criteria:

$$Aw = \lambda_{\max} w \tag{2}$$

where $\lambda_{\max}$ is the largest eigenvalue. Although pairwise comparison is a valid method for obtaining weights, inconsistencies should be considered.

In addition, to avoid the uncertainty when DM performs the pairwise comparision, in this study we adopt Hurley's method (Hurley, 2001) to vary the weights by giving each element of a pairwise matrix an exponential parameter φ as follows but preserves the ranked order of the attributes in a matrix, which not only results in confidence for the AHP recommendations, but also provides the DM some flexibility in adjusting the weights:

$\varphi = 1$: it represents the original matrix and will not affect the consistency ratio of the pairwise matrix.

$\varphi > 1$: the order of weights will be the same as the original, but the largest weight will increase while the other weights decrease, and the consistency ratio will increase

$0 < \varphi < 1$: the order of weights will not change, but the largest weight will decrease while the other weights will increase, and the consistency ratio will decrease.

$\varphi = 0$: all the elements in the comparison pairwise matrix are equal to 1, thus, all the weights remain the same. The matrix becomes the most consistent matrix, so the consistency ratio is 0.

3.3 Measures of Criteria

This section introduces the method for quantification, including the four major criteria: IQC, DEI, vendor management, and logistics.

3.3.1 Income Quality Control (IQC, *q*)

To ensure the material/components conform with RoHS, this criterion is used to evaluate the risk of hazardous substance base on the feedstock inspection report.

(a) Severity, S_q:

S_q defines the probability that the content of hazardous materials will not pass the required level. It can use the request of RoHS as the upper bound of normalization. The lower bound is dependent on the technical development.

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Therefore, by Equation (3), the data of inspection report can be normalized into a value between 0 and 1:

$$x_{ijk} = \frac{Inspected\quad Value - \mathrm{LB}}{UB - LB}, \quad i \in \{1 \sim n\}, \quad j \in \{1,2,3\}, \quad k \in \{1 \sim 6\} \tag{3}$$

where, i is the number of inspection reports, j indicates a risk level, and k is a kind of hazardous materials indicated in Table 1. Each hazardous material will only belong to one type of risk level of high ($\tilde{H}$), medium ($\tilde{M}$) and low ($\tilde{L}$).

Table 1. Hazardous materials

k =	1	2	3	4	5	6
	Hg	Cd	Pb	Cr(VI)	PBBs	PBDEs

Because results are according to the experience of inspector, each risk level is represented by a fuzzy number, define by Equation (4).

On the premise that the categorization's reliability is λ, the fuzzy number $\tilde{L}$, $\tilde{M}$, and $\tilde{H}$ will become the crisp set L_λ, M_λ, and H_λ. Integrate each part of a component's risk estimation to denote the severity of the component, which may not pass EU detection, as shown in Equation (5).

$$\left.\begin{array}{l} \mu_{\tilde{L}}(x) = \begin{cases} 1, & 0 \le x \le 0.25 \\ 4(0.5 - x), & 0.25 \le x \le 0.5 \\ 0, & x \ge 0.5 \end{cases} \\ \mu_{\tilde{M}}(x) = \begin{cases} 0, & x \le 0.25 \\ 4(x - 0.25) & 0.25 \le x \le 0.5 \\ 4(0.75 - x) & 0.5 \le x \le 0.75 \\ 0, & x \ge 0.75 \end{cases} \\ \mu_{\tilde{H}}(x) = \begin{cases} 0, & x \le 0.5 \\ 4(x - 0.5), & 0.5 \le x \le 0.75 \\ 1, & x \ge 0.75 \end{cases} \end{array}\right\} \tag{4}$$

$$S_q = \frac{L_\lambda}{L_\lambda + M_\lambda + H_\lambda} \times \left(\sum_{i=1}^{n} \sum_{k \in 1} \frac{x_{i1k}}{n} \right) + \frac{M_\lambda}{L_\lambda + M_\lambda + H_\lambda} \times \left(\sum_{i=1}^{n} \sum_{k \in 2} \frac{x_{i2k}}{n} \right) + \frac{H_\lambda}{L_\lambda + M_\lambda + H_\lambda} \times \left(\sum_{i=1}^{n} \sum_{k \in 3} \frac{x_{i3k}}{n} \right) \tag{5}$$

(b) Frequency, F_q:

The total number of failed inspection reports are recorded in S_q. Frequency F_q refers to the ratio of total inspection reports to failed inspection reports. When a failed report appears in the inspection process, it means the supplier's product contains some type of risk C. Then the failed inspection reports' ratio cannot over a ratio C' which is established by the DM. If a failed report appears, F_q will increasing from C. C plus C' will become 1. The calculation method is as shown in Equation (6).

$$F_q = \begin{cases} 0 & if\ x_q = 0 \\ C + \frac{x_q}{n} & if\ 0 < \frac{x_q}{n} \le C' \\ M & otherwise \end{cases} \tag{6}$$

where, n denotes the total number of inspection reports, and x_q denotes the number of failed inspection reports. M represents a large positive number. If the failed inspection reports' ratio over C', then the supplier will not be considered at all.

(c) Detection, D_q **:**

The level of difficulty in detection is dependent on the ratio of the degree of disassembly to pure material. Upon inspection of an entire component, the concentration of hazardous material would be diluted, and thus, decrease the accuracy of the inspection. This paper uses a mixed ratio to denote the risk of detection. D_q is a real number which represented by the mix ratio of inspection.

After obtaining the three dimensions of risk estimates, according to the weight aggregate, it becomes the IQC's risk estimate. Each dimensions' weight obtained from AHP, which the index denoted different dimension of weight. The risk estimate of IQC can be obtained through following Equation (7).

$$Risk_{IQC} = w_{S_q} S_q + w_{F_q} F_q + w_{D_q} D_q \tag{7}$$

3.3.2 Disassembly Effort Index

The ideal green supply chain is a closed-loop. All components/materials can be reused, remanufactured, or recycled, and will not produce any waste. Therefore, at the beginning stage, preconceptions of the other stage situations requires pre-action, using the Disassembly Effort Index (DEI) score card (Kuo, 2006) to analyse the supplier's components/materials effects during the disassembly stage.The DEI card is shown in Figure 2.

Each criterion score ranges between 0 and 25, the smaller the better. Each score is then normalized into a unit interval between 0 and 1 in order to express the risk estimation.

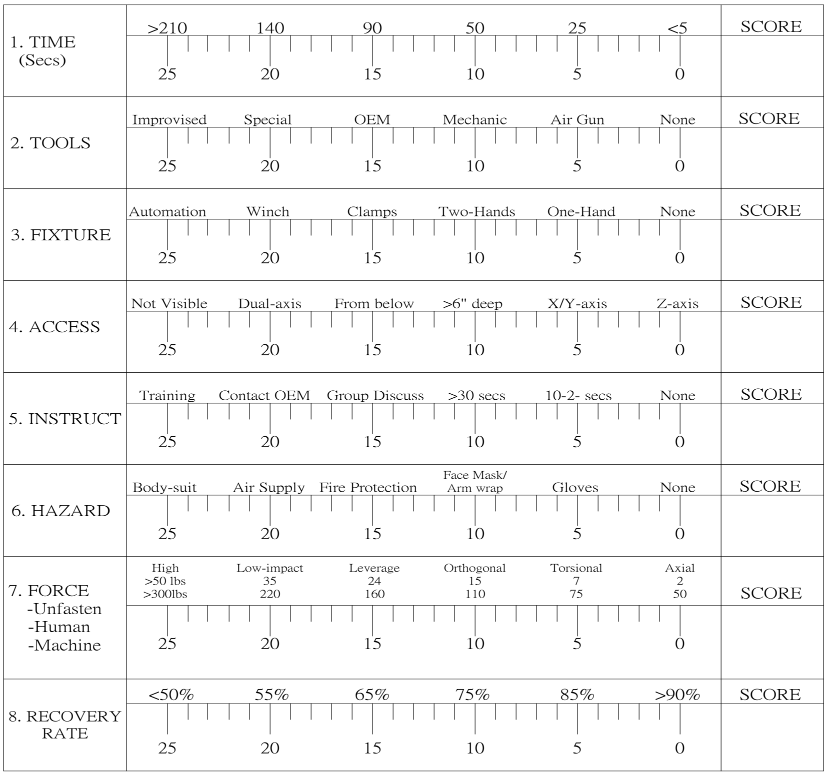

Figure 2. DEI score card (Kuo, 2006)

After obtaining all criteria risk estimations, and according to each weighted aggregate to become the DEI's risk estimation. Each criterion's weight is computed by AHP, which the index denoted different criterion of weight.

$$Risk_{DEI} = \sum_{i \in DEI} w_i y_i, \quad DEI \in \{DT,\ TO,\ FI,\ A,\ I,\ H,\ FO,\ R\} \tag{8}$$

3.3.3 Vendor Management

According to the practice of AVECTEC (2009), the criteria of vendor management includes two major evaluation items and three bonus items. The two major evaluated resources are self-inspection reports and actual-inspection reports.

There are 12 main items in the inspection reports, and each main item has different number of sub-items.

3.3.3.1 Rule of Report Evaluation

(a) Recording Method:

There are four levels of scores to evaluate each sub-item: 0 denotes totally unsatisfied, 1 denotes seldom satisfies, 3 denotes partly satisfied, and 9 denotes totally satisfied. When the sub-item's score is lower than, or equal to 1, then the sub-item is recorded as "1" for a failure (AVECTEC, 2009).

$$f_r(item_{ij}) = \begin{cases} 1, & if \quad item_{ij} \le 1 \\ 0, & if \quad item_{ij} \ge 3 \end{cases} \quad i \in \{1 \sim 12\} \tag{9}$$

Table 2. Amount of sub-items in a main item (AVECTEC, 2009)

$i=$	1	2	3	4	5	6	7	8	9	10	11	12
$j=$	19	9	9	21	12	24	76	15	14	6	8	8

(b) Evaluation Method:

Each main item uses the average score of the sub-items for performance expression:

$$item_i = f_s(item_{ij}) = \frac{\sum_j item_{ij}}{\# j} \quad i \in \{1 \sim 12\} \tag{10}$$

(c) Standard for Pass:

When the average score of the main items is over 7 as commonly adopted, then the supplier passes the inspection standards. If a supplier's average score is lower than 7, it means the supplier's management performance has not yet reached the requested level. Then the performance of vendor management will show a large number *M* for expression.

3.3.3.2 Inspection Report

Since there are two types of inspection reports: self- inspection report, and the actual inspection report. They are denoted s and a respectively.

(a) Severity, S_s and S_s:

When the score of an inspection report is high, the vendor management has the greater performance. When a supplier has a good performance in management, then the component/material's reliability will also be high. As 1 denotes the worst case in risk evaluation, this study uses a 1 minus average score of the main items in order to represent the severity, as shown in Equation (11).

$$S_\varepsilon = 1 - \frac{\sum_i item_i}{12 \times 9} \quad \varepsilon \in \{s, a\} \tag{11}$$

(b) Frequency, F_s and F_a:

F_s and F_a use the ratio of the total number of sub-items to failure items in order to express frequency. The severity S_s and S_a represent the risk of degree, and frequency F_s and F_a represent the risk of occurrence. The computation method is as shown in Equation (12).

$$F_{\varepsilon} = \frac{\sum_{i=1}^{12}\sum_{j} f_r(item_{ij})}{\sum j} \qquad \varepsilon \in \{s, a\} \tag{12}$$

(c) Detection, D_s **and** D_a **:**

This rating is according to an auditor's subjective opinion, and can result in a three level rating inspection process, and as the rating is in a linguistic form, this study uses three fuzzy numbers, namely, $\tilde{E}$, $\tilde{N}$, and $\tilde{H}$ in order to express, which are similar to Equation (7). On the premise that the auditor's reliability is μ, then, the fuzzy numbers $\tilde{E}$, $\tilde{N}$, and $\tilde{H}$ will become the crisp set, E_μ, N_μ and H_μ.

After obtaining the three dimensions of risk estimations, due to that each weight aggregate may become a self-inspection or an actual inspection risk estimation, each dimensions' weight is obtained from AHP, and the index denoted different dimension of weight. As these two evaluation items' forms are the same, the only difference is the auditor's opinion. Thus, the weights of S_s and S_a are denoted by w_{S_i} respectively. Similarly, w_{F_i} and w_{D_i} denote the weights of the respective frequency and detection. The risk estimation of a self- inspection and actual inspection can be obtained by following Equations (13) and (14).

$$Risk_{self-inspect} = w_{S_i} S_s + w_{F_i} F_s + w_{D_i} D_s^{\mu} \tag{13}$$

$$Risk_{actual\ \ inspect} = w_{S_i} S_a + w_{F_i} F_a + w_{D_i} D_a^{\mu} \tag{14}$$

3.3.3.3 Recognition and Certification

The warranty declarations of powerful enterprises and certification are items of exception for vendor management, as the warranty is a basic guarantee of a supplier's product. Standardized certification of those international organizations that use ISO includes the two binary variables, P and C, in order to express the class of warranty and certification. The other item of exception is the declaration of powerful enterprise, by admitting to products with different standards and effects, this will enable special classification for these enterprises. There are three level of classification, namely, α, β, and γ. α class is the most famous and powerful international enterprises, followed by β class, etc. Y_i is a positive integer which expresses the number of declaration from different levels of enterprise. After obtaining a risk estimation of both self and actual inspection reports, and any items of exception data, the next step is the aggregation by the respective weights which are obtained from AHP.

$$\begin{aligned} Risk_{management} = MAX\{ & w_A Risk_{actual\ \ inspect} + w_S Risk_{self-inspect} \\ & - (w_P P + w_C C + w_\alpha Y_\alpha + w_\beta Y_\beta + w_\gamma Y_\gamma),\quad 0\}\ Y_i \in \mathrm{Z}^+ \quad P, C \in \{0,1\} \qquad i \in \{\alpha, \beta, \gamma\} \end{aligned} \tag{15}$$

Note that while risk estimation is computed, the range of a risk value is between 0 and 1. Therefore, we take the maximum between the computed result and 0, and thus, obtain a reasonable value.

3.3.4 Logistic

(a) Severity, S_l**:**

S_l measures the time period, x_t, of the number of weeks ago the supplier was out of stock in the past two years. The unit between the two time points is one week and thus 104 weeks in total of two years. An power function, $f_l(x_t)$ will express the severity of the time period x_t. Because the time period x_t is the larger the better, so using total weeks minus time period x_t express the risk of out of stock. Parameter a represents the influence of out of stock, which is decided by the DM.

$$S_l = f_l(x_t) = (\frac{104 - x_t}{104})^a \quad 0 \le x_t \le 104 \quad 0 \le a \le 1 \tag{16}$$

(b) Frequency, F_l:

This represents the number of orders, x_N, that have been out of stock among the total orders N, as shown in Equation (6). The ideal is the similar with F_q.

(c) Detection, D_l:

Because S_l and F_l uses the records of transactions to evaluate a supplier's logistics level, an auditor will, according to their assessment, provide a linguistic statement to describe the transaction records' status. There are three levels of status: Clear $\tilde{C}$, Normal $\tilde{N}$, and Unclear $\tilde{U}$ which are similar to Equation (4). On the premise that the auditor's reliability is η, the fuzzy numbers $\tilde{C}$, $\tilde{N}$, and $\tilde{U}$ will become a crisp set C_η, N_η, and U_η.

After obtaining the three dimensions of risk estimation, and according to each weight to aggregate, to become the logistics' risk estimation. Each dimensions' weight obtained from AHP, which the index denoted different dimension of weight. The risk estimate of logistics can be obtained by following Equation (17).

$$Risk_{logistic} = w_{S_l} S_l + w_{F_l} F_l + w_{D_l} D_l^\eta \tag{17}$$

3.4 Supplier Evaluation and Selection

The risk aggregation method and supplier ranking method are introduced, as follows.

3.4.1 Risk Aggregation Method

Prior to quantification, the calculated utility functions of the four major criteria are based on the risk attitude of the DM, and are obtained through the quantification process, in order to determine each criterion's risk estimation. Each dimension's risk estimation will transfer to the risk utility value, by the utility function. However, the risk estimations have different patterns of single values and crisp sets. The transformation method is as shown in Equation (18).

$$f_v(x) = \begin{cases} f_v(x) & if \quad UB = LB \\ \int_{LB}^{UB} f_v(x)dx \Big/ (UB - LB) \times 1 & if \quad UB \ne LB \end{cases} \tag{18}$$

The final step is integrating the risk utility values with objective weights. There are four main criteria in supplier selection, namely, IQC, DEI, vendor management, and logistics. Each criteria's weight obtained from AHP, which the index denoted different criteria of weight. For example w_q denote the weight of the IQC, etc. The integrated function is determined as shown in Equation (19).

$$R_s = f_q(Risk_{IQC})w_q + f_d(Risk_{DEI})w_d + f_{vm}(Risk_{management})w_{vm} + f_l(Risk_{logistic})w_l \tag{19}$$

3.4.2 Ranking Method

Each supplier will have a risk estimation R_s and cost. The supplier risk map uses this information as two coordinates' values, of which each has its threshold as the minimum allowed value, and the risk of violating an green legislation is considered more serious than cost in vendor evaluation. One threshold is the expected costs of the DM, the other is the expected risk level of the DM. Therefore, there are four categories of suppliers, namely, A, B, C and D as shown in Figure 3.

Category A is the first priority because their risk estimations and costs are lower than the expectations of the DM. Category B is the second priority. Although the cost is high, if the enterprise has any record of violation green legislation, the damage is much more serious. If the cost to the company reputation is not too high, DM will consider the suppliers in category C, which can offer low costs, but have high risk components/materials, and thus, requires guidance and assistance to cross the threshold.

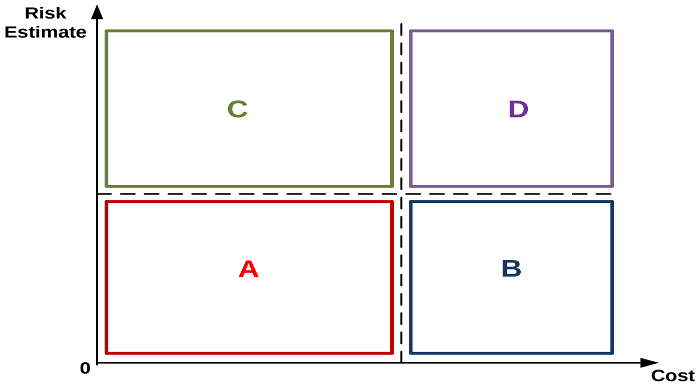

Figure 3. Risk map of the suppliers

The supplier which is classified in Category D means it has both high risk and cost, and would be the last choice for supplier selection.

The DM may adjust the decision process to allow the supplier's level changing. How to adjust a level with the least change and how to provide guidance and assistance are discussed in the next section.

3.5 Sensitivity Analysis and Alliance Development

Because it is important for an enterprise to develop a good alliance relation along the supply chain, therefore, the purposes of sensitivity analysis in this study are focused on the identification of critical factors; and also to establish a guideline for improving the suppliers in order to conform to the requirement of manufacturer.

In this study, there are two channels for a DM to present the preferences: AHP and the utility theory. These two methods are independent of each other with respect to the objective and subjective judgement. After calculating a supplier's risk estimation, sensitivity analysis can be employed to find the critical factor of risk measure for developing a guidance for suppliers in Category C to cross the threshold. In the other hand, critical factor in cost can be identified for supporting the suppliers in Category B on getting better green performance, and increased competitiveness.

Therefore, sensitivity analysis is performed by holding two conditions of (1) retaining a supplier's category when the parameters have varied; and (2) retaining the order of a supplier's risk estimate when parameters have varied. In consequence, the outcome of the sensitivity analysis determines the allowable ranges of parameter a_v of the utility functions, of which the smaller the allowable range, the greater is the degree of sensitivity. Also, by applying Hurley's method (2001) of assigning each element in the main criteria's comparison pairwise matrix with an exponent parameter φ as stated in Section 3.2.2, the sensitivity of the parameters in AHP can be evaluated.

3.6 Summary and Discussion

The risk estimation of a green supplier can be computed by following the procedure. Based on different DM, the preference and the risk attitude of each criterion will lead to different risk estimations. In summary, the risk estimation of a green supplier can be computed by following the procedure.

Step1: Construct a hierarchy structure base on the relation of the considered criteria.

Step2: Derive the subjective risk estimates by Utility Functions of the main criteria and measure the weights of Criteria by AHP by Sec. 3.2.

Step3: Quantify the risk level of each sub-criterion by following the procedure of Section 3.3.

Step4: Aggregate the risk estimations by Equation (19) to obtain the overall risk level.

Step5: Given the thresholds of the allowed risk and cost to establish a risk map; then plot the risk score of each supplier on the map for ranking.

Step6: Through sensitivity analysis to find the most sensitive parameter and establish alliance strategy.

Different decision makers would have different preference and the risk attitude of each criterion which will lead to different risk estimations. According to sensitivity analysis, the DM could understand the allowed variation and also the key factors for management.

The proposed method has been applied to the case of selecting a backlight supplier that conforms to EU regulations and directives by a TFT-LCD Original Equipment Manufacturer (OEM). Two suppliers have first undergone 5 steps; and

Supplier 1 which fell in the Category A with less risk level and cost has been selected. Although Supplier 2 with higher risk was not in favour, in order to maintain the partnership along the supply chain, it is the DM of this OEM who is responsible to supervise Supplier 2 so that Supplier 2's risk level can be reduced. Consequently, sensitivity analysis to identify the significant factor in risk was conducted for such alliance management. The result has shown that, IQC is the most critical factor and should be improved to effectively reduce the risk level. Furthermore, among the factors of IQC, the outcome from the sensitivity analysis suggested that if Supplier 2 wants to advance to a higher class, the first improvement should be taken to decrease the number of failed inspect report. That is, they have to check the content of hazardous substances, which includes the improvement of their technology of production and their manufacturing quality level. Secondly, it is to increase the accuracy of inspect reports by disassembling the component so that purer material can be presented for inspection.

4 CONCLUSION

This paper proposes an evaluation procedure to support the decision of green supplier selection. Different from traditional supplier selection, the criteria of green supplier selection must consider world-wide regulations for environmental protection. Based on these green criteria, this thesis constructs a hierarchy structure to conduct a complete analysis of green suppliers. Through risk analysis of green suppliers, each supplier will be classified according to their risk estimation and the cost, tracked on a supplier risk map. The supplier risk map provides the required reference for the DM to make a decision.

In summary, the improvements of this paper over other literature are as follows:

1. By engaging in discussions with numerous experts in related fields, the green criteria of this study, completely considers the regulations of the EU, such as RoHS, WEEE and EuP, and are suitable for instant application.
2. Integrating FMEA with AHP renders risk evaluation more systematic, and the integration of the utility theory reflects the risk attitude of a DM more honestly.
3. This paper provides a method of risk quantification for each green criterion by using fuzzy numbers to express some linguistic information.
4. The supplier risk map provides instinctive information, which can help the DM to comprehend the interrelations between each supplier.
5. The scheme of sensitivity analysis provides the DM to conform the selected vendor and above all to improve the alliance relation with the candidate suppliers.

Future works that can be extended from this study is suggested to apply the risk estimations and costs as input parameters of a mathematical programming model such that the purchase quantity of each supplier can be calculated (Kokangul *et al.*, 2009).

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