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研究論文

# A Supplier Evaluation Method for Sustainable Project Management

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Due to the environmental legislation, closed-loop supply chain management has become an important issue for many companies all over the world. Considering sustainable project management, supplier selection and evaluation phase in CLSC is one of the crucial decision points not only for QCD but also environmental impacts. As well as choosing the suppliers to work with is one of the key points of project management, semi- annually or annually evaluation is very important to keep track of vendors' performance level to be successful on sustainable development.
There are, a lot of factors can affect companies' ability to evaluate all suppliers and then to choose the best one. In this step, firms have to define several criteria due to their firm culture, aim and mission. There are various approaches to determine performance level of suppliers. This paper presents a supplier evaluation method for sustainable project management in closed-loop supply chain and aims to create a model to help evaluating suppliers by using hybrid grey relational analysis for a firm in cable industry. To be developed model is compared with hybrid fuzzy logic method integrated with AHP. Results identify the current status of suppliers to keep track on sustainability of outsourcing success in CLSC network.
Keywords : Supplier Evaluation, Closed-loop Supply Chain, Fuzzy Logic, Grey Relational Analysis, AHP, Sustainable Project Management

## 1. Introduction

Any organizations, today, which wants to stay competitive, must satisfy customers' demand, obey the environmental legislation and follow a sustainable approach. Sustainability includes not only economic side of a project but also environmental and earth issues. It is a fact that environmental issues and then protection and enhancement of the human and naturel resources will be needed in near future are cross-boundaries ranging from companies to customers, suppliers, competitors, and the community. REACH and RoHS environmental legislation issued by EU are prevailing all over the world related to sustainability problem of companies. When considered from this point of view, supplier selection and evaluation is recognized as a critical decision phase of project management related to closed loop supply chain (CLSC), which is a long term project for companies. Because reliable vendors can help their manufacturer partners to reduce approximately 70% of total costs and to design, produce products having regard to environmental issues, it is perceptible that firstly selection and then evaluation of

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appropriate suppliers in a certain time period are key factors in raising satisfaction of each part of the closed loop supply chain, so it affects the competitiveness and the sustainability of the companies.

### 1.1 Problem Statement

Most of the electronic equipment companies in the world are in the process of integrating sustainability factors into sourcing processes and decisions internally. Sustainability in general, has received much attention in the past few years, while sustainability in closed loop supply chain models has been attracting much attention within the last decade. This study aims to create a model to help evaluating suppliers by using hybrid grey relational analysis for a firm in cable industry. To be developed model is compared with hybrid fuzzy logic and AHP model. Output of the system will be a semi-annually or annually credit report for all suppliers to identify the current status to keep track on sustainability of outsourcing success of closed loop supply chain network.

As a solution case, this paper also conducts a case study of supplier evaluation from the aspect of integrating sustainability factors into sourcing processes and decisions to be developed a general evaluation model of closed loop supply chain (Figure 1) in a cable manufacturer named Vatan Cable Inc., which is a trading company in electronic components and energy sector in Turkey. It is quite difficult to increase market share into cable market in Turkey and also all over the world. The increasing raw materials price would affect the competition of the products and makes more difficult the first step of the selection approach and then for each phase of CLSC. Above all, there are three questions need to be answered in this study, which are; Which criteria and processes are used by company on the evaluation of suppliers? What are the selection and evaluation methods are recommended by the literatures? What the criteria and processes must be used by the company can be matched the aim of the project sustainability and CLSC approach?

### 1.2 Objectives

In this study, two major topics are mentioned to develop a new model to combine reverse logistics and forward supply chain management; Sustainability and Evaluations in CLSC.

Firstly, in the light of the sustainability, the projects, programs and supply chain of organizations' to be involved must be considered to have sustainable. Unlike the traditional supply chain models, which focus on only economic benefits for each member of the network, closed loop supply chain must consider economic, environmental and social aspects of sustainability. The term of Reverse Logistics is firstly defined by The Council of Logistics Management (CLM) in the early nineties (Stock, 1992) as "often used to refer to the role of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all relating to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal." This term could have some additions according to the types of organization such as business, industrial, government, commercial, and consumer organizations, but regardless of the type of organization, reverse logistics activities should be considered as an important percentage of sustainable development.

Secondly, Close loop supply chain includes forward supply chain and interdependent reverse logistics. This subject area which is focus on to combine and create reverse logistics and traditional supply chain approaches, still relatively new. If we need to make a definition, Closed loop supply chain system is, in which materials are returned and reused by the same originator, as the supplier or the manufacturer brings product back in, remanufactures it, refurbishes it then resells it (Kopicki, et al., 1993).

### 1.3 Methods Used in Previous Researches

In most articles, scholars agree that selection and evaluation of vendors are complicated and difficult because of the large number of both quantitative and qualitative criteria to be conceived (Yang & Chen, 2006). In the past, a number of methods are used for supplier selection and evaluation problem. Most of these approaches have limitations such as evaluation is based on just operational scales, subjective judgment, lack of information and relative evaluation between all suppliers (Talluri & Narasimhan, 2004). In order to deal with these limitations supplier selection and evaluation problem should be solved by using multi-criteria decision making approaches (MCDM). Multi-criteria decision making can be defined as the evaluation of the alternatives for the purpose of selection and evaluation or, using a number of qualitative and / or quantitative criteria that have different measurement units (Özcan et. al., 2011).

There are several common methodologies for MCDM, such as simple additive weighting (SAW), the technique for order preference by similarity to ideal solution (TOPSIS), analytical hierarchy process (AHP),analytical network process (ANP), data envelopment analysis (DEA) and so on (Kuo et. al., 2008). However these evaluation methods use only one rating scale to find final score for each vendor, despite the characteristic of criteria is quantitative or qualitative. Unlike these methods, in order to fill the gap in those methodologies, Grey Relational Analysis this is a mathematical analysis of the systems that are partly known and partly unknown and defined as weak knowledge and insufficient data, was introduced by Deng in 1982. Grey theory examines the interactional analysis when the decision making process is not clear (Özcan et. al., 2011).Grey Relational analysis is used in many decision making problems such as supplier selection, facility layout selection, and finance performance evaluation and material selection.

## 2. General Decision Making Model

In proposed selection and evaluation decision model, there are two different phases (Figure 1). First phase is related to Forward Supply Chain and other one is especially related to recycle management and reverse logistics. In first phase, decision making structure is generally the same and it may be indicated that it is possible to use same methodologies to make selection and evaluation. In this paper, as an example to present two proposed solution methodologies, supplier evaluation is studied.

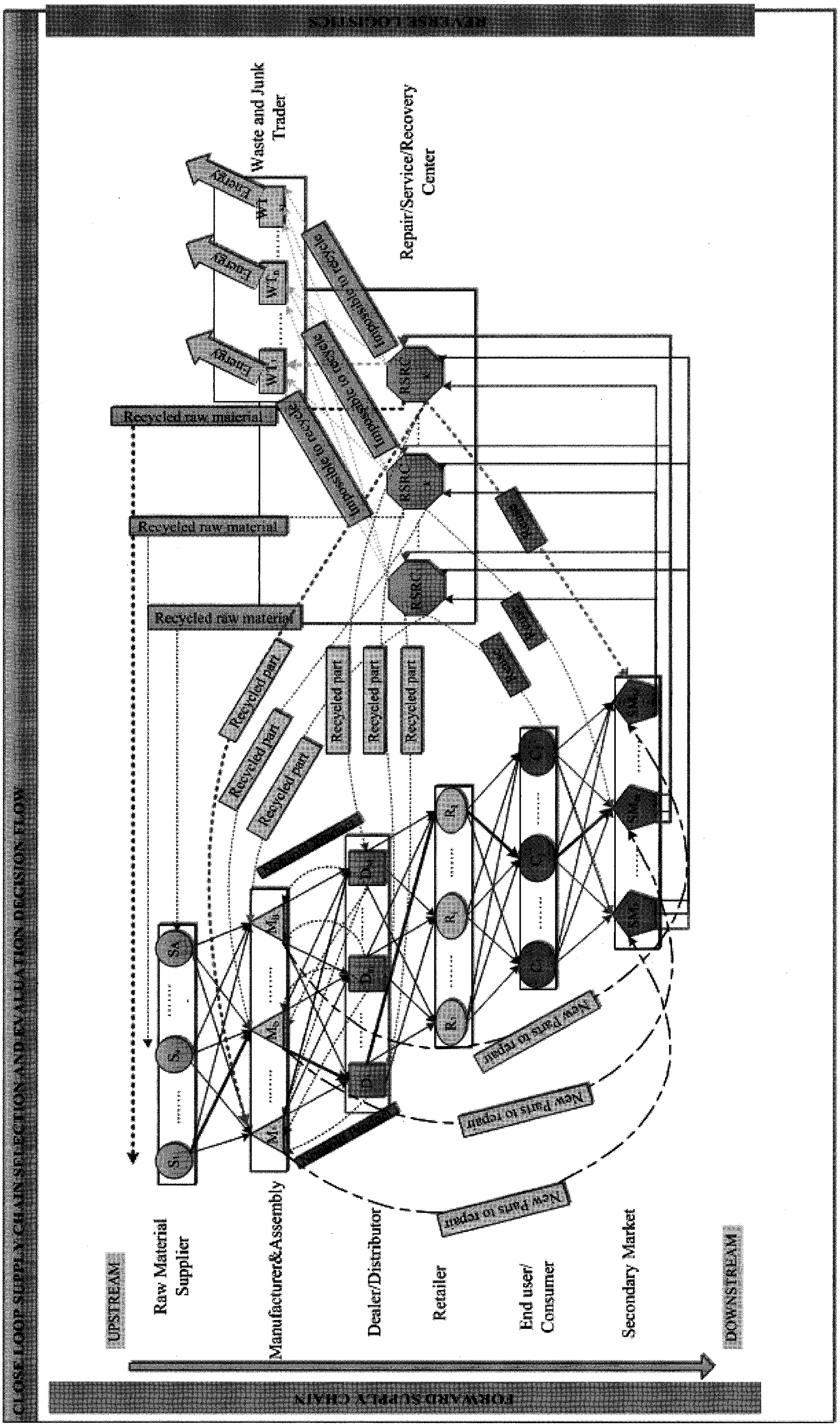


**Figure 1:** General Decision Making Model for Closed Loop Supply Chain

## 2.1. Proposed Solution Methodologies

### 2.1.1 Hybrid Grey Relational Analysis

Grey relational analysis (GRA) is a part of Grey System Theory, which is suitable for solving problems with complicated interrelationships between multiple factors and variables (Moran et al., 2006). It uses the grey relational grade to measure the relational degree of criteria (Wen, 2007). GRA possesses the merit of point set topology and such as the global comparison between two sets of data is undertaken instead of local comparison by measuring the distance between two point (Pai et al., 2007).

The main procedure of GRA is, translating the performance of all alternatives into a comparability sequence. This step is called grey relational generating. According to these sequences, a reference sequence is defined. Then, the grey relational coefficient between all comparability sequences and the reference sequence is calculated. Finally, base on these grey relational coefficients, the grey relational grade between the reference sequence and every comparability sequences is calculated. If a comparability sequence translated from an alternative has the highest grey relational grade between the reference sequence and itself, that alternative will be the best choice (Kuo et. al, 2008). According to GRA, if any of the alternatives has a higher grey relational grade than others, it is the most important (or optimal) alternative. This study uses this technique to rank candidate suppliers performance in accordance with GRA values (Yang & Chen, 2006).The steps of GRA are explained in details below and shown in Figure 2.

**1.** Referential series and compared series: If there are m alternatives and n criteria, the i th alternative can be expressed as $Y_i = (y_{i1}, y_{i2},\ldots, y_{ij}, \ldots, y_{in})$ where $y_{ij}$ is the performance value of criteria j of alternative i. These performance values of each criteria are evaluated according to the proposed evaluation scales given in Appendix A.

Calculations for Copper supplier 1 presented as an example in Appendix B.

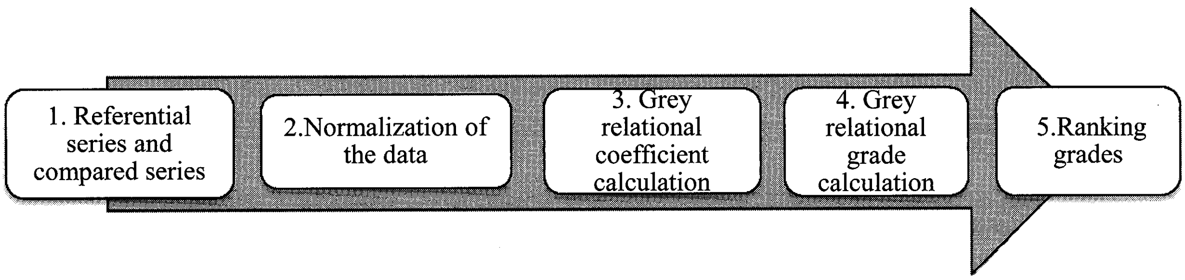


**Figure 2:** Steps of Grey Relational Analysis

The term of $Y_i$ can be translated into the comparability sequence $X_i = (x_{i1}, x_{i2},\ldots, x_{ij}, \ldots\ldots, x_{in})$ by using one of the formulas given is Step 2 according to the characteristics of the critera. Referential series $X_0$ is defined as $X_0 = ( x_{01}, x_{02},\ldots, x_{0j},\ldots, x_{0n} )$.

**2.** Normalization of the data: Processing all criteria values for every alternative into a comparability sequence in a process analogous to normalization, is necessary. This processing is called grey relational generating in GRA.

If the expectancy for the criteria is larger-the-better, it can be calculated by the following formula:

$$x_{ij}=\frac{y_{ij}-\min y_{ij}}{\max y_{ij}-\min y_{ij}} \qquad i=1,2,3.....,m \quad j=1,2,3,......,n \qquad (1)$$

If the expectancy for the criteria is smaller-the-better, it can be calculated by the following formula:

$$x_{ij}=\frac{\max y_{ij}-y_{ij}}{\max y_{ij}-\min y_{ij}} \qquad i=1,2,3.....,m \quad j=1,2,3,......,n \qquad (2)$$

If the expectancy for the criteria is the closer –to-the-desired-value ($y_j^*$)-the-better, it can be calculated by the following formula:

$$x_{ij}=\frac{\left|y_{ij}-y_j^*\right|}{\max\{\max y_{ij}-y_{ij}^* ; y_{ij}^*-\min y_{ij}\}} \qquad i=1, 2, 3....., m \quad j=1,2,3,......,n \qquad (3)$$

The series data in this study, can be treated using two approaches: larger better and smaller better. It is explained completely which criterion's characteristic is larger better and which one's smaller better. The calculations of normalization should be done according to equation which fits to the characteristics of criterion. $x_{ij}*$ means that characteristic of criterion is smaller better and equation (1) is used for normalization. $x_{ij}$ that characteristic of criterion is larger better and equation (2) is used for normalization.

**3.** Grey relational coefficient calculation: Grey relational coefficient is used for determining how close $x_{ij}$ is to $x_{0j}$. The larger the grey relational coefficient, the closer $x_{ij}$ and $x_{oj}$ are. The grey relational coefficient can be expressed as $\gamma(x_{oj},x_{ij})$ between $x_{ij}$ and $x_{oj}$ and calculated by using the formula given below.

$$\gamma(x_{oj},x_{ij})=\frac{\Delta_{min}+\varphi\Delta_{max}}{\Delta_{ij}+\varphi\Delta_{max}} \qquad i=1, 2, 3....., m \quad j=1,2,3,......,n \qquad (4)$$

$$\Delta_{ij}=\left|x_{oj}-x_{ij}\right|$$

$$\Delta_{min}=\mathrm{Min}\ \Delta_{ij} \quad ,$$

$$\Delta_{max}=\mathrm{Max}\ \Delta_{ij} \quad ,$$

$\varphi$ is the distinguishing coefficient, $\varphi\in[0,1]$ the value of distinguishing coefficient can be adjusted by the decision maker but in literature $\varphi = 0,5$ is commonly used, so in this study value of coefficient = 0,5 is used.

**4.** Grey relational grade calculation: The final step to calculate the grade of the grey relational coefficient $\Gamma_{0i}$ by using the equation below.

$$\Gamma_{0i}=\sum_{k=1}^{n} w_i(k)\times\gamma_{0i}(k) \qquad (5)$$

In this equation, $w_i(k)$ is the weight of each criterion, which can be assigned by experts or can be calculated by using some approaches such as AHP, ANP and other weight computable approaches.

In hybrid grey relational analysis, all of the procedure and the formulas are the same with grey relational analysis. But only at final step; in equation of grey relational grade calculation, $w_i(k)$ values which are the weights of criteria are calculated in procedure of Analytic Hierarchy Process or by using other weight computable approaches.

According to GRA, the alternative with the highest grey relational grade is the most important (or optimal) alternative. Therefore, in this study, the priorities of potential suppliers can be ranked in accordance with the grey relational grade values because the relative weights ($W_i$) of evaluative criteria are determined by using AHP.

### 2.1.2. Fuzzy Logic Integrated AHP

The procedure for determining weights of the evaluation criteria and performance values for alternatives is shown in Figure 3.

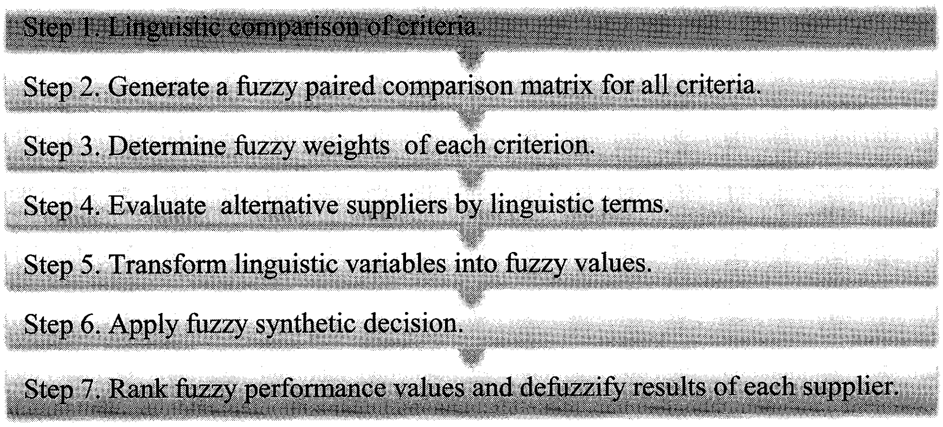


**Figure 3:** The procedure of Fuzzy Logic integrated adapted from AHP (Sun, 2010)

These steps can be summarized as follows:

**Step 1:** It is used to compare evaluation criteria by five basic linguistic terms, as "absolutely important," "very strongly important", "essentially important," "weakly important" and "equally important" with respect to a fuzzy five level scale (Table 1). According to the formulated structure of suppliers' evaluation, the weights of the criterion hierarchy can be analyzed. Decision making group contains two manager; purchasing department manager and quality management manager and two assistant expert. Weights were obtained by using the Fuzzy Logic Integrated AHP method, then the weights of each decision maker and average weights were derived by geometric mean method (Buckley, 1985).

**Step 2:** Generate a fuzzy paired comparison matrix for all criteria: Construct pair wise comparison matrices among all criteria in the dimensions of the hierarchy system. Assign linguistic terms to the pair wise comparisons by asking which one is the more important of each two criteria. After applying fuzzy numbers to see each decision makers' evaluations, the elements of synthetic pair wise comparison matrix can be computed by using the geometric mean method by using equation;

$$\tilde{a}_{ij}=(\tilde{a}_{ij}^{1}\otimes\tilde{a}_{ij}^{2}\otimes\tilde{a}_{ij}^{3}\otimes\tilde{a}_{ij}^{4})^{1/4} \quad (6),$$

**Table 1:** Scale of fuzzy numbers of linguistic scale for measuring weights of criteria

| Fuzzy Number | Linguistic Scales | Scale of Fuzzy Number | Reciprocal |
|---|---|---|---|
| $\tilde{1}$ | Equally important | (1 1 3) | (0.33, 1 ,1) |
| $\tilde{3}$ | Weakly important | (1 3 5) | (0.2, 0.33, 1 ) |
| $\tilde{5}$ | Essentially important | (3 5 7) | (0.14, 0.2, 0.33) |
| $\tilde{7}$ | Very strongly important | (5 7 9) | (0.11, 0.14, 0.2) |
| $\tilde{9}$ | Absolutely important | (7 9 9) | (0.14, 0.11, 0.11 ) |

**Step 3:** Determine fuzzy weights of each criterion: Geometric mean is one of the techniques is used to define the fuzzy geometric mean and fuzzy weights of each criterion by using the equation shown below;

$$\tilde{r}_i=(\tilde{a}_{i1}\otimes\tilde{a}_{i2}\otimes\ldots\ldots\otimes\tilde{a}_{in})^{1/n} \quad (7),$$

$$\tilde{w}_i=\tilde{r}_i\otimes(\tilde{r}_1\otimes\tilde{r}_2\otimes\ldots\ldots\otimes\tilde{r}_n)^{-1} \quad (8),$$

where $\tilde{a}_{in}$ is fuzzy comparison value of criterion i to criterion n and $\tilde{r}_i$ is geometric mean of fuzzy comparison value, $\tilde{w}_i$ is the fuzzy weight of criterion i. $\tilde{w}_i = (Lw_i, Mw_i, Uw_i)$ . So here $Lw_i$, $Mw_i$ and $Uw_i$ stand for the lower, middle and upper values of the fuzzy weight of criterion i.

To employ the Center of Area method to compute the Deffuzified Performance Value (DPV) of the fuzzy weights of each criteria, , the calculation process is as follows, As an example, the calculation of the fuzzy weights for main criteria process for Copper suppliers is shown below.

$$DPV_{w_i}=\frac{[(U_{w_i}-LR_{w_i})+(MR_{w_i}-LR_{w_i})]}{3}+LR_{w_i} \quad (9),$$

**Table 2:** Scale of fuzzy numbers of linguistic scale for measuring performance of alternatives

| Linguistic Scales | Scale of Fuzzy Number |
|---|---|
| Very poor | (0 0 10) |
| Poor | (10 25 40) |
| Fair | (30 50 70) |
| Good | (60 75 90) |
| Very Good | (80 100 100) |

**Step 4:** Evaluate alternatives by linguistic terms: By using the measurement of linguistic variables decision makers demonstrate the criteria performance for each alternative by expressions such as very good, good, fair, poor, very poor (Table 2).

**Step 5:** Transform linguistic variables into fuzzy values: Each linguistic variable can be defined by a triangular fuzzy number within a scale of [0,100].Fuzzy performance evaluation for a decision maker can be shown by $\tilde{E}_{ij}^{k}=(LE_{ij}^{k},ME_{ij}^{k},UE_{ij}^{k})$. If there is more than one evaluator (m evaluator), fuzzy performance value $\tilde{E}_{ij}$ is calculated by using the equations given below;

$$\tilde{E}_{ij} = {}^{1}/_{m} \otimes (\tilde{E}_{ij}^{1} \oplus \tilde{E}_{ij}^{2} \oplus \ldots\ldots \oplus \tilde{E}_{ij}^{m})$$

(10)

$$\tilde{E}_{ij}=\left(LE_{ij},ME_{ij},UE_{ij}\right);$$

$$LE_{ij}=\left(\textstyle\sum_{k=1}^{m} LE_{ij}^{k}\right) \ / \ m \ ,$$

$$ME_{ij}=\left(\textstyle\sum_{k=1}^{m} ME_{ij}^{k}\right) \ / \ m \ ,$$

$$UE_{ij}=\left(\textstyle\sum_{k=1}^{m} UE_{ij}^{k}\right) \ / \ m \qquad \text{where } k= 1, 2, \ldots\ldots\ldots, m$$

**Step 6:** Apply fuzzy synthetic decision: The weights of each criterion to find the performance evaluation values of alternatives', weight vectors of criteria $\tilde{w}_j = (\tilde{w}_1, \tilde{w}_2, \ldots\ldots, \tilde{w}_n)$ which is derived by Fuzzy integrated AHP and the fuzzy performance matrix of alternatives under n criteria $\tilde{E} = \left(\tilde{E}_{ij}\right)$ must be conducted to find fuzzy synthetic decision matrix $\tilde{R}_I$ of alternatives. This calculation can be done by using equation $\tilde{R}_i = \tilde{w}_j \odot \tilde{E}_{ij}$ where $\odot$ indicates operation of fuzzy addition and fuzzy multiplication. After calculation, fuzzy synthetic decision value as a fuzzy number of each alternative matrix is composed.

$$\tilde{R}_i=(LR_I,MR_I,UR_I) \qquad (11)$$

$$LR_i=\textstyle\sum_{i=1}^{n} LE_{ij} \times Lw_j , \qquad i= 1, 2, \ldots\ldots\ldots, t ; j=1, 2 , \ldots\ldots\ldots, n \qquad (12)$$

$$MR_i= \textstyle\sum_{i=1}^{n} ME_{ij} \times Mw_j , \qquad i= 1, 2, \ldots\ldots\ldots, t ; j=1, 2 , \ldots\ldots\ldots, n \qquad (13)$$

$$UR_i= \textstyle\sum_{i=1}^{n} UE_{ij} \times Uw_j, \qquad i= 1, 2, \ldots\ldots\ldots, t ; j=1, 2 , \ldots\ldots\ldots, n \qquad (14)$$

where $\tilde{E}_j=\left( Lw_j,Mw_j,Uw_j\right)$ and $\tilde{E}_{ij}=\left(LE_{ij},ME_{ij},UE_{ij}\right)$ are given above.

From the criteria weights obtained by FAHP and the average fuzzy performance values of each criterion of experts for each alternative, the final fuzzy synthetic decision step can then be processed.

**Step 7:** Rank fuzzy performance values and defuzzify results of each alternative: The result of the fuzzy synthetic decision step, reached by each alternative is a fuzzy number. A defuzzify ranking method is necessary for fuzzy numbers to be employed for comparison of each alternative. At this last step, main idea is to apply procedure of defuzzification to locate the defuzzified performance value of alternatives. Methods of such defuzzified fuzzy ranking generally include mean of maximal, center of area and α-cut. To utilize the Center of Area method to find out the defuzzified performance score (DPV) a simple and practical method, and there is no need to bring in the preferences of any evaluators which in α-cut method there is a need to consider preferences, so it is used in this study. The DPV value of the fuzzy number $\tilde{R}_i$, can be found by the following equation:

$$DPV_i=\frac{[(UR_i-LR_i)+(MR_i-LR_i)]}{3}+LR_i \quad (15),$$

According to the value of the derived DPV for each of the alternatives, the ranking of each alternative can then be proceeded. Next, the process is shown to find out each suppliers' DPV value as follows

## 3. Illustrative Example

To realize sustainable project management in supply chain, a general methodology is improved for supplier evaluation problem of the company. This evaluation methodology should be extended and applied to all phase of the developed decision model for close loop supply chain to reach expected results. To keep track of performance level of the ERP project and the results for the developed supply chain model, each layer should evaluate performances of former one which could provide raw material, parts, service or logistic .The company produces halogen free cables, medium voltage cables, high voltage cables, copper conductor.

To be able to manufacture these products there are many raw materials need to be bought from various suppliers. Three main raw materials is very crucial for production in cable manufacturing industry; Copper, PVC and DOP chemical. Copper is the vital point of cable industry in whole companies so there is a great competition among suppliers and producers. PVC, DOP chemical and especially copper market is so nonstable and suppliers must be checked too often to be able to lower raw material costs. For supplying copper, the company makes business partnership with six suppliers. (CS1, CS2, CS3, CS4, CS5, CS6).For supplying PVC, the company makes a business partnership with seven suppliers. (PS1, PS2, PS3, PS4, PS5, PS6, PS7)For supplying DOP chemical, the company makes a business partnership with five suppliers. (sDS5, DS2, DS3, DS4, DS5).

In supply chain of the company, purchasing department and quality management department is responsible for selecting and evaluating suppliers which provides raw materials to use in production. The current procurement system cannot respond the whole needs of the company. According to the ERP project aims, purchasing department is supposed to monitor their suppliers closely to keep their aims alive and applicable. To make the company goals applicable and sustainable, in current procurement system of the company, three main and twelve performance sub criteria were used (Figure 4). After a literature review about which supplier evaluation criteria can be used in cable, telecommunication, electronic component industry and brainstorming with two responsible department manager ,one new main criteria, plus with three sub criteria and nine new criteria addition to current main criteria is decided to be added in as a performance evaluation criteria for new evaluation model.

To demonstrate the hybrid GRA model in this supplier evaluation problem, the suppliers were considered as alternatives i, whereas evaluative factors were viewed as criteria j for each alternative. According to the grey information principle in Grey system theory, to calculate suppliers performance. value for each criterion, a scale that is special to each criterion, is developed by searching literature and brainstorming with department managers. The sub criteria that had the characteristic of "larger better" are frequency of price increase requirement from price performance main criteria , Sending order confirmation, On time delivery, Appropriate packing, Meeting requirements of delivery contract from delivery performance main criteria and Product development, Process development, Quality planning, Inspection and experimental studies, Quality audit results, Environmental audit results, After sales support, Success in R&D tests and approval for new material from quality performance main criteria, and the last one, all of the sub criteria in company profile main criteria. Then the sub criteria that had the characteristic of "smaller better" are price affordability, Room for negotiation from price performance main criteria, Meeting requirements of order quantity, Sending order confirmation from delivery performance main criteria and the last one Raw material entrance quality return rate from quality performance main criteria.

## 4. Results and Conclusion

In this paper, two integrated approaches has been formulated and applied to a energy sector company to examine its feasibility in evaluating the three absolute must and causing most percent of cost raw material (Copper, DOP, PVC) suppliers' performance in aspect of project management. First method is Hybrid Grey Relational Analysis and this integrated model is very flexible and more mathematical analysis of the decision making systems, for example; using the AHP can reflect weights of criteria, it is suitable to deal with take account into both qualitative and quantitative factors and adding new criteria and changing weight of them can be included to the easily to the suggested model and examines the analysis if there are discrete and insufficient input data.. Second approach is Fuzzy Logic integrated AHP. This integrated model uses linguistic expressions to determine performance scores. FAHP is very suitable and easy to apply for experts' assessments in fuzzy and complex decision making processes like MCDM problems. The Hybrid GRA approach ranks the importance to raw material suppliers of the various criteria used to compare desirability of them by using AHP method. FAHP approach ranks the importance to raw material suppliers of the various criteria by using FAHP criteria weighting method. For proposed evaluation framework for Hybrid GRA model, four main criteria and 21 sub criteria are used. According to the overall ranking calculations depends on AHP, Financial indicators ranks first, Environmental audit results ranks second, Quality planning ranks third. Criterion which has the lowest importance weight is Sending order confirmation. For proposed evaluation framework for FAHP, four main criteria and twenty one sub criteria are used as the same like

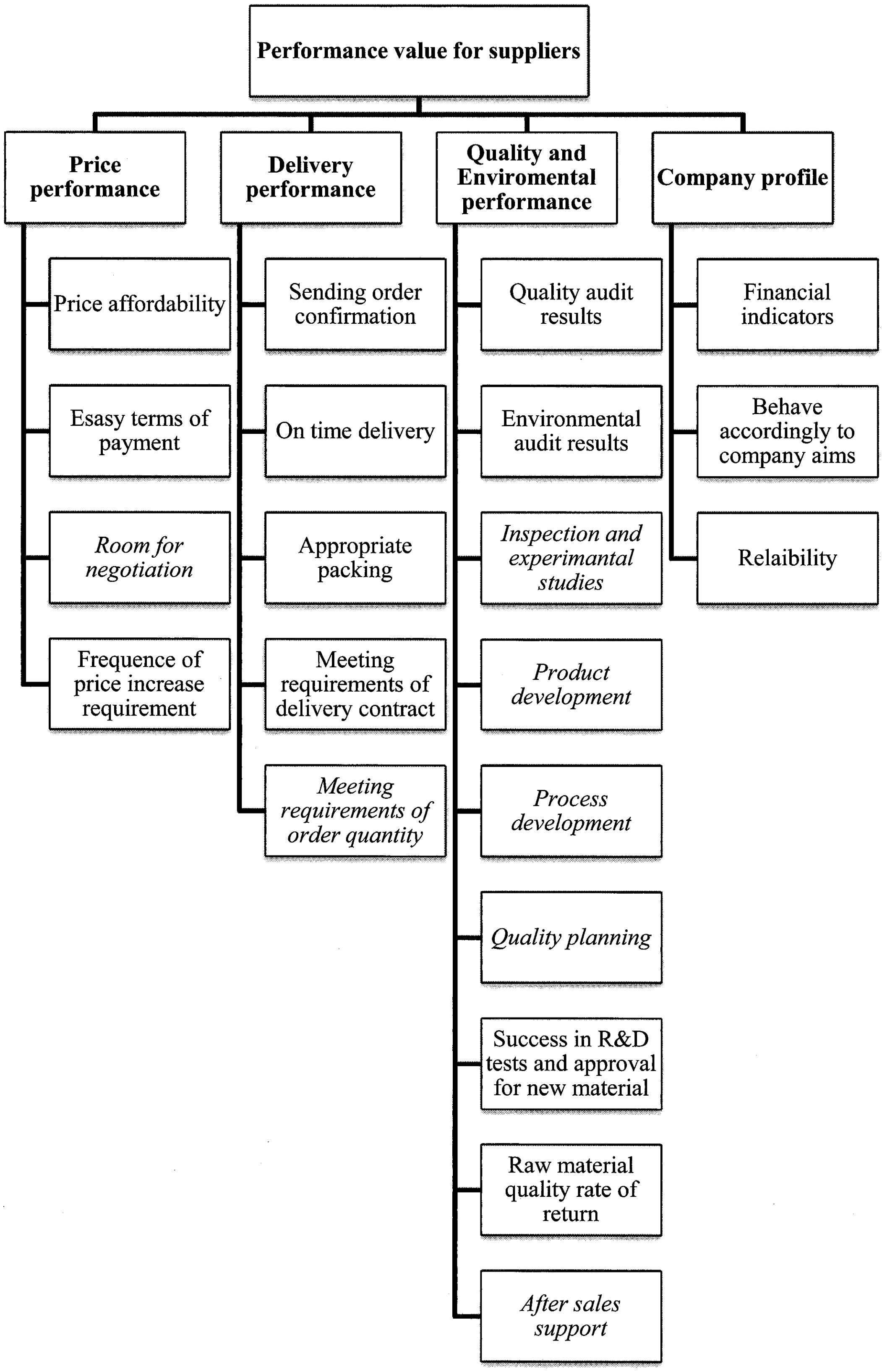


**Figure 4:** Performance evaluation framework with new criteria

previous method. According to the overall ranking calculations, Quality planning ranks first, Quality audit results ranks second, Environmental audit results ranks third. Criterion which has the lowest importance weight is Sending order confirmation. It is obvious that ranking orders and importance level of evaluation criteria are nearly the same for both approaches.

According the performance score results for Copper suppliers, first, second, third and fourth supplier is the same with Hybrid GRA results but fifth supplier in Hybrid GRA is sixth in FAHP and sixth supplier is fifth in FAHP results ranking (Table 3). In light of the results, total performance score of DOP chemical suppliers ranking is same with Hybrid GRA results DS5 is the first, then DS4, DS1, DS2 and the last supplier is DS3 which has the lowest performance score. For PVC suppliers, total performance score ranking is same with Hybrid GRA results. PS6 is the first, and then PS5, PS1, PS4, PS7, PS2 and the last supplier is PS3 which has the lowest performance score. In this study it is clear that performance score results of three raw materials' supplier for two approaches are nearly the same.

**Table 3:** Comparison of ranking results of two approaches for Copper Suppliers

| | Fuzzy AHP Rank | Hybrid Grey Relational Analysis RANK |
|---|---|---|
| **CS1** | 3 | 3 |
| **CS2** | 4 | 4 |
| **CS3** | **6** | **5** |
| **CS4** | **5** | **6** |
| **CS5** | 2 | 2 |
| **CS6** | 1 | 1 |
| **DS1** | 3 | 3 |

## 5. Comments And Future Works

It is not easy to say which MCDM approach is more suitable, satisfactory and desirable for supplier selection and evaluation problem. The best thing is to apply several MCDM methods to the same problem, comparing the results and then making the final decision. Except Hybrid GRA and FAHP, other MCDM approaches can be applied for this study and it is better to see which differences occur. In order to follow sustainability goal for newly improved general closed loop supply chain model, this study could be taken as a reference to be able to evaluate performances of material, part, logistics or reuse and recycled component provider for each member of the CLSC

## References

[1] Stock J.R. (1992), Reverse Logistics, Council of Logistics Management, Oak Brook, IL, 1992.

[2] Blumberg, D. F., Introduction to Reverse Logistics and Closed Loop Supply ChainProcess, pp. 243, Taylor&Francis, 2005.

[3] Kopicki, R., Berg, M.J., Legg, L., Dasappa, V., and Maggioni, C., Reuse and Recycling–Reverse Logistics Opportunities, Oak Brook, IL: Council of Logistics Management, 1993.

[4] Yang, C.C., Chen, B.S., Supplier selection using combined analytic hierarchy process and grey relational analysis, Journal of Manufacturing Technology Management, Vol.17, No 7, pp 926–941, 2006

[5] Talluri, S., Narasimhan, R., A methodology for strategic sourcing, European Journal of Operational Research Vol. 154 No 1, pp 236–250, 2004.

[6] Özcan, T., Çelebi, N., Esnaf, Ş.., Comparative Analysis of Multi-criteria decision making Methodologies and Implementation of a Warehouse Location Selection Problem, Expert Systems with Applications, Vol. 38, No 8, pp 9773 – 9781, 2011.

[7] Kuo, Y., Yang, T., Huang, G., The use of grey relational analysis in solving multiple attribute decision- making problems, Computers & Industrial Engineering, Vol 55, No 1,pp 80 – 93,2008.

[8] Hu, Y., Supplier Selection Based on Analytic Hierarchy Process and Grey Relational Analysis, International Colloquium on Computing, Communication, Control and Management, August 2009, Vol. 4, pp 607- 610, 2009.

[9] Yang, G.F., Wang, Z.P., Li, X.Q., The optimization of the closed-loop supply chain network. Transportation Research Vol.46, pp 16-28, 2009

[10]Olugu E.U., Wong K.Y.,,Shaharoun A.M, A Comprehensive Approach in Assessing the Performance of an Automobile Closed-Loop Supply Chain, Sustainability, Vol 2,pp 871-889, 2010

[11] Sahraeian R., Tafti A.F., A Multi-objective Model for Decision Making in A Closed-loop Supply Chain Network, International Journal Of Business And Management Studies, Vol. 3, No. 1, pp 309-318, 2011

[12] Ho W., Xu X., Dey P. K., Multi-criteria decision making approaches for supplier evaluation and selection: A literature review, European Journal of Operational Research, Vol.202, No 1, pp 16- 24, 2010

[13] Lui S., Lin Y., Grey Systems: Theory and Applications, Springer-Verlag Berlin Heidelberg Press, India, 2010

[14] Silvius, A.J.G., Schipper, R., A Maturity Model for Integrating Sustainability in Projects and Project Management, 24th IPMA World Congress, Istanbul, Turkey, 2010.

[15] Silvius, A.J.G., Birnk, J. van der,Köhler, A., The impact of sustainability on Project Management, Asia Pasific Research Conference on Project Management (APRPM), Melbourne, Australia, 2010

[16] Zavadskas, E.K., Turskis, Z., Tamosaitiene, J., Marina, V., Multi criteria Selection of Project Managers by Applying Grey Criteria, Technological and Economic Dvelopment of Economy, Vol. 14, No 4, pp 462 – 477, 2008

[17]Tsai, C.H., Chang C. L., Chen L., Applying Grey Relational Analysis to the Vendor Evaluation Model, International Journal of the Computer, the Internet and Management, Vol. 11, No. 3, pp 45 – 53, 2003

[18] http://ec.europa.eu/environment/chemicals/reach/enforcement_en.htm

[19] http://www.bis.gov.uk/nmo/enforcement/rohs-home

[20] Yamane, S., Miura T., Asada T., Actual Condition and Assignment in Japanese recycling Business of PC, Journal of the International Association of Project & Program Management Vol. 5, No. 2, pp 41 –

52, 2011

[21] Nakayama, M., Noji H., Hayashi K., Sogo, N.,Kameyama, H., Cpnstruction of Enviromental Platform for Local Activation Applying P2M Theory, Journal of the International Association of Project & Program Management Vol. 5, No. 2, pp 53 – 62, 2011

## APPENDIX A: Proposed Evaluation Scales of Each Main Criteria

**Proposed Evaluation Scale for Price Performance**

| **Price affordability** | | **Easy terms of payment** | | **Frequency of price increase requirement** | | **Room for negotiation** | |
|---|---|---|---|---|---|---|---|
| | **S** | | **L** | | **S** | | **L** |
| Lower than market price | 1 | Sufficient number | 10 | Fewer than expected | 1 | High | 10 |
| Market price | 5 | Lower than sufficient number | 5 | Expected | 5 | Fair | 5 |
| Higher than market price | 10 | No payment term option | 1 | Higher than expected | 10 | Low | 1 |

**Proposed Evaluation Scale for Company Profile Performance**

| **Behave accordingly to company aims** | | **Reliability** | | **Financial indicators** | |
|---|---|---|---|---|---|
| | **L** | | **L** | | **L** |
| Very poor | **1** | Very poor | **1** | Very poor | **1** |
| Poor | **3** | Poor | **3** | Poor | **3** |
| Fair | **5** | Fair | **5** | Fair | **5** |
| Good | **7** | Good | **7** | Good | **7** |
| Very good | **9** | Very good | **9** | Very good | **9** |

**Proposed Evaluation Scale for Delivery Performance**

| Meeting requirements of order quantity | | Sending order confirmation | | On time delivery | | Appropriate packing | | Meeting requirements of delivery contract | |
|---|---|---|---|---|---|---|---|---|---|
| | S | | L | | L | | L | | L |
| Lower than ordered quantity | 15 | No missing order confirmation in 6 months | 15 | On time | 9 | In 6 months all delivery packages certificated | 10 | No missing rule in delivery certifications in 6 months | 6 |
| More than exact ordered quantity | 10 | In 6 months 1-5 missing order confirmation 1-5 | 10 | 1-2 days late | 7 | In 6 months most of the delivery packages certificated | 5 | In 6 months 1-2 missing rule in delivery certifications | 5 |
| Exact ordered quantity | 5 | In 6 months more than 5 missing order confirmation | 5 | 3-4 days late | 5 | In 6 months most of the delivery packages are not certificated | 1 | In 6 months 2-4 missing rule in delivery certifications | 4 |
| | | In 6 months no order confirmation | 1 | 5-6 days late | 3 | | | In 6 months 4-6 missing rule in delivery certifications | 3 |
| | | | | More than 7 days late | 1 | | | In 6 months 6-8 missing rule in delivery certifications | 2 |
| | | | | | | | | In 6 months more than 8 missing rule in delivery certifications | 1 |

**Proposed Evaluation Scale for Quality Performance**

| Product development | | Process development | | Quality planning | | Inspection and experimental studies | | Quality audit results | | Environmental audit results | | Success in R&D tests and approval for new material | | Raw material quality rate of return | | After sales support | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | | L | | L | | L | | L | | L | | L | | S | | L |
| Successful | 10 | Successful | 10 | Very poor | 1 | Successful | 10 | Very poor | 1 | Very poor | 1 | Successful | 10 | %0 -%1 | 0,5 | Good in support | 10 |
| Progress success | 5 | Progress success | 5 | Poor | 3 | Progress success | 5 | Poor | 3 | Poor | 3 | Progress success | 5 | %1-%2 | 1,5 | Fair support but not enough | 5 |
| Not enough | 1 | Not enough | 1 | Fair | 5 | Not enough | 1 | Fair | 5 | Fair | 5 | Not enough | 1 | %2-%3 | 2,5 | No support | 1 |
| | | | | Good | 7 | | | Good | 7 | Good | 7 | | | %3-%4 | 3,5 | | |
| | | | | Very good | 9 | | | Very good | 9 | Very good | 9 | | | %4-%5 | 4,5 | | |
| | | | | | | | | | | | | | | More than %5 | 6 | | |

## APPENDIX B: Calculation Sheets for Hybrid Grey Relational Analysis

### Step 1: Evaluation of Copper suppliers

| | CS1 | CS2 | CS3 | CS4 | CS5 | CS6 |
|---|---|---|---|---|---|---|
| C1 | 1.00 | 1.00 | 5.00 | 5.00 | 5.00 | 1.00 |
| C2 | 10.00 | 10.00 | 5.00 | 10.00 | 5.00 | 5.00 |
| C3 | 10.00 | 10.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| C4 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 1.00 |
| C5 | 5.00 | 5.00 | 5.00 | 15.00 | 10.00 | 5.00 |
| C6 | 7.00 | 9.00 | 7.00 | 7.00 | 9.00 | 9.00 |
| C7 | 10.00 | 5.00 | 5.00 | 5.00 | 10.00 | 10.00 |
| C8 | 15.00 | 15.00 | 15.00 | 15.00 | 10.00 | 15.00 |
| C9 | 5.00 | 6.00 | 6.00 | 5.00 | 5.00 | 6.00 |
| C10 | 10.00 | 10.00 | 5.00 | 5.00 | 10.00 | 10.00 |
| C11 | 10.00 | 10.00 | 5.00 | 5.00 | 10.00 | 10.00 |
| C12 | 9.00 | 7.00 | 7.00 | 7.00 | 7.00 | 9.00 |
| C13 | 10.00 | 5.00 | 10.00 | 5.00 | 10.00 | 10.00 |
| C14 | 7.00 | 7.00 | 7.00 | 7.00 | 9.00 | 9.00 |
| C15 | 7.00 | 7.00 | 7.00 | 7.00 | 9.00 | 9.00 |
| C16 | 10.00 | 5.00 | 10.00 | 5.00 | 10.00 | 10.00 |
| C17 | 1.50 | 1.50 | 2.50 | 1.50 | 1.50 | 0.50 |
| C18 | 10.00 | 5.00 | 10.00 | 10.00 | 5.00 | 10.00 |
| C19 | 7.00 | 9.00 | 7.00 | 7.00 | 7.00 | 9.00 |
| C20 | 9.00 | 7.00 | 7.00 | 7.00 | 7.00 | 7.00 |
| C21 | 9.00 | 9.00 | 7.00 | 7.00 | 7.00 | 7.00 |

**Step 1**.The first supplier's comparised serie can be expressed as

$Y_1$=(1,10,10,5, 5,5,7,10,15,5,10,10,9,10,7,7,10,1.5,10,7,9,9 ) where $Y_i$ is the performance value of criteria of supplier 1.

$Y_2$=(1,10,10,5,5,9,5,15,6,10,10,7,5,7,7,5,1.5,5,9,7,9),

$Y_3$=(5,5,5,5,5,7,7,15,6,5,5,7,10,7,7,10,2.5,10,7,7,7),

$Y_4$=(5,10,5,5,15,7,5,15,5,5,5,7,5,7,5,7,7,5,1.5,10,7,7,7),

$Y_5$=(5,5,5,5,10,9,10,15,6,10,10,9,10,9,9,10,0.5,10,9,7,7)

$Y_6$= (1,5,5,1,5,9,10,15,6,10,10,9,10,9,9,10,0.5,10,9,7,7).

And then to normalize the data, referential series

$Y_{min}$=(1,5,1,1,5,5,3,1,2,1,5,3,1,3,5,1,0.5,5,3,3,3)

$Y_{max}$= (10,10,10,10,10,15,9,10,6,10,15,7,10,9,9,10,6,10,9,5,9) should be used.

Other raw materials'referential series other raw materials'referential series can be written at the same way.

**Step 2.** Normalization calculations are given below for raw material Cooper as an example:

$x_{11} *= \frac{5-1}{5-1} = 1$ $x_{12} = \frac{10-5}{10-5} = 1$ $x_{13} *= \frac{10-10}{10-5} = 0$

$x_{14} = \frac{10-10}{15-10} = 0$ $x_{15} = \frac{9-7}{9-7} = 1$ $x_{16} = \frac{10-5}{10-5} = 1$

$x_{17} = \frac{5-1}{6-1} = 0.8$ $x_{18} *= \frac{9-7}{9-1} = 0.25$ $x_{19} = \frac{2.5-0.5}{6-0.5} = 0.36$

$x_{1\,10} = \frac{5-1}{9-1} = 0.5$ $x_{1\,11} = \frac{7-1}{9-1} = 0.75$ $x_{1\,21} = \frac{9-7}{9-7} = 1$

The calculations show that the referential series $X_0$ = (1,1,1,1,1,1,1,1,1,1,1,1).

**Step 3: Table of Normalization of data calculation for Cooper Suppliers**

| | L/S | CS1 | CS2 | CS3 | CS4 | CS5 | CS6 |
|---|---|---|---|---|---|---|---|
| **C1** | 0 | 0.56 | 0.56 | 0.00 | 0.00 | 0.00 | 1.00 |
| **C2** | 1 | 1.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 |
| **C3** | 0 | 0.00 | 0.56 | 1.00 | 1.00 | 0.00 | 0.00 |
| **C4** | 1 | 0.00 | 0.44 | 1.00 | 1.00 | 0.44 | 1.00 |
| **C5** | 0 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **C6** | 1 | 0.00 | 0.00 | 0.50 | 1.00 | 1.00 | 0.50 |
| **C7** | 1 | 1.00 | 0.00 | 0.33 | 1.00 | 0.33 | 1.00 |
| **C8** | 0 | 0.56 | 1.00 | 0.56 | 0.56 | 0.00 | 0.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **C9** | 1 | 1.00 | 0.00 | 0.25 | 0.75 | 0.75 | 1.00 |
| **C10** | 1 | 1.00 | 0.44 | 1.00 | 0.00 | 1.00 | 0.44 |
| **C11** | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 | 0.00 |
| **C12** | 1 | 0.00 | 0.00 | 0.50 | 1.00 | 1.00 | 1.00 |
| **C13** | 1 | 0.44 | 0.44 | 1.00 | 0.00 | 1.00 | 0.00 |
| **C14** | 1 | 1.00 | 0.00 | 0.33 | 0.67 | 1.00 | 0.33 |
| **C15** | 1 | 0.00 | 1.00 | 0.00 | 0.50 | 1.00 | 0.50 |
| **C16** | 1 | 1.00 | 0.44 | 0.00 | 1.00 | 1.00 | 1.00 |
| **C17** | 0 | 0.00 | 0.27 | 0.45 | 0.64 | 0.82 | 1.00 |
| **C18** | 1 | 0.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 |
| **C19** | 1 | 0.67 | 0.67 | 0.33 | 0.67 | 1.00 | 0.00 |
| **C20** | 1 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 0.00 |
| **C21** | 1 | 0.67 | 0.00 | 0.00 | 0.00 | 0.00 | 1.00 |

**Step 3.** For Copper suppliers the Grey relational coefficient calculation solutions are given below as an example,

$$\gamma(x_{o1},x_{11})=\frac{0+0.5\times 1}{1+0.5\times 1} = 0.33$$

.

$$\gamma(x_{o12},x_{1\,11})=\frac{0+0.5\times 1}{0+0.5\times 1} = 1.00$$

.

$$\gamma(x_{o12},x_{1\,21})=\frac{0+0.5\times 1}{0+0.5\times 1} = 1.00$$

**Step 3: Table of Grey relational coefficient calculation for Copper Suppliers**

| Supplier / MA | Weights | CS1 | CS2 | CS3 | CS4 | CS5 | CS6 |
|---|---|---|---|---|---|---|---|
| **C1** | **7.68%** | 0.026 | 0.026 | 0.077 | 0.077 | 0.077 | 0.026 |
| **C2** | **4.05%** | 0.040 | 0.040 | 0.013 | 0.040 | 0.013 | 0.013 |
| **C3** | **3.01%** | 0.030 | 0.030 | 0.010 | 0.010 | 0.010 | 0.010 |
| **C4** | **1.60%** | 0.016 | 0.016 | 0.016 | 0.016 | 0.016 | 0.005 |
| **C5** | **2.58%** | 0.009 | 0.009 | 0.009 | 0.026 | 0.013 | 0.009 |
| **C6** | **2.50%** | 0.008 | 0.025 | 0.008 | 0.008 | 0.025 | 0.025 |
| **C7** | **2.99%** | 0.030 | 0.010 | 0.010 | 0.010 | 0.030 | 0.030 |
| **C8** | **0.99%** | 0.010 | 0.010 | 0.010 | 0.010 | 0.003 | 0.010 |
| **C9** | **6.92%** | 0.023 | 0.069 | 0.069 | 0.023 | 0.023 | 0.069 |
| **C10** | **3.28%** | 0.033 | 0.033 | 0.011 | 0.011 | 0.033 | 0.033 |
| **C11** | **2.39%** | 0.024 | 0.024 | 0.008 | 0.008 | 0.024 | 0.024 |
| **C12** | **9.92%** | 0.099 | 0.033 | 0.033 | 0.033 | 0.033 | 0.099 |
| **C13** | **5.06%** | 0.051 | 0.017 | 0.051 | 0.017 | 0.051 | 0.051 |
| **C14** | **8.90%** | 0.030 | 0.030 | 0.030 | 0.030 | 0.089 | 0.089 |
| **C15** | **9.01%** | 0.030 | 0.030 | 0.030 | 0.030 | 0.090 | 0.090 |
| **C16** | **6.88%** | 0.069 | 0.023 | 0.069 | 0.023 | 0.069 | 0.069 |
| **C17** | **2.55%** | 0.013 | 0.013 | 0.026 | 0.013 | 0.013 | 0.009 |
| **C18** | **2.66%** | 0.027 | 0.009 | 0.027 | 0.027 | 0.009 | 0.027 |
| **C19** | **13.25%** | 0.044 | 0.133 | 0.044 | 0.044 | 0.044 | 0.133 |
| **C20** | **1.89%** | 0.019 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| **C21** | **1.89%** | 0.019 | 0.019 | 0.006 | 0.006 | 0.006 | 0.006 |

**Step 4.**For example, for Copper suppliers, the Grey relational grade calculation of total performance score is given below;

$\Gamma_{01}$=(0.077×0.33+0.041×1+0.03×1+0.016×1+…+0.0189 × 1)=0.65.

.

.

$\Gamma_{06}$=(0.077×0.33+0.041×0.33+0.0301×0.33+0.0106×0.33+…+0.0189×0.33)=0.83

**Step 4: Table of Grey Relational Grade Scores for Copper Suppliers**

| RANK | Name of Supplier | Total Performance Score | Price Performance Score | Quality Performance Score | Delivery Performance Score | Firm Profile |
|---|---|---|---|---|---|---|
| **3** | **CS1** | 0.65 | 0.11 | 0.08 | 0.37 | 0.08 |
| **4** | **CS2** | 0.60 | 0.11 | 0.12 | 0.21 | 0.16 |
| **5** | **CS3** | 0.56 | 0.12 | 0.11 | 0.28 | 0.06 |
| **6** | **CS4** | 0.47 | 0.14 | 0.08 | 0.19 | 0.06 |
| **2** | **CS5** | 0.68 | 0.12 | 0.09 | 0.41 | 0.06 |
| **1** | **CS6** | 0.83 | 0.05 | 0.14 | 0.49 | 0.15 |

The priority of the six supplier for copper, in accordance with their grey relational grades is CS1= 0.65, CS2=0.60, CS3=0.56, CS4= 0.47, CS5=0.68 and the last one CS6=0.83,so the ranking order is CS6 > CS5 > CS1 > CS2 > CS3 > CS4

**Table of Grey Relational Grade Scores for DOP Suppliers**

| RANK | Name of Supplier | Total Performance Score | Price Performance Score | Quality Performance Score | Delivery Performance Score | Firm Profile Score |
|---|---|---|---|---|---|---|
| **3** | **DS1** | 0.62 | 0.05 | 0.10 | 0.31 | 0.16 |
| **4** | **DS2** | 0.59 | 0.11 | 0.10 | 0.32 | 0.07 |
| **5** | **DS3** | 0.51 | 0.11 | 0.12 | 0.23 | 0.06 |
| **2** | **DS4** | 0.71 | 0.11 | 0.09 | 0.37 | 0.15 |
| **1** | **DS5.** | 0.85 | 0.16 | 0.14 | 0.40 | 0.15 |

**Table of Grey Relational Grade Scores for PVC Suppliers**

| RANK | Name of Supplier | Total Performance Score | Price Performance Score | Quality Performance Score | Delivery Performance Score | Firm Profil Score |
|---|---|---|---|---|---|---|
| **3** | **PS1** | 0.60 | 0.08 | 0.12 | 0.32 | 0.08 |
| **6** | **PS2** | 0.57 | 0.13 | 0.07 | 0.31 | 0.07 |
| **7** | **PS3** | 0.56 | 0.11 | 0.06 | 0.25 | 0.15 |
| **4** | **PS4** | 0.60 | 0.11 | 0.14 | 0.26 | 0.09 |
| **2** | **PS5** | 0.62 | 0.10 | 0.08 | 0.34 | 0.10 |
| **1** | **PS6** | 0.72 | 0.09 | 0.11 | 0.44 | 0.08 |
| **5** | **PS7** | 0.58 | 0.16 | 0.08 | 0.29 | 0.06 |

**Table of Comparison of ranking results for DOP and PVC Suppliers**

| DOP Suppliers | FAHP RANK | HYBRID GRA RANK |
|---|---|---|
| **DS1** | 3 | 3 |
| **DS2** | 4 | 4 |
| **DS3** | 5 | 5 |
| **DS4** | 2 | 2 |
| **DS5.** | 1 | 1 |
| | | |
| | | |

| PVC Suppliers | FAHP RANK | HYBRID GRA RANK |
|---|---|---|
| **PS1** | 3 | 3 |
| **PS2** | 6 | 6 |
| **PS3** | 7 | 7 |
| **PS4** | 4 | 4 |
| **PS5** | 2 | 2 |
| **PS6** | 1 | 1 |
| **PS7** | 5 | 5 |

査読　2012 年 6 月 15 日
受理　2012 年 8 月 15 日