Green supplier selection using hybrid grey relational analysis with fuzzy logic method

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Abstract: Green supplier selection is an integral part of Supply Chain Management in recent times. With increasing concern on environment protection and ecological preservation use of green factors in supplier selection is vital for every organization. The general concept behind green supplier selection is to evaluate suppliers based on certain environmental and cost effective criteria and select the one with best ranking. Hence green supplier selection is a crucial process. Present work proposes the application of a hybrid MCDM method, Grey relational analysis with fuzzy logic for green supplier selection. An example problem is solved by this method and a comparison with the outcome obtained using MOORA and COPRAS method for same problem is presented to verify the proposed method. Results revealed that ranking orders for the first supplier and second supplier were interchanged with grey relational analysis when compared with COPRAS and MOORA methods. But after using fuzzy logics GFRG values of both the supplier obtained are same. This indicates that both the suppliers are equally competitive and there is flexibility to choose any one of them. It indicates that when vagueness is involved, grey- fuzzy logic algorithm can be effectively applied for solving multi-criteria supplier selection problems.

Keywords: Green Supplier selection, Grey Relational Analysis Fuzzy Logic.

1. Introduction;
Supplier assessment and selection is an important strategic decision for minimizing operating costs and enhancing organizational efficiency. Every customer has different expectations from the suppliers. Various companies may have varies organizational and cultural backgrounds, which may also affect the supplier selection process. Therefore, a systematic method is required to determine which criteria are suitable and should be used for assessment of suppliers for an enterprise. At the same time environment protection and ecological preservation is one of the main challenges faced in recent times. And measures are being taken in all possible fields to do so. Until recent times supply chain management was based completely on economic factors but now there is a need for taking the environmental factors too in consideration for supplier selection. Green supplier selection (GSS) is a supplier selection process where equilibrium between the economics and environmental consideration of the suppliers are considered for
evaluation and selection. There are numerous sources which focuses on the GSS issues, using different strategies include, linear weighting models, data envelopment analysis (DEA), decision models for the final choice-phase, mathematical programming models, cluster analysis, case-based-reasoning systems etc. [1]. It’s been seen over a period of time that supplier evaluation has been done keeping the economic aspects into considerations rather than the environmental considerations in the supplier selection [2]. Environmental issues are growing concern and it is the time to consider environmental and sustainable matters. When taking criteria into consideration for supplier selection, environmental factors should also be incorporated in GSS [3-5]. Criteria such as cost, delivery, pollution control, green product, service, quality, environment management, energy and natural resource consumption etc. These criteria are provided with weightage according to their importance, customer requirements and technical requirements.

The study on Green Supplier Chain (GSC) is gaining wide popularity specifically, in multi-objective decision making for green supply chain management (GSCM). AHP method is used in order to solve green supplier selection problems [6]. In order to eliminate or minimize the uncertainty of opinion of experts a hybrid AHP - fuzzy logic was used to solve supplier selection problem [7]. Methods including integration of hybrid fuzzy ANP with Fuzzy PROMETHEE are also used in GSS problem and solution can be obtained by analysis using sensitivity analyses [8]. Green supplier selection is done on the foundation of certain criteria including hazardous substance management (HSM), ANP process was applied to solve problems with that for supplier selection [9]. To solve the uncertainties arising in ANP method for GSCM due to interdependent criteria Grey relation analysis is integrated with ANP [10]. Another method for GSS in the Fuzzy –NGT- VIKOR method where the problem is solved by evaluating the criteria for selection using NGT method and then the substitutes are evaluated using VIKOR and finally the uncertainties are solved by the fuzzy logic [11]. Instead of only focusing on traditional criteria for evaluation human perceptions can also be converted to values and used to solve the supplier selection problem, these values can be considered as criteria and evaluated along with the other criteria using fuzzy TOPSIS [12]. Keeping the general criteria for the GSS the main criteria are senior management commitment, product designs with three R’s (recycle, reuse, reduce) and agreement with legal environmental needs and auditing programs these criteria are incorporated for GSS using fuzzy TOPSIS [13]. Fuzzy entropy TOPSIS for green supplier selection was used for selection of supplier in thermal power plant were linguistic ratings were provided for the method for green supplier selection [14]. The integration of Fuzzy AHP and TOPSIS is used to govern selection of green supplier; the subjectivity in the problem solving is eliminated by use of fuzzy logics [15]. Fuzzy integrated VIKOR method was used for supplier selection based on four alternative supplier companies with main criteria being green, purchasing, transportation and recycling etc. for comparison and selection [16]. Another model was based on the framework obtained by the preprocessing of the socio-environmental and economic data of suppliers for use in fuzzy AHP method coupled with multi product lot sizing and multi period supplier selection problem [17]. A combined approach of (DEA-GEP) gene expression programming (GEP) with Data Envelopment Analysis (DEA) was used to select supplier and then the results were compared with results obtained by (DEA- ANN) Artificial Neural Network [18]. A new approach of GSS using SWARA, QFD using WASPAS tool was introduced where customer attitudes in the process of supplier evaluation is considered. Here customer requirements are given priority [19].

Recently an integrated approach using QFD and MCDM method was proposed by Morteza Yazdani et al [20] for GSS using DEMTEL and QFD for customer evaluation by incorporating green factors in the selection. COPRAS and MOORA methods were used to arrange and rank supplier then both results are
compared with each other. Present work uses the integration of QFD and an integrated MCDM method grey base fuzzy logic method for solving the same problem in order to eliminate the uncertainties. The ranking obtained by this method is compared with ranks and results obtained by using earlier methods for the same supplier selection problem for the validity of the suggested method. Next section present the GSS using grey based fuzzy logic approach.

2. Methodology for green supplier selection integrated grey-based fuzzy logic

The procedures adopted for selection of a supplier with multiple conflicting criteria are presented in the following nine steps:

Step 1: Identification of criteria and weightage for each criteria.

Step 2: Shortlisting of the green suppliers satisfies the criteria and assigning the indices for different criteria to the suppliers.

Step 3: Normalization of the data (data preprocessing) applying Eqns. (1)-(3). As most of material properties require either greater-the-better or lower-the-better characteristics, Eqns. (1) and (2) are most widely used.

Step 4: Calculation of the GRC for each criterion.

Step 5: Calculation of the overall GRG value.

Step 6: Fuzzification of the grey relational coefficients for each criteria and the overall GRG applying appropriate fuzzy membership functions.

Step 7: Establishing of fuzzy rules relating to the grey relational coefficients and with GRG.

Step 8: Obtaining the fuzzy output using max-min interface operation.

Step 9: Calculation of GFRG ($G_0$) using centroid defuzzification approach.

Step 10: Selection of the supplier having the maximum GFRG.

A detailed formula for the calculation of GRG and GFRG is presented elsewhere [21]

3. Illustrative example

To validate accuracy and potentiality of the proposed methodology, the following green supplier selection problems is considered and subsequently solved. The ranking orders obtained using the adopted method is compared with those obtained by the past research work. Illustrative example problem is chosen from Yazdani et al. [20], Green Supplier Selection (GSS) which is applied in planning and logistics section of a typical Iranian dairy industry. They considered ten green suppliers to evaluate on the basis of seven different criteria considering the customer requirements (CRs) and Technical Requirements (TRs) and the chosen criteria are namely Price (P), Green design (GD), Energy and natural resource consumption (ENRC), quality adaptation (QD), Delivery system (DS), Reuse and Recycle rate (RRR) and Production planning (PP). They used integration of DEMTEL and QFD for determining the weights for the criteria. The initial decision matrix is shown in Table.1. They used COPRAS and MOORA methods for ranking
the suppliers and to choose the supplier of lowest rank. In variation this method present work uses a grey based Fuzzy logic method for ranking and selection of supplier for the same GSS problem.

Table 1. Initial Decision Matrix for GSS problem along with criteria weight [20]

| Weight | Supplier | QD | P | ENRC | DS | GD | RRR | PP |
|--------|----------|----|---|------|----|----|-----|----|
| .132   | A1       | .068 | .066 | .150 | .098 | .156 | .114 | .098 |
| .135   | A2       | .078 | .076 | .108 | .136 | .082 | .171 | .105 |
| .138   | A3       | .157 | .114 | .128 | .083 | .108 | .113 | .131 |
| .162   | A4       | .106 | .139 | .058 | .074 | .132 | .084 | .120 |
| .90    | A5       | .103 | .187 | .125 | .176 | .074 | .064 | .057 |
| .223   | A6       | .105 | .083 | .150 | .051 | .134 | .094 | .113 |
| .120   | A7       | .137 | .127 | .056 | .133 | .122 | .119 | .114 |
| .0.94  | A8       | .100 | .082 | .086 | .060 | .062 | .109 | .093 |
| .0.53  | A9       | .053 | .052 | .043 | .100 | .050 | .078 | .063 |
| .0.104 | A10      | .094 | .074 | .097 | .087 | .080 | .054 | .106 |

In this problem P and ENRC are non-beneficial attributes having lower-the-better characteristic and remaining five are beneficial attributes higher-the better characteristics, normalized values are calculated using normalized data, the deviation sequence, GRCs and overall GRG values are computed. The GRCs and overall GRG values for all the ten suppliers are provided in Table 2. From the Table 2 it can be noted that supplier A2 is the best supplier whereas A10 is the worst supplier.

Table 2. GRCs and GRG values for green suppliers

| Suppliers | QD | P | ENRC | DS | GD | RRR | PP | GRG | Rank |
|----------|----|---|------|----|----|-----|----|-----|------|
| A1       | 0.3688 | 0.8282 | 0.3333 | 0.4448 | 1.0000 | 0.5065 | 0.5286 | 0.5449 | 5     |
| A2       | 0.3969 | 0.7377 | 0.4515 | 0.6098 | 0.4173 | 1.0000 | 0.5873 | 0.6441 | 1     |
| A3       | 1.0000 | 0.5212 | 0.3863 | 0.4019 | 0.5248 | 0.5021 | 1.0000 | 0.6000 | 3     |
| A4       | 0.5049 | 0.4369 | 0.7810 | 0.3799 | 0.6883 | 0.4021 | 0.7708 | 0.5391 | 6     |
| A5       | 0.4906 | 0.3333 | 0.3948 | 1.0000 | 0.3926 | 0.3535 | 0.3333 | 0.4804 | 9     |
| A6       | 0.5000 | 0.6853 | 0.3333 | 0.3333 | 0.7067 | 0.4317 | 0.6727 | 0.4991 | 7     |
| A7       | 0.7222 | 0.4737 | 0.8045 | 0.5924 | 0.6902 | 0.5294 | 0.6852 | 0.6214 | 2     |
| A8       | 0.4771 | 0.6923 | 0.5544 | 0.3501 | 0.3605 | 0.4855 | 0.4933 | 0.4896 | 8     |
| A9       | 0.3333 | 1.0000 | 1.0000 | 0.4513 | 0.3333 | 0.3861 | 0.3524 | 0.5485 | 4     |
| A10      | 0.4522 | 0.7542 | 0.4977 | 0.4125 | 0.4109 | 0.3333 | 0.5968 | 0.4799 | 10    |

The corresponding GFRG values are obtained using Fuzzy logic tool box in MATLAB (R2017b). The grey relational coefficients for QD, P, ENRC, DS, GD, RRR, and PP are the inputs to the Fuzzy logic system. Triangular membership functions are adopted for Fuzzy modeling. Membership functions, like Lowest (LT), Low (L), Medium (M), High (H) and Highest (HT) are utilized to represent the GRCs of inputs. For the related output, the GFRG membership functions are represented as Lowest (LT), Very Low (VL), Medium Low (ML), Low (L), High (H), Medium High (MH), Higher (HR), Medium Higher (MHR) and Highest (HT). These Fuzzy membership functions are shown in Figures 1.
The GFRG values are shown in Fig. 2 as shown in the rule viewer in the Fuzzy tool box. In Fig. 3 & 4, rows represent the Fuzzy rules and the first five columns represent the grey relational coefficients for QD, P, ENRC, DS, GD, RRR, and PP, and the last column provides the defuzzified GFRG values. The GFRG values obtained for the ten suppliers are given in Table 3.

**Fig 1.** Fuzzy membership functions for QD, P, ENRC, DS, GD, RRR and PP.

**Fig 2.** Fuzzy membership functions for grey-fuzzy reasoning grade

**Fig 3.** Fuzzy logic rule viewer (for alternative S₂)
Fig 4. Fuzzy logic rule viewer (for alternative S7)

Table 3. Grey fuzzy reasoning grade and rank for green suppliers

| Supplier | A₁ | A₂ | A₃ | A₄ | A₅ | A₆ | A₇ | A₈ | A₉ | A₁₀ |
|----------|----|----|----|----|----|----|----|----|----|-----|
| GFRG     | 0.500 | .625 | .600 | .500 | .500 | .625 | .500 | .500 | .505 | .500 |
| Rank     | 7.5 | 1.5 | 3 | 7.5 | 7.5 | 1.5 | 7.5 | 4 | 7.5 |

A comparison of the rank arrangements for suppliers obtained using the proposed method is carried out with those attained by Yazdani et al. [20], using COPRAS and MOORA methods is shown in Table 4. It is fascinating to note that ranking orders for the first and second were interchanged with grey relational analysis when compared with COPRA and MOORA methods. But after using fuzzy logics (grey based fuzzy logic) GFRG for both the suppliers A₁, A₇ is 0.625. This indicates that both the suppliers are equally competitive and there is flexibility to choose any one of them. It is also observed that the GFRG values of all the suppliers except A₁, A₃, A₇ and A₉ shows same value as 0.5. This may be because of close GRG values, which are ranging from 0.4799-0.5449 and hence their corresponding fuzzy values are same. The computed $r_j$ values between the rank orders of the considered methods are depicted in Table 5.

Table 4. Comparison of rankings with different methods for green suppliers

| Supplier | COPRAS | MOORA | Grey-relational analysis | Grey-based fuzzy logic |
|----------|--------|--------|--------------------------|-----------------------|
| S₁       | 5      | 4      | 5                        | 7.5                   |
| S₂       | 2      | 2      | 1                        | 1.5                   |
| S₃       | 4      | 3      | 3                        | 3                     |
| S₄       | 6      | 5      | 6                        | 7.5                   |
| S₅       | 10     | 10     | 9                        | 7.5                   |
| S₆       | 8      | 8      | 7                        | 7.5                   |
| S₇       | 1      | 1      | 2                        | 1.5                   |
| S₈       | 7      | 6      | 8                        | 7.5                   |
| S₉       | 3      | 7      | 4                        | 4                     |
| S₁₀      | 9      | 9      | 10                       | 7.5                   |
Table 5. Spearman’s Rank Correlation Coefficients

| Method                  | COPRAS | MOORA | Grey-relational analysis | Grey-based fuzzy logic |
|-------------------------|--------|-------|--------------------------|-----------------------|
| COPRAS                  | -      | 0.878 | 0.939                    | 0.878                 |
| MOORA                   | 0.878  | -     | 0.878                    | 0.764                 |
| Grey-relational analysis| -      | -     | ---                      | 0.999                 |

From Table 5, it can be noted that the computed $r_s$ values for the ranking orders of the proposed method with the other considered approaches are above 0.7 showing strong correlation between grey-based fuzzy logic and the other methods.

4. Conclusions
Present work shows an application of grey-based Fuzzy logic for solving green supplier selection problems. It was found that ranking orders for the first and second rankings were interchanged with grey relational analysis when compared with COPRA and MOORA methods. Using fuzzy logics (grey based fuzzy logic) GFRG for both the suppliers $A_1$, $A_7$ is 0.625 showing both the suppliers are equally competitive and there is flexibility to choose any one of them. For most of the cases, the Spearman’s correlation coefficients between the ranking orders of the previously employed methods and the grey-based fuzzy logic are greater than 0.7, showing strong correlation between these methods. This integrated grey relational - fuzzy logic approach can be suitably adopted for solving other complex supplier selection problems. When GRG values are close, precise GFRG values are same. This may be a limitation. Present study uses triangular membership function in future attempts can be made with other shapes of membership function to obtain accurate values.

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