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GRAHP TOP model for supplier selection in Supply Chain: A hybrid MCDM approach

Venkata Krishnarao Koganti[a], Nagaraju Menikonda[b], S. P. Anbuudayasankar[c*], T. Krishnaraj[c], Rajesh Kumar Athhukuri[d] and Mokkapati Sai Vastav[e]

[a]*The University of Texas, Dallas, USA*
[b]*Hochschule Stralsund University of Applied Sciences, Germany*
[c]*Amrita School of Engineering,Amrita Vishwa Vidhyapeetham, India*
[d]*Infosys Limited, India*
[e]*HAN University of Applied Sciences, Netherlands*

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A B S T R A C T

Decision makers of various disciplines are facing challenges because of vast availability of options in the real world. Even though each and every decision made by a decision maker is being done with a great knowledge and conscience, the decision maker needs suitable support to choose the most favorable option to acquire great results in an agile environment. Supplier selection is imperative for an efficient supply chain management. Many industries are in need of effective decision making tools which aids them in valuable supplier selection. This paper proposes a model using Multi Criteria Decision Making (MCDM) tools viz., Grey Relational Analysis (GRA), Analytical Hierarchy Process (AHP) and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). GRA is used to shortlist the criteria from the available options, while AHP is used to assign weights to the criteria. The final supplier in the selection process is obtained using TOPSIS. The proposed GRA-AHP-TOPSIS model (GRAHP TOP) is used to analyze and formulate the important criteria and the applicability of the model is tested on a case of a small scale industry located in South India.

1. Introduction

Multi-criteria decision making (MCDM) techniques are used where there are several conflicting criteria through which a decision has to be made. MCDM works with prioritizing, organizing and solving problems involving multiple criteria. It aids the decision makers and gives a better understanding of the problem. These tools take into account of the opinion of various decision makers and gives importance to each decision maker's opinion. The abstract of the optimal solution is being replaced by a non-dominated set of solutions and it makes decision maker to choose from these set of solutions. However, the solutions to a set of non-dominated criterions are too large to be evaluated by the decision makers to conclude to a solution. Hence, we need different tools to address the issue of problems with multiple attributes. Several tools have been used to address multi criteria problems over a period of time. So it needs significant amount of time to investigate on the tools which can provide better solutions for a variety of such problems. So hybridization of the tools may be used to utilize the expertise of an array

* Corresponding author.
E-mail address: sp_anbu@cb.amrita.edu (S.P.Anbuudayasankar)

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of tools. Supplier selection is one of the key processes in supply chain in which the heads of the firm select the best suppliers from all the available sources. Since the process plays an important role in determining the accomplishment of the system there should be a specific scientific process to select a supplier, rather than mere brainstorming and taking a decision. Though there are plenty of researches carried out in the supplier selection and there are several hybridization of tools (Prasad et al., 2017). Recently there is an increase in the usage of hybrid MCDM (HMCDM) to assist the decision maker. The primary reason is the credence in the results obtained when more than one method is combined to solve multiple criteria problem. HMCDM can address challenging problems involving diverse and complex information. In this paper an attempt has been made to develop a HMCDM combining Grey Relation Analysis (GRA), Analytical Hierarchy Process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

2. Literature review

Conventional decision-making methods are used to ameliorate overall sustainability and create efficient organizations. During the past few years, there is a rapid increase in works aggregating sustainability by using variety of MCDM. Huge amount of literature encapsulating these techniques have been reported. The importance and usefulness of MCDM in supplier selection can be seen by the number of papers on literature review alone. To quote some important review papers are Agarwal et al. (2011); Govindan et al. (2015); Chai et al. (2013); Govindan and Jepsen. (2016); Ho et al. (2010); Mardani et al. (2015a); Mardani et al. (2015b); Zare et al. (2016); Zavadskas et al. (2016); Renganath and Suresh, (2016).

Table 1
Literature on criteria for supplier selection

Criteria	Questionnaire Code	Reference
Commitment to Delivery Schedule	Q1	Galankashi et al., 2016; Deng et al., 2014; Polat & Eray, 2015; Lima-junior & Carpinetti, 2016; Adalı et al., 2016
Willingness of Supplier to Continuously Improve Quality	Q2	Rezaei et al., 2014; Lima-junior & Carpinetti, 2016; Gupta & Barua, 2017; Azimifard et al., 2018
Post Sale Service by Supplier	Q3	Wan & Beil, 2009; Shemshadi et al., 2011
The Sample Quality Checking Report	Q4	Rezaei et al., 2014; Deng et al., 2014; Polat & Eray, 2015; Lima-junior & Carpinetti, 2016; Singh et al., 2018
Financial Stability of the Supplier	Q5	Rezaei et al., 2014; Junior et al., 2014; Büyüközkan & Çifçi, 2012; Mwikali & Kavale, 2012
An ISO 9000 Certified Supplier	Q6	Rouyendegh & Saputro, 2014; Akman, 2015; Shemshadi et al., 2011; Mwikali & Kavale, 2012
Past Supply Record	Q7	Deng et al., 2014; Peng, 2012; Rouyendegh & Saputro, 2014; Büyüközkan & Çifçi, 2012; Mwikali & Kavale, 2012; Hamdan & Cheaitou, 2017
Supply Capacity of Supplier	Q8	Rezaei et al., 2014; Deng et al., 2014; Polat & Eray, 2015; Lima-junior & Carpinetti, 2016; Banaeian et al., 2018
Packing Done to The Raw Material by The Supplier	Q9	Büyüközkan & Çifçi, 2012; Awasthi & Kannan, 2016; Petrudi et al., 2017
Geographical Position of the Supplier	Q10	Rouyendegh & Saputro., 2014; Büyüközkan & Çifçi, 2012; Awasthi & Kannan, 2016
Authorized Suppliers for the Material	Q11	Rezaei et al., 2014; Deng et al., 2014; Polat & Eray, 2015; Lima-junior & Carpinetti, 2016
Reference of Customers	Q12	Rouyendegh & Saputro, 2014; Akman, 2015; Shemshadi et al., 2011; Mwikali & Kavale., 2012

Supplier selection is one of the standards and, is extremely researched area in procuring and subcontracting. In fact, analyses of literature in vendor selection specify a strong diversity in the universal approaches for selection (Ho et al., 2010) and as well as in the assessment of criteria (Weber et al., 1991).There are many criteria which affect the supplier selection. Busch (1962) and Dickson (1966) institute that criteria similar to quality, assurances and delivery schedule are vital assessment factors among many others like administration capability, value, manufacturing capability, monetary position, labor associations, vendor standing, technical competence, post sales services and numerous other relationship explicit qualities like reciprocal provisions and past business chronicles. The effectiveness of the supplier selection depends on the preciseness of the criteria to be considered in the process. Numerous literatures have been analyzed and a survey has been prepared with the criteria that are considered as prominent ones. This survey was filled by experts from ten different firms. Table 1 shows the criteria that were considered in the questionnaire with which a survey is taken from 10 industries in South India. The criteria that are selected through literature review are used in different scenarios by the above mentioned authors. They are systematically presented in Table 2.

Table 2
Literature on the scenario of criteria used for supplier selection

Criteria	Scenario	Reference
Commitment to delivery schedule	Supplier selection with incomplete and imprecise information	Deng et al., 2014
	Subcontractors in railway industry	Polat & Eray,2015
	Supplier selection in automobile industry	Galankashi et al., 2016
	Supplier selection in automobile supply chain	Lima-junior & Carpinetti, 2016
Willingness of supplier to continuously improve quality	Supplier selection in airline retail industry	Rezaei et al., 2014
	Supplier selection in automobile supply chain	Lima-junior & Carpinetti, 2016
	Green supplier selection	Gupta & Barua.,2017
	Supplier selection in steel industry	Azimifard et al., 2018
Post sales service by supplier	Supplier selection in Contracting	Wan & Beil, 2009
	Supplier selection in petro chemical Industry	Shemshadi et al., 2011
The sample quality checking report	Supplier in airline retail industry	Rezaei et al., 2014
	Supplier selection with incomplete and imprecise information	Deng et al., 2014
	Subcontractors selection in railway industry	Polat & Eray, 2015
	Supplier selection in automobile supply chain	Lima-junior & Carpinetti, 2016
Financial stability of the supplier	Supplier selection in procurement	Mwikali & Kavale, 2012
	Supplier selection in automotive industry	Junior et al., 2014
	Supplier selection in airline retail industry	Rezaei et al., 2014
	Green supplier selection	Büyüközkan & Çifçi, 2012
An ISO 9000 certified supplier	Supplier selection in automobile industry	Akman, 2015
	Supplier selection in petro chemical industry	Shemshadi et al., 2011
	Supplier selection in procurement	Mwikali & Kavale, 2012
	Supplier selection in fertilizer industry	Rouyendegh & Saputro, 2014
Past supply record	Supplier selection in logistics industry	Peng, 2012
	Supplier selection in procurement	Mwikali & Kavale, 2012
	Supplier selection in fertilizer industry	Rouyendegh & Saputro, 2014
	Supplier selection with incomplete and imprecise information	Deng et al., 2014
	Green supplier selection	Büyüközkan & Çifçi, 2012
	Green supplier selection	Hamdan & Cheaitou, 2017
Supply capacity of supplier	Supplier selection in airline retail industry	Rezaei et al., 2014
	Supplier selection with incomplete and imprecise information	Deng et al., 2014
	Subcontractor selection in railway industry	Polat & Eray, 2015
	Supplier selection in automobile supply chain	Lima-junior & Carpinetti, 2016
	Supplier selection in agro-food industry	Banaeian et al., 2018
Packing done to the raw material by the supplier	Green supplier selection	Büyüközkan & Çifçi, 2012
	Green supplier selection	Awasthi & Kannan, 2016
Geographical position of the supplier	Supplier selection in fertilizer industry	Rouyendegh & Saputro, 2014
	Green supplier selection	Büyüközkan & Çifçi, 2012
	Green supplier selection	Awasthi & Kannan, 2016
Authorized suppliers for the material	Supplier selection in airline retail industry	Rezaei et al., 2014
	Supplier selection with incomplete and imprecise information	Deng et al., 2014
	Subcontractor selection in construction industry	Polat and Eray, 2015
	Supplier selection in automobile supply chain	Lima-junior & Carpinetti, 2016
Reference of customers	Supplier selection in fertilizer industry	Rouyendegh & Saputro, 2014
	Supplier selection in automobile industry	Akman, 2015
	Supplier selection in petro chemical industry	Shemshadi et al., 2011
	Supplier selection in procurement	Mwikali & Kavale, 2012

3. GRA – AHP – TOPSIS (GRAHP TOP)

Hybrid tool combination: (GRAHP TOP)

GRA ⟶ AHP ⟶ TOPSIS

Grey Relation Analysis (GRA) is used to find the Grey Relation Grades and is used to reduce the uncertainty of the results and to prioritize the criteria that are considered. Short listing of criteria and a pair wise comparison matrix has been formed using Analytical Hierarchy Process (AHP). Weights for the criteria are obtained from AHP and these weights are further used in TOPSIS to find out the best alternative from among all the alternatives available.

The proposed methodology consists of fifteen steps

Step 1: Identification of important criteria for selection using a survey

Step 2: Collection of the results for the calculation of the difference between sequences and reference sequence

Step 3: Calculation of the grey relational coefficient

Step 4: Calculation of the grey relational grades

Step 5: Formulation of the aim of the work

Step 5: Evaluation of the criteria for selection of the alternatives

Step 6: Pair wise comparison using Saaty nine-point scale

Step 7: Computation of relative criteria weights

Step 8: Determination of consistency ratio

Step 9: Formulation of the decision matrix

Step 10: Calculation of the Standard Decision Matrix

Step 11: Construction of the Weighted Standard Matrix

Step 12: Determination of the ideal solution and the negative ideal solution

Step 13: Determination of the separation from the ideal solution S_i*

Step 14: Determination of the separation from the negative ideal solution S_i'

Step 15: Determination of the comparative closeness to the ideal solution to declare the best alternative

Generally, the data that is collected from survey will be uncertain like the uncertainties in subjective judgments. People are not sure while making subjective decisions. In some cases information pertaining to some attributes may not be available at all. Hence an uncertainty caused due to lack of data is a common problem faced by a decision maker. So this incomplete information would give a vague output. In order to avoid this and reduce the uncertainty in the survey values, GRA is used. GRA reduces the fuzziness in the data and gives the output as Grey Relational Grades. Hence pre-processing of the data is done to get the optimized output.

AHP has been the decision making methodology which is helpful in making judgments by breaking down a complicated and complex problem into a multi-level hierarchy structure. It is one of the simplest and powerful methodologies used to address MCDM problems (Mohanavelu et al., 2017). AHP method is one of the best methodologies to prioritize various selection criteria. The AHP method is useful in determining weights of the criteria and to find the consistency ratio which is used for examination of the degree of consistency for the pair wise comparison (Saaty, 1980)

TOPSIS methodology is an MCDM system which enables the decision makers to establish the problem in a simplified way, and carry out analysis. Also it helps in comparing and determining ranks of the alternatives of actual problems (Hwang & Yoon, 1981). The rankings of the alternatives are obtained by perceiving shortest distance from the ideal solution and the utmost distance from the negative ideal solution. Cheng et al. (2002) report TOPSIS as the usefulness based methodology as it does the comparison of each and every alternative directly depending on the available information that is available in the evaluation matrices and weights. Also TOPSIS is one of the techniques that have answered numerous real world glitches. TOPSIS is useful in attaining final ranking of supplier selection criteria. Fig.1 summarizes the hybrid tool combination.

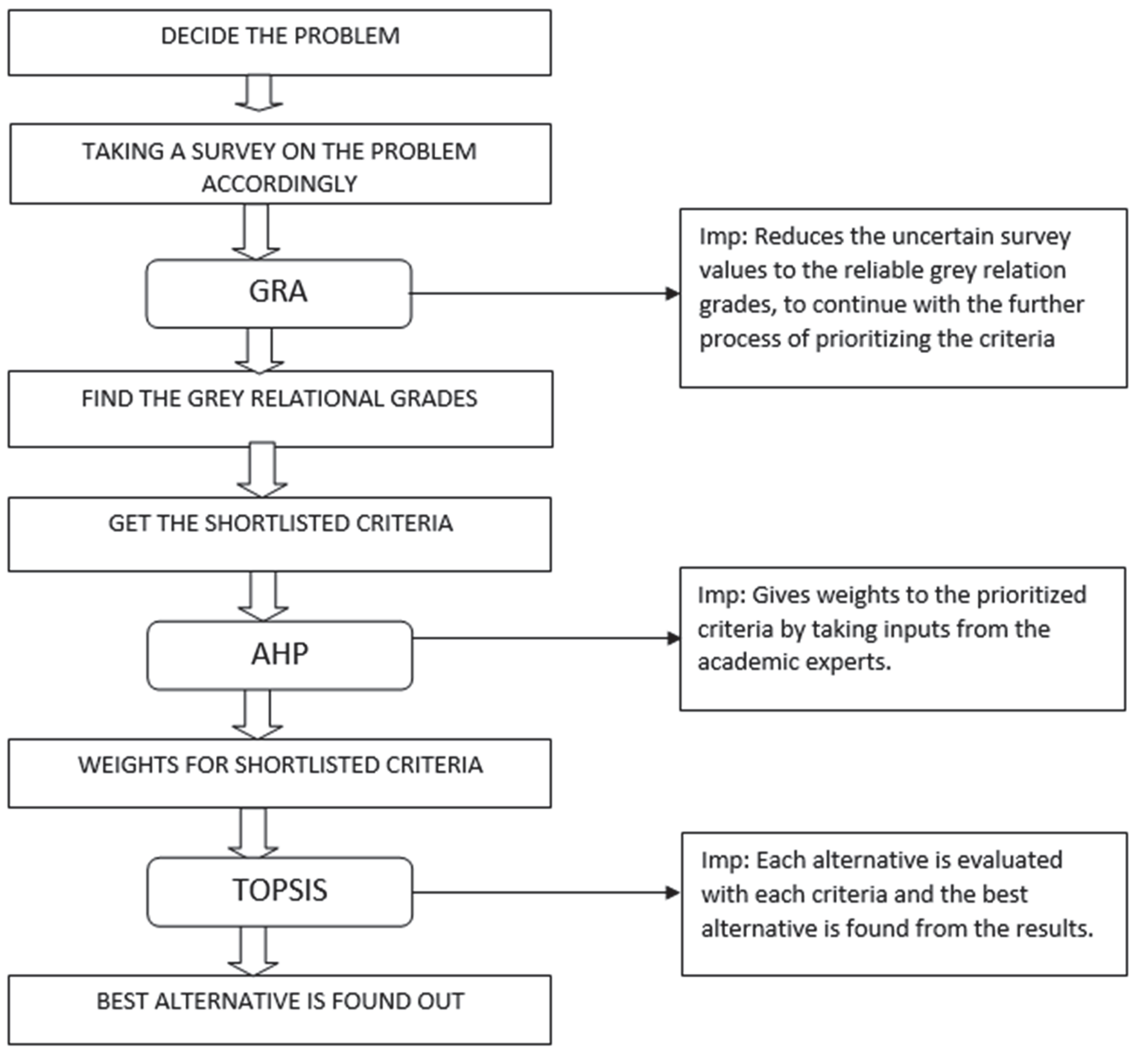

Fig. 1. Methodology - Hybrid tool combination - GRAHP TOP

4. Case study

A valve manufacturing industry is considered for the case study to validate the GRAHP TOP. The company receives many outsourcing orders from medium and large scale industries. The design is provided by an outsourcing company and manufactures the product from scratch i.e., procurement of raw materials, manufacturing, quality checking and delivery of the product. Therefore, the company requires suppliers to provide raw materials on a regular basis. Generally, the company manufactures valves with cast iron and the company gets the material from five suppliers in lots whenever required. Recently the company got an order from new outsourcing company to manufacturer piston cylinders of cast iron. So it has to get the extra quantity of material from the available suppliers. All the five suppliers are supplying the cast iron material for the manufacture of valves. Now the company has to choose a supplier from regular pool and decide upon from whom to acquire the raw material for the new product piston cylinder. Being associated with the existing suppliers for a long time the company is in a position to evaluate the suppliers on different criteria. The proposed tool is applied to facilitate effective supplier selection from the pool of available suppliers.

4.1 GRA

Grey relational analysis (GRA) technique was proposed by Deng in 1989 and has been effectively used in unraveling a plethora of MCDM complications. It is used for addressing many problems in the sectors like routing, business, academic, financial series, design evaluation problems etc. Generally, for any problem, the solution begins with the questionnaire and the survey. So, better survey gives best output. But it is found that the data that is collected from the survey is uncertain. So, in order to reduce this uncertainty in the value, GRA is used. The procedure of GRA starts with finding the comparability sequence from the performance of all alternatives. To proceed with the first step, an ideal sequence for which all the criteria are rated as 5 on a 5 scale is defined. Then, the grey relational coefficient between the comparability sequences and the ideal sequence is calculated. Finally, the grey relational degree between ideal sequence and every comparability sequences are calculated with the help of grey relational coefficients. Thus, the more the grade, the more important the sequence is.

A list of criteria is shown below with which the questionnaire for taking a survey from industry experts is prepared.

Generally, the GRA is done in four steps:

1) Listing the results from questionnaire responses.

2) Derivation of the reference sequence.

3) Calculation of Grey Relation Coefficient.

4) Determination of Grey Relation Grade.

Step 1: A survey is taken on the scale of 5 from 10 Small and Medium scale Industries in south India for the importance of the respective criteria in the selection process of the supplier.

Table 3
Survey values from 10 industry experts who are involved in supplier selection

Response from Experts												
R1	4	4	5	4	4	3	4	3	4	3	3	4
R2	5	5	5	5	4	5	5	3	4	5	3	4
R3	4	3	5	4	3	4	3	3	3	3	4	5
R4	3	4	5	3	3	5	3	3	2	3	4	5
R5	1	4	5	3	3	4	4	3	2	4	4	4
R6	2	3	5	5	2	5	2	2	3	3	3	5
R7	3	3	4	5	3	4	3	2	3	3	3	5
R8	4	5	5	3	3	4	4	3	2	3	3	4
R9	2	2	5	4	3	5	3	3	3	3	3	4
R10	5	5	5	4	4	5	3	3	4	4	4	5

Let X_i (k) be the value of importance of with criteria given by the k^{th} respondent.

Step 2: List the results from the questionnaire responses, and calculate the difference between sequences with the reference sequence (1) (Table 4.)

$$\text{e. } X_0(k)-X_i(k)=\Delta X_i(k) \quad (1)$$

Table 4
Difference with reference sequence values

Response from Experts	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
R1	1	1	0	1	1	2	1	2	1	2	2	1
R2	0	0	0	0	1	0	0	2	1	0	2	1
R3	1	2	0	1	2	1	2	2	2	2	1	0
R4	2	1	0	2	2	0	2	2	3	2	1	0
R5	4	1	0	2	2	1	1	2	3	1	1	1
R6	3	2	0	0	3	0	3	3	2	2	2	0
R7	2	2	1	0	2	1	2	3	2	2	2	0
R8	1	0	0	2	2	1	1	2	3	2	2	1
R9	3	3	0	1	2	0	2	2	2	2	2	1
R10	0	0	0	1	1	0	2	2	1	1	1	0

Step 3: Calculate the grey relational coefficient according to Eq. (2).

The grey relational coefficient (2) is calculated to express the relation between the reference sequence and sequences to be compared for each effort driver.

$$\xi_i(K)=\frac{\Delta\min+p\Delta\max}{\Delta X_i(K)+p\Delta\max} \quad (2)$$

Where,

$\Delta_{min} = \min_{\forall i} \min_{\forall k} \Delta X_i(k)$,

$\Delta_{max} = \max_{\forall i} \max_{\forall k} \Delta X_i(k)$.

Here "p" is called distinguishing coefficient and is taken as 0.5. The tenacity of the peculiar coefficient is to increase/decrease the range of the grey relational coefficients.

Table 5
Calculated Grey Relational Coefficients

Response from												
R1	0.67	0.67	1	0.67	0.67	0.5	0.67	0.5	0.67	0.5	0.5	0.67
R2	1	1	1	1	0.67	1	1	0.5	0.67	1	0.5	0.67
R3	0.67	0.5	1	0.67	0.5	0.67.	0.5	0.5	0.5	0.5	0.67	1
R4	0.5	0.67	1	0.5	0.5	1	0.5	0.5	0.4	0.5	0.67	1
R5	0.333	0.67	1	0.5	0.5	0.67	0.67	0.5	0.4	0.67	0.67	0.67
R6	0.4	0.5	1	1	0.4	1	0.4	0.4	0.5	0.5	0.5	1
R7	0.5	0.5	0.67	1	0.5	0.67	0.5	0.4	0.5	0.5	0.5	1
R8	0.67	1	1	0.5	0.5	0.67	0.67	0.5	0.4	0.5	0.5	0.67
R9	0.4	0.4	1	0.67	0.5	1	0.5	0.5	0.5	0.5	0.5	0.67
R10	1	1	1	0.67	0.67	1	0.5	0.5	0.67	0.67	0.67	1

Step 4: The grey relational grades, which are equal to the arithmetic mean of the grey relation coefficients, is calculated. So, the arithmetic mean of Grey Relational Coefficients for the values of all the 10 industries gives the final grey relational grade of the particular question/criteria/factor. The grey relational grade characterizes the association between sequence and comparison sequence. If the

change in two factors shows the same tendency, it means that the extent of synchronous change is high, as well as the degree of the correlation. Thus, the factor with high grey relational grade factor can more possibly consider as an important factor that influences the selection of the supplier. (Table 6.)

Table 6
Calculated Grey Relational Grades

Criteria	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
GRG	0.613	0.69	0.967	0.717	0.54	0.817	0.59	0.48	0.52	0.583	0.567	0.833

From these Grey Relational Grades, the most prominent criteria are shortlisted and are provided to AHP for further evaluation of those criteria and to find out the weights of those prioritized criteria. Here among the eleven criteria that are considered five criteria are selected as prominent when compared to the other criteria.

4.2 AHP

Analytical Hierarchy Process (AHP) is a structured technique which is used to make decisions in an organized way. Developed by Dr. Thomas L Saaty in 1970's, AHP is mostly used Multi Criteria Decision Making process (Saaty, 1980). AHP is being widely used in engineering, manufacturing, management, education, IT, medical sectors etc. (Vaidya & Kumar, 2006) due to its ease, simplicity and flexibility. With AHP, the decision grows into the step-by-step process, which abridges decision-making, allows association and advances the value of decisions. It breaks down the problem into a hierarchical structure consisting of several levels, such as goal, criteria and sub-criteria (Saaty, 1980; Mangla et al., 2015a & Mangla et al., 2015b; Yazdani, 2014). Once the hierarchy tree is set up the decision maker does the pairwise comparison by comparing two criteria at a time. This gives the decision maker and evaluator a clear idea about the understanding of the problem. AHP takes qualitative inputs and gives quantitative outputs. The steps used for this study in AHP are given as follows:

Step 5: Formulation of the aim of the work: Evaluating the criteria of supplier selection which is a common problem faced by companies, is the aim of AHP in this particular problem.

Step 6: Formulation of pair wise comparisons: Pair wise comparison is done by collecting data from panel of experts. The panel consists of managing director and board of directors of the company who are having a strong enterprise experience. The pair wise comparisons are done using Saatynine-point scale

Step 7: Computation of relative weights: The final pair wise comparison matrix is used to determine Eigen vectors and Eigen values, which are later processed to find the relative criteria weights.

Step 8: Determination of consistency ratio: The consistency ratio (CR) is computed to determine the consistency of pair wise comparisons. The mathematical expression for finding CR is,

$$C.R = C.I / R.I, \tag{3}$$

Where consistency index is denoted by

$$(C.I) = (\lambda max - n) / (n - 1) \tag{4}$$

where λmax is the maximum Eigenvalue and *n* is the number of criteria being evaluated. The value of the random consistency index (R.I) depends on the value of (n) as shown in Table 6. The value of C.R should me less than 0.1 in order to have a better level of consistency. The shortlisted criteria are taken as input from Grey Relational Analysis and is ranked using AHP. Five criteria were shortlisted out the twelve. The panel of experts did a pairwise comparison for the shortlisted five criteria and relative weights are found for the criteria as shown in Table below. (Table 7)

Table 7
Ranking of the shortlisted criteria using AHP

Shortlisted Criteria	Weight	Ranking
Commitment to Delivery Schedule	0.275413	2
Willingness of Supplier to Continuously Improve Quality	0.322713	1
Post Sale Service by the Supplier	0.137904	4
The Sample Quality Checking Report	0.217610	3
Financial Stability of Supplier	0.046360	5

The consistency of the ranking can be tested by calculating the Consistency Ratio (CR). CR calculates to be 0.0785685 which is found using Eq. (3). The calculated CR is less than 0.1 which can be inferred that the judgment is consistent.

The results of AHP are further given to TOPSIS for determining the best alternative. TOPSIS method is used to determine the best alternative since it relates each alternative straightly depending on the data in judgment matrices and weights.

4.3 TOPSIS

Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is a tool used for solving MCDM complications in the real world and was technologically advanced by Hwang and Yoon in 1981 (Hwang & Yoon, 1981) and further developed by Lai and Liu (1993). It aids the decision maker to organize and rank the alternatives. Based on the ranking the best alternative can be found. However, as TOPSIS is applied to MCDM problems it will be a collective effort of decision makers. It compares the distance between the alternatives from an ideal solution and non-ideal solution. The alternative which is at least distance from ideal solution is the best alternative. (Belenson & Kapur, 1973; Zelany, 1974). Hwang and Yoon (1981) later proposed that the ranking of the alternatives will depend on on the closest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). TOPSIS method ponders both the distances to PIS and NIS simultaneously and a ranking order is given based on the relative closeness-distance. The advantages of TOPSIS are (Kim et al., 1997): (i) a logic that represents the mindset of human choice; (ii) a measurable value that accounts for both the ideal and non-ideal choices concurrently; (iii) an easy computation process that is easy to program into a spreadsheet. These advantages make TOPSIS most frequently used tool along with Analytical hierarchy process (AHP), ELECTRE and more. TOPSIS is a utility based method which directly relates each alternative directly based on the data obtained in the evaluation matrices (Cheng et al., 2002). In recent times TOPSIS found its wide application across different fields like human resource management (Chen & Tzeng, 2004), transportation (Janic, 2003), product design (Kwong & Tam, 2002), manufacturing (Milani et al., 2005), water management (Srdjevic et al., 2004), quality control (Yang & Chou, 2005) and location analysis (Yoon & Hwang, 1985). The high flexibility of TOPSIS allowed the decision makers to apply on various occasions and this enabled to further extend the model and apply to multi-objective decision making (Yoon & Hwang1985) and group decision making. TOPSIS is hybridized with various other MCDM tools to get a better output.

Step 9: Write the decision matrix.

This decision matrix values are the values obtained from a survey conducted in a company located in South India. (Table 8.)

Table 8

Decision Matrix

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Commitment to Delivery Schedule	5	5	3	5	3
Willingness of Supplier to continuously improve quality	4	4	4	3	3
Post sale service by Supplier	5	4	4	3	3
The sample quality checking report	5	5	4	3	3
Financial stability of the supplier	3	4	3	3	3

Step 10: Calculate the Standard Decision Matrix

Numerous attribute dimensions converted into non-dimensional attributes, which consents assessments across criteria. Each column of decision matrix is divided by root of the sum of the square of respective columns for the purpose of standardization. (Table 9.)

Table 9

Extra column is added showing the root of sum of squares

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Root of sum of squares
Commitment to Delivery Schedule	5	5	3	5	3	9.64365
Willingness of Supplier to continuously improve quality	4	4	4	3	3	8.124038
Post sale service by Supplier	5	4	4	3	3	8.660254
The sample quality checking report	5	5	4	3	3	9.165151
Financial stability of the Supplier	3	4	3	3	3	7.2111025

An extra column is added showing the root of sum of squares of respective criteria, each value in that extra column divides each and every value in that particular row for making the decision matrix standardized. (Table 9)

Table 10

Standard Decision Matrix

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Commitment to Delivery Schedule	0.518475	0.518475	0.311085	0.518475	0.311085
Willingness of Supplier to continuously improve quality	0.492366	0.492366	0.492366	0.369274	0.369274
Post sale service by Supplier	0.577350	0.461880	0.461880	0.346410	0.346410
The sample quality checking report	0.545544	0.545544	0.436435	0.327326	0.327326
Financial stability of the Supplier	0.4160251	0.554700	0.4160251	0.4160251	0.4160251

Step 11: Construct the Weighted Standard Matrix

The weighted standardized decision matrix is constructed by multiplying criteria weights to each rating in the standardized decision matrix. These criteria weights are already obtained from AHP before. (Table 12)

Table 11
Multiplying criteria weight to each rating in the standardized decision matrix

Criteria	Weights	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Commitment to Delivery Schedule	0.275413	0.518475	0.518475	0.311085	0.518475	0.311085
Willingness of Supplier to continuously improve quality	0.322713	0.492366	0.492366	0.492366	0.369274	0.369274
Post sale service by Supplier	0.137904	0.577350	0.461880	0.461880	0.346410	0.346410
The sample quality checking report	0.21761	0.545544	0.545544	0.436435	0.327326	0.327326
Financial stability of the Supplier	0.04636	0.4160251	0.554700	0.4160251	0.4160251	0.4160251

The criteria weights obtained from AHP are shown in Table 11. These criteria weights are multiplied to every corresponding value in standardized decision matrix for making it weighted standardized decision matrix.

Table 12
Weighted Standardized Decision Matrix

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Commitment to Delivery Schedule	0.142794	0.142794	0.085676	0.142794	0.085676
Willingness of Supplier to continuously improve quality	0.1588929	0.1588929	0.1588929	0.1191695	0.1191695
Post sale service by Supplier	0.0796188	0.063695	0.063695	0.04777132	0.04777132
The sample quality checking report	0.1187158	0.1187158	0.0949726	0.0712294	0.0712294
Financial stability of the Supplier	0.019286	0.0257158	0.019286	0.019286	0.019286

Step 12: Determine the ideal solution and the negative ideal solution.

The ideal solution and negative ideal solution are marked. (Table 13.)

A set of maximum values for each criterion is the Ideal solution.

A set of minimum values for each criterion is the Negative Ideal solution.

Table 13
Determining the ideal solution and the negative ideal solution

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Commitment to Delivery Schedule	**0.142794**	**0.142794**	*0.085676*	**0.142794**	*0.085676*
Willingness of Supplier to continuously improve quality	**0.1588929**	**0.1588929**	**0.1588929**	*0.1191695*	*0.1191695*
Post sale service by Supplier	**0.0796188**	0.063695	0.063695	*0.0477132*	*0.0477132*
The sample quality checking report	**0.1187158**	**0.1187158**	0.0949726	*0.0712294*	*0.0712294*
Financial stability of the Supplier	*0.019286*	**0.0257158**	*0.019286*	*0.019286*	*0.019286*

IDEAL SOLUTION *NEGATIVE IDEAL SOLUTION*

Ideal solution = {0.20479469, 0.1925947, 0.09188, 0.1044032, 0.222987} = S*

Negative Ideal solution = {0.1535970, 0.10592695, 0.044872, 0.09, 0.1052995} = S'

Step 13: Determine separation from the ideal solution. S_i*

Subtract the ideal solution from each value and square each value for more accuracy and all values in an alternative will be added and named as Si*. (Table 14.)

Table 14

Separation from the ideal solution

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Commitment to Delivery Schedule	0	0	0.003262	0	0.003262
Willingness of Supplier to continuously improve quality	0	0	0	0.001577	0.001577
Post sale service by Supplier	0	0.00025356	0.00025356	0.0010179	0.0010179
The sample quality checking report	0	0	0.00056373	0.0022549	0.0022549
Financial stability of the Supplier	0.000041342	0	0.000041342	0.000041342	0.000041342

Step 14: Determine separation from the negative ideal solution Si'.

Subtract the negative ideal solution from each value and square each value for more accuracy and all values in an alternative will be added and named as Si'. (Table 15.)

Table 15

Separation from the Negative ideal solution

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Commitment to Delivery Schedule	0.003262	0.003262	0	0.003262	0
Willingness of Supplier to continuously improve quality	0.001577	0.001577	0.001577	0	0
Post sale service by Supplier	0.0010179	0.000255418	0.000255418	0	0
The sample quality checking report	0.0022549	0.0022549	0.00056373	0	0
Financial stability of the Supplier	0	0.00004134	0	0	0

Step 15: Determine comparative closeness to the ideal solution. (Table 16.)

Table 16

The comparative closeness of different suppliers

Criteria	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier5
S_i^*	0.000041342	0.00025356	0.0041206	0.004891	0.008153142
$S_i^{'}$	0.008118	0.0073906	0.00239615	0.003262	0
$S_i^*+ S_i^{'}$	0.008159342	0.00764416	0.00651675	0.008153	0.008153142
$S_i^{'}/(S_i^*+ S_i^{'})$	**0.994933**	0.966829	0.367690	0.40	0

From Table 16, it is evident that "Supplier 1" is comparatively close to the positive ideal solution and comparatively far from the negative ideal solution of the problem. So, "Supplier 1" is the best supplier amongst the other alternatives mentioned.

5. Conclusion

The problems in conventional supply chain were studied and understood, that it is a drawback for the enterprises in this competitive global market. A decision maker spends a great amount of time in selecting the appropriate method. This is an important setback in the case of individual MCDM methods. Hybrid approach combining more methods can consolidate the results for decision making, thus making the decision making process efficient. One of the main benefits of hybrid tools over traditional tools is to uncover a possibility of harmonizing subjective and objective criteria. A hybrid tool was coined, combining GRA, AHP and TOPSIS considering the pros and cons of the tools. The GRAPHTOP hybrid tool was then used to evaluate supply chain processes.

The GRAPHTOP was used to perform an analysis on small and medium scale industries in the selection of suppliers and was applied to a small scale industry in South India. In the initial stage, GRA was used to reduce the uncertainty and used to prioritize the criteria. Among the twelve criteria that were considered initially, the five most important criteria were used for AHP. When the results were analyzed, it is understood that the pair wise decision matrix made by the expert team is congruous as the consistency ratio is less than 0.1. It shows that the decision made by the team is proper for the further analysis. The results of GRA were used by AHP to give criteria weights to the shortlisted criteria. Later at the final stage of testing of the tool TOPSIS was used to find the best alternative. The tool analysis shows that supplier 1 is closer to the positive ideal solution which is evident that it is the ideal option. The scope of the work can be extended to all industries and aid the decision makers in MCDM scenarios.

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