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Supplier selection using grey theory: a case study from Indian banking industry

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Abstract

Purpose – As the suppliers of any organization are considered as the strategic partners and taken as the integral part of the supply chain network, hence it is very crucial decision to select the suppliers in order to get the competitive edge. Whenever, any organization select its suppliers then organization evaluates every supplier with respect to certain criteria, which are already listed in the organization's policies. Since supplier selection is based on the evaluation of various attributes of each alternative; therefore this problem is a multi-attribute decision-making (MADM) problem. The purpose of this paper is to propose a model for selecting the best supplier.

Design/methodology/approach – This paper reports the implementation of grey theory to choose the appropriate supplier with uncertain information. Grey values have been used to give the ratings and weightage to various criteria which are being used to evaluate the different supplier alternatives. And finally the grey possibility degree has been calculated to rate the various alternatives.

Findings – This paper proposed a MADM model based on grey theory to select the optimal supplier and finally, the proposed model has been applied to select the best supplier for "optimizing digital banking" in the Indian context.

Research limitations/implications – The selection criteria selected here through literature review may not fit the whole industry and moreover this paper can be extended into the field where multiple-supplier selection is required, like in manufacturing sector where the authors cannot rely always on single supplier. So, in that case the authors need to pick more than one best alternatives.

Practical implications – The grey theory approach can be applied almost all the services industries, where the exact information about the suppliers in quantitative terms is very difficult to find. So the authors can use the grey numbers to rate the suppliers.

Social implications – Since, the coming generation is more dependent on the internet banking, so it becomes very much necessary for the banking sector to update the existing system. Due to lack in technical skills, outsourcing the information technology and software development is the best option. Hence, Grey theory based model can be used in selecting the best supplier under uncertain information.

Originality/value – Very few studies have been done in India using grey theory approach for supplier selection and moreover, to the best knowledge of the authors' this is the first study which employs grey theory for selecting the best supplier in banking industry. Moreover the digital banking system is the future of banking industry, so every player should provide the digital banking structure in order to survive in the market.

Keywords Supplier selection, Grey number, Grey theory, Linguistic variable

Paper type Research paper

1. Introduction

Today's competitive world, it is very important for every banking organization to be cost effective and at the same time quite responsive toward the feedback from end customers to gain position in the market. Therefore, the banks must concentrate on the efficiency of various operations, which are being done within the organization in order to produce the services and outside of the organization to deliver services to the end

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consumer at desired service level. Hence, banking industry is facing tough challenges to make the services available at desired rate and quality with lesser cost. In order to reduce the cost of operations, the banks must focus on their core competencies and outsource the rest of the functions. So, to meet the needs, the banks must select their partners more objectively and systematically. The supplier selection is the process of picking up the one who is capable to deliver goods/services of right quality, at right price, at right place and at right time (Mandal and Deshmukh, 1994; Sarkis and Talluri, 2002). Therefore, evaluating suppliers is depending upon various factors, which will help the organization to choose best option out of the available alternatives. Usually, the process of selecting the supplier is a multi-attribute decision-making (MADM) problem, which involves different alternatives and various attributes on which these alternatives are being evaluated. The process of choosing the supplier can be improved if we can include both the quantitative as well as qualitative factors. According to De Boer and Wegen (2003), selecting a supplier consists of five main steps: first, feeling the need for new supplier; second, finalizing the decision criteria; third, short listing of the potential suppliers out of the available; fourth, final supplier selection; and fifth, continuous monitoring of the selected suppliers.

In the past, various individual methodologies (like; data envelopment analysis, mathematical programming, goal programming, analytic hierarchy process (AHP), analytic network process (ANP), fuzzy-set theory, genetic algorithm etc.) as well as other integrated approaches (like: integrated AHP approach, integrated fuzzy approach) have been developed to solve the supplier selection problem (Ho *et al.*, 2009). In conventional MADM methods, the weights and ratings of all the attributes are well known to the decision makers (Kaufmann and Gupta, 1991; Delgado *et al.*, 1992) and then decision makers used to give ratings to various suppliers depending upon all the attributes considered. This method of rating the suppliers and attributes depends on the subjective judgments given by various decision makers (Li *et al.*, 2006). To predict the exact numerical value for the attributes is very difficult as it involves very high degree of uncertainty. According to Deng (1989), grey theory can deal with this uncertain information by giving the opportunity to decision makers to express their preferences in terms of linguistic variables. Wang (2005) has used fuzzy-based approach to deal with the uncertainty in selecting the suppliers. Grey theory is better than the fuzzy theory in dealing with uncertainty, because grey theory can handle fuzziness more flexibly. Grey process helps the decision makers to evaluate the alternatives when incomplete information is available (Goyal and Grover, 2012).

Hence, the current study proposes a grey theory based model to select the best partner for outsourcing the digital services in banking sector. The paper is organized as follows: in Section 2, the literature on supplier selection criteria and grey theory is analyzed. Section 3 explains the rationale of the study. Section 4 explains the methodology for supplier selection model. Section 5 proposes a model for supplier selection using grey theory approach. Section 6 includes the case study, which applies the supplier selection model to the banking industry. Finally, results and discussion is demonstrated in Section 7 and the last section concludes the whole paper.

2. Literature review

The grey system theory can be applied in various fields like medicine, history, agriculture, ecology, economy, earthquake, material science, environment, geology, meteorology, geography, industry, hydrology, sports, traffic, management, irrigation strategy, military affairs, judicial system, etc. (Deng, 1989). Many researchers and academicians have utilized the grey theory approach in multi-criteria decision making like: analyzed information entropy of discrete grey numbers (Zhang *et al.*, 1994); evaluated the performance of airline (Feng and Wang, 2000); multi-criteria models for grey relationships (Olson and Wu, 2006); selecting the best supplier (Li *et al.*, 2006); selecting the best material (Chan and Tong, 2007); grey relational analysis in multiple criteria decision-making problems (Kuo *et al.*, 2008); and ranking the knowledge management system (Mehregan *et al.*, 2012). Ni and Xu (2011) used grey relation decision-making method for selecting the suppliers, taking into consideration following four criteria: quality; price; delivery; and service. Sadeghieh *et al.* (2012) addressed the problem of parts supplier evaluation and selection for manufacturing industry and proposed an integrated genetic algorithm based on grey goal programming approach. Hashemi *et al.* (2013) developed a grey-based carbon management model for green supplier selection and considered planning, implementation and management as the main dimensions to evaluate the suppliers. Hashemi *et al.* (2015) took the economic and environmental factors as the selection criteria, and used an integrated approach with ANP and improved grey relational analysis for green supplier selection.

The current study has used the following six criteria from the literature in selecting the best supplier, as shown in Table I.

Dickson (1966) collected the opinion from the purchasing managers and identified 23 factors for evaluating the suppliers and showed that among them quality is the most important criterion followed by delivery and performance history. Abratt (1986) also found from his study conducted with the experts that quality is the most important parameter when evaluating the suppliers and price is the least important factor. Min and Galle (1999) calculated the average degree of importance of key factors, that affect the buying firm's purchasing decision and found quality as the most important followed by delivery performance, then price followed by environmental friendly manufacturing and last the supplier's capability to operate by e-commerce. Pi and low (2006) proposed the supplier evaluation and selection system based on Taguchi loss function and AHP and considered quality, on-time delivery, price and service as their main parameters of evaluation. Ho *et al.* (2009) analyzed all the articles appeared in international journals from 2000 to 2008 and found quality as most popular factors followed by delivery, price, manufacturing capability, service, management, research and development, finance, flexibility, reputation, relationship, risk, and safety and environment. Based on the literature review done we can prioritize the all the criteria depending upon the focus of various researchers on different criteria. As shown in Figure 1 quality, cost/price and delivery and reliability were the focus for the researchers and each criterion contributed 87.11 percent in the total literature reviewed. As, this is also supported by Lin and Kuo (2013), that quality is the prime factor for evaluating the suppliers. According to Degraeve and Roodhooft (2006), total cost of ownership is the main criteria for effectively selecting the suppliers. Flexibility/responsiveness/services contributed up to 67.74 percent and location/facilities and assets share is 35.48 percent. Researchers have given least importance to long-term relationship (i.e. 12.90 percent) as a criterion for supplier selection.

3. Rationale of the study

Implementing the digital banking fully, needs the high-end modernization of the whole infrastructure of the banks, which is usually outdated. Banking is the industry, which is centered around the huge customer potential and to keep those customers satisfied and

Focussed attributes						
Quality	Cost/ price	Flexibility/ responsiveness/ services	Location/ facilities and assets	Delivery and reliability	Long-term relationship	Reference
✓	✓	✓	✓	✓		Dickson (1966)
✓	✓		✓	✓		Wind *et al.* (1968)
✓	✓	✓		✓		Lehman and Shaughnessy (1974)
✓	✓		✓	✓		Perreault and Russ (1976)
	✓	✓				Abratt (1986)
✓	✓	✓		✓		Billesbach *et al.* (1991)
✓	✓	✓	✓	✓		Weber *et al.* (1991)
✓	✓			✓		Min and Galle (1999)
✓	✓	✓		✓		Krause *et al.* (2001), Lee *et al.* (2001), Yan and Wei (2002), Gonzalez *et al.* (2004), Svensson (2004)
	✓	✓		✓		Wang *et al.* (2004)
✓		✓	✓		✓	Liu and Hai (2005)
✓	✓	✓		✓		Li *et al.* (2006)
✓	✓	✓	✓	✓	✓	Shyur and Shih (2006)
✓			✓	✓		Gencer and Gurpinar (2006)
✓	✓	✓		✓		Pi and Low (2006)
✓	✓				✓	Jharkharia and Shankar (2007)
✓	✓	✓	✓			Stevenson (2007)
✓	✓			✓		Teeravaraprug (2008)
✓	✓	✓		✓	✓	Ho *et al.* (2009)
✓	✓	✓		✓		Li (2010)
	✓		✓	✓		Betul *et al.* (2011)
✓	✓	✓		✓		Ni and Xu (2011)
✓				✓		Tektas and Aytekin (2011)
	✓	✓		✓		Beşkese and Evecen (2012)
✓	✓	✓	✓	✓		Parthiban *et al.* (2012)
✓	✓		✓			Peng (2012)
✓				✓		Bilisik *et al.* (2012)
✓	✓	✓		✓		Mehralian *et al.* (2012)
✓	✓	✓	✓	✓	✓	Sadeghieh *et al.* (2012)
✓	✓	✓		✓	✓	Hashemi *et al.* (2015)

Note: ✓, particular criteria has been included in the cited study

Table I.
Set of supplier selection attributes

loyal, digitization of the banking activities are very important in this era. Whenever we talk about the modernization in the banking industry, it is the slower industry to accept change. This is the only reason; the traditional banks in the world are losing their monopoly and facing tough competition. The developing countries like India are not able to change their infrastructure due to internal institutional problems and technical barriers.

Digital banking helps to manage the banking data in a smart way and return on investment is substantial. These days more and more customers using online banking services and the banks who are not able to provide the digital services are experiencing increased customer attrition rate and lower business. Banks, which are providing digital services, reduce the number of visits of the customers to the banks that do not add any value.

Either Banks can offer the digital services to their customers directly or they can outsource this to some partners to acquire more competencies while reducing the cost.

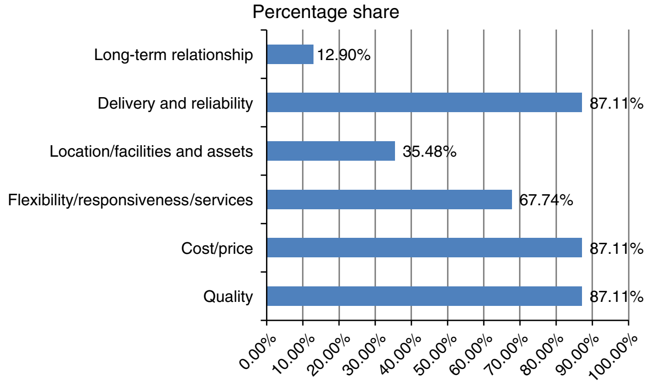


Figure 1. Percentage share of various criteria in previous research

American online banking offered a contract of $117 million to BBVA for digital platform. According to Loh and Venkatraman (1992), outsourcing the information system to the third party started in 1989 when Eastman Kodak handed over its entire data center, networks and microcomputer operation to three external partners. Pearlson (2001) argued the organizations go for this kind of outsourcing, when they realize that information technology is not their strategic advantage. According to Adeleye *et al.* (2004), factors, forcing the outsourcing, are: global competition; downsizing; flatter organizations structure; reducing the costs; improving the quality, service and delivery; improved organizational focus; and increase the flexibility. But, if outsourcing is not done by proper strategic planning and risk evaluation it may results in financial loss, damaged reputation, increased customer attrition and collapse of the business (Adeleye *et al.*, 2004). Therefore, this is very important to evaluate the channels partners keeping in view all the factors and select the best strategic partner. In India, very few studies have been done on selecting the strategic partners in banking industry. Indian commercial banks has just started providing digital online services including: data transformation; multi-channeled reporting; file delivery transactions; transaction initiation, etc. Digital banking is more user friendly and requires fewer efforts to operate and also lower down the cost of providing the banking services to the nation. Some examples of digital banking system in India are like: online messenger; messenger financial center; mobile banking; M-square online banking; messenger integrated payables, etc. Since, we were having very few literature and information regarding the supplier selection in banking industry. Hence, to deal with this uncertain information we have opted grey theory based approach to select the best supplier.

4. Research methodology

Deng discussed grey theory first time in 1982, which includes five major parts: grey prediction; grey relational analysis; grey decision; grey programming; and grey. Here grey theory has been used to select the best supplier out of the various alternatives, by using multiple attributes criteria. From Figure 2, in grey theory we can divide the system into three categories depending upon the degree of information known: black, white and grey systems (Li *et al.*, 2006). If the full information is available with the decision maker, then the system is known as white system; if the information about the system is unknown then it is known as black system. System with partial information is known as grey system.

In grey approach, the decision makers can use the linguistic variables to give their preference on the weights of various attributes and their ratings for different suppliers and then later on these linguistic variables are converted into grey numbers, which are shown with symbol ⊗. Grey number is represented in numerical interval, which shows the uncertain information and is written as $\otimes G$. Grey number can be of three types:

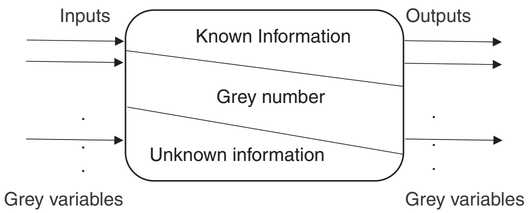
(1) Lower limit grey number: if only lower limit of the grey number can be predicted and is given by $[\underline{G}, \infty)$.

(2) Upper limit grey number: if only upper limit of grey number can be found and is written as $(-\infty, \overline{G}]$.

(3) Interval grey number: if both upper and lower limits can be estimated and is written as $[\underline{G}, \overline{G}]$.

Linguistic variables can be converted into grey numbers by the 1-7 scale shown in Table II and attribute/criteria ratings $\otimes G$ can be given by grey numbers by 1-7 scale shown in Table III.

Using these scales given in Table II and III, the decision makers give different weightage to all the criteria according to their importance and then assign the ratings to these criteria depending upon the performance of the different alternatives. The present study has collected the opinion from five decision makers and then computed the average values in terms of grey numbers. Then we computed the grey decision matrix, which is being further normalized and then multiplied with the criteria weights in order to find out the grey weighted normalized decision table. In the end, grey possibility degree has been calculated to rank the various alternatives. The overall research design, outline and flow of the research has been reflected in the Figure 3.



Source: Li *et al.* (2006)

Figure 2. Concept of grey system

Scale	$\otimes W$
Very low (VL)	[0.0, 0.1]
Low (L)	[0.1, 0.3]
Medium low (ML)	[0.3, 0.4]
Medium (M)	[0.4, 0.5]
Medium high (MH)	[0.5, 0.6]
High (H)	[0.6, 0.9]
Very high (VH)	[0.9, 1.0]

Table II. Scale of attributes weights $\otimes W$

5. Proposed model for supplier selection

Figure 4 highlights the model that is based on the grey approach, which is very useful to select the best supplier out of the various alternatives available in an uncertain information condition. The proposed model constitutes following steps.

Step 1. Analyze the supplier selection problem to find out whether the full information is available or not and to define what kind of variables we are going to use: either linguistic or numerical variables.

Step 2. In step 2 the experts assign the weights to various criteria/attributes depending upon their preferences to each criterion. Assume there are total j attributes ($C1$, $C2$, $C3, \ldots, Cj$) and experts' panel consists of k members, then the weight of jth criteria (C_j) can be calculated as:

$$\otimes W_j = \frac{1}{k}\left[\otimes W_j^1 + \otimes W_j^2 + \ \ldots \ + \otimes W_j^k\right] \tag{1}$$

where $\otimes W_j^k$ ($j = 1, 2, 3, \ldots, n$) is the criterion weight assigned by kth decision maker and can be expressed in terms of grey number as $\otimes W_j^k = [\underline{W}_j^k, \overline{W}_j^k]$.

Step 3. Define the various alternatives out of which we have to pick the best alternative. So, different ratings are made by the decision makers by using the linguistic variables. The rating for ith supplier for the jth attribute can be calculated as:

$$\otimes G_{ij} = \frac{1}{k}\left[\otimes G_{ij}^1 + \otimes G_{ij}^2 + \ \ldots \ + \otimes G_{ij}^k\right] \tag{2}$$

where $\otimes G_{ij}^k = [\underline{G}_{ij}^k, \overline{G}_{ij}^k]$, ($i = 1, 2, 3, \ldots, m; j = 1, 2, 3, \ldots, n$) is the attribute rating value of kth decision maker given in terms of grey number.

Step 4. Compute the grey decision matrix for all suppliers and for all the attributes that will define the rating of various suppliers in terms of linguistic variables as shown

Scale	$\otimes G$
Very poor (VP)	[0, 1]
Poor (P)	[1, 3]
Medium poor (MP)	[3, 4]
Fair (F)	[4, 5]
Medium good (MG)	[5, 6]
Good (G)	[6, 9]
Very good (VG)	[9, 10]

Table III. Scale of attribute ratings $\otimes G$

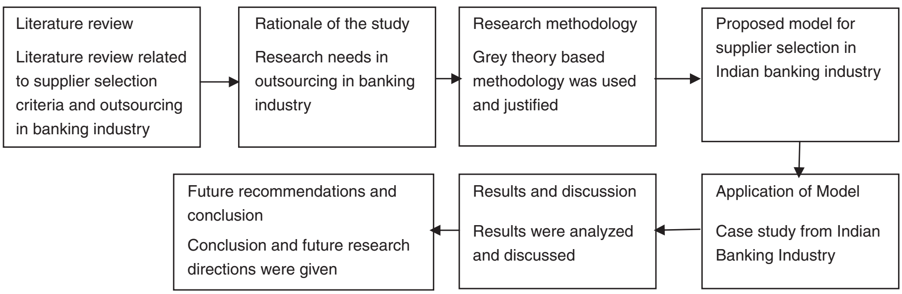


Figure 3. Overall research design, outline and flow of this research

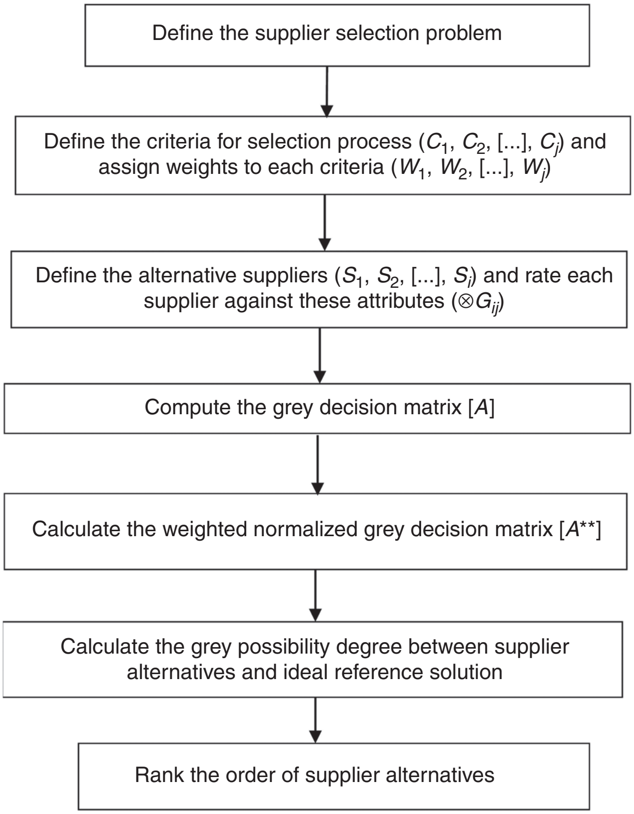


Figure 4.
Proposed grey approach model in supplier selection

in the following matrix:

$$A = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} \ldots \ \ldots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} \ldots \ \ldots & \otimes G_{2n} \\ . & . & . \\ . & . & . \\ . & . & . \\ \otimes G_{m1} & \otimes G_{m2} \ldots \ \ldots & \otimes G_{mn} \end{bmatrix} \tag{3}$$

Step 5. First, calculate the normalized grey decision matrix, by defining the benefit and cost attributes. For benefit attribute the normalized values can be calculated as:

$$\otimes G_{ij}^{*} = \left[\frac{\underline{G}_{ij}}{G_j^{max}}, \frac{\overline{G}_{ij}}{G_j^{max}} \right] \tag{4}$$

$$G_j^{max} = max\, 1 \leqslant i \leqslant m \left\{ \overline{G}_{ij} \right\};$$

For cost attribute, the normalized values can be calculated as:

$$\otimes G^*_{ij} = \left[\frac{G^{min}_j}{\overline{G}_{ij}}, \frac{G^{min}_j}{\underline{G}_{ij}}\right] \quad (5)$$

$$G^{min}_j = min\, 1 \leqslant i \leqslant m\left\{\underline{G}_{ij}\right\}$$

$$A^* = \begin{bmatrix} \otimes G^*_{11} & \otimes G^*_{12} & \cdots & \otimes G^*_{1n} \\ \otimes G^*_{21} & \otimes G^*_{22} & \cdots & \otimes G^*_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes G^*_{m1} & \otimes G^*_{m2} & \cdots & \otimes G^*_{mn} \end{bmatrix} \quad (6)$$

Now to find out the weighted normalized grey decision matrix, multiply Equation (1) with Equation (6):

$$A^{**} = \begin{bmatrix} \otimes V_{11} & \otimes V_{12} & \cdots & \otimes V_{1n} \\ \otimes V_{21} & \otimes V_{22} & \cdots & \otimes V_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \otimes V_{m1} & \otimes V_{m2} & \cdots & \otimes V_{mn} \end{bmatrix} \quad (7)$$

where $\otimes V_{ij} = \otimes G^*_{ij} \times \otimes W_j$

Step 6. Compute the ideal solution for the reference. For m number of supplier alternatives $S = \{S_1, S_2, \ldots, S_m\}$, the ideal referential solution $S^{max} = \{\otimes G^{max}_1, \otimes G^{max}_2, \ldots, \otimes G^{max}_n\}$ can be calculated as:

$$S^{max} = \left\{\left[\underset{1 \leqslant i \leqslant m}{max}\underline{V}_{i1}, \underset{1 \leqslant i \leqslant m}{max}\overline{V}_{i1}\right], \left[\underset{1 \leqslant i \leqslant m}{max}\underline{V}_{i2}, \underset{1 \leqslant i \leqslant m}{max}\overline{V}_{i2}\right], \ldots, \left[\underset{1 \leqslant i \leqslant m}{max}\underline{V}_{in}, \underset{1 \leqslant i \leqslant m}{max}\overline{V}_{in}\right]\right\} \quad (8)$$

Find out the grey possibility degree between the ideal referential supplier alternative S^{max} and the set of suppliers alternatives $S = \{S_1, S_2, \ldots, S_m\}$:

$$P\left\{Si \leqslant S^{max}\right\} = \frac{1}{n}\sum_{j=1}^{n} P\left\{\otimes V_{ij} \leqslant \otimes G^{max}_j\right\} \quad (9)$$

For two grey numbers, the possibility degree of $\otimes G_1 \leqslant \otimes G_2$ can be expressed as follows:

$$P\{\otimes G_1 \leqslant \otimes G_2\} = max\frac{\left(0, L^* - max(0, \overline{G}1 - \underline{G_2}\right)}{L^*} \quad (10)$$

where $L^* = L(\otimes G_1) + L(\otimes G_2)$.

Step 7. Rank all the suppliers according to their values of $P\{S_i \leqslant S^{max}\}$. Smaller the value better will be the ranking of that supplier. So, by this approach we can we can find the grey possibility degree for every alternative and then can pick the best alternative.

6. Application: case study from Indian banking industry

The proposed model of supplier selection using grey theory approach has been implemented into the banking industry. This case study focussed on selecting the best supplier for "optimizing digital banking" out of the four available suppliers. We have conducted the interviews of managers, who used to evaluate and select the suppliers and they have given their preferences in terms of linguistic variables according to the evaluation criteria.

Step 1. In order to achieve the full gains of digital optimization, it is very important to understand how operations, sales, marketing and servicing processes can be improved to better meet the needs of the digital customer. This requires "agile" change management, strong stakeholder skills and the ability to embed a culture of rapid continuous improvement. Therefore, banking industry needs to select the best strategic partner who can provide the digital optimization banking solution and can help in improving the operations continuously.

Step 2. As reported in earlier research and the consultation of bank managers, we have suggested the following six main attributes, which are very important for supplier selection in banking industry in Indian context. These are: first, quality (C_1); second, cost/price (C_2); third, flexibility/responsibility/service level (C_3); fourth, location/assets/facilities (C_4); fifth, delivery/reliability (C_5); and sixth, long-term relationship (C_6).

A panel of five decision makers (D_1, D_2, D_3, D_4 and D_5) gave their preferences in terms of linguistic variables which are being converted into grey numbers and as per Equation (1) the values of attribute weights had been calculated as shown in the following Table IV.

Step 3. Here, four supplier alternatives for "optimizing digital banking" were identified. Then again, the committee of five decision makers assigns the attributes rating values for all the four supplier alternatives in terms of linguistic variables, which are converted into grey number. According to Equation (2), we have calculated the results of attribute rating values and are shown in the following Table V.

Step 4. From Equation (3), we have calculated the following grey decision table for all the suppliers as shown in Table VI.

Step 5. In the present study, we have only one cost attribute, i.e. cost/price (C_2) and rest all four attributes are benefit attributes. We have used Equation (4) to find the normalized values for benefit attributes and Equation (5) for cost attribute. According to Equation (6), the following normalized grey decision Table VII is given.

Now, to find out the weighted grey normalized decision table, multiply the criteria weights table with the normalized grey decision table as per Equation (7) and results are shown in the following Table VIII.

C_j	D_1	D_2	D_3	D_4	D_5	$\otimes W_j$
C_1	H	VH	VH	H	H	[0.72, 0.94]
C_2	M	MH	MH	M	MH	[0.46, 0.56]
C_3	VH	VH	VH	H	VH	[0.84, 0.98]
C_4	M	MH	MH	MH	M	[0.46, 0.56]
C_5	VH	H	H	H	VH	[0.72, 0.94]
C_6	H	H	MH	M	MH	[0.52, 0.70]

Table IV.
Criteria weights

Criteria (C_j)	S_i	D_1	D_2	D_3	D_4	D_5	$\otimes G_{ij}$
(i) *Quality* (C_1)							
C_1	S_1	G	G	MG	G	F	[5.4, 7.6]
	S_2	MG	MG	F	MG	F	[4.6, 5.6]
	S_3	VG	G	G	G	MG	[6.4, 8.6]
	S_4	G	VG	VG	G	MG	[7.0, 8.8]
(ii) *Cost/price* (C_2)							
C_2	S_1	G	MG	MG	MG	F	[5.0, 6.4]
	S_2	MG	F	F	MG	F	[4.4, 5.4]
	S_3	G	VG	G	G	G	[6.6, 9.2]
	S_4	MG	MG	G	MG	VG	[6.0, 7.4]
(iii) *Flexibility/responsibility/service level* (C_3)							
C_3	S_1	MP	F	F	F	MG	[4.0, 5.0]
	S_2	G	G	F	MG	G	[5.4, 7.6]
	S_3	G	VG	VG	MG	G	[7.0, 8.8]
	S_4	MG	MG	F	G	MG	[5.0, 6.4]
(iv) *Location/assets/facility* (C_4)							
C_4	S_1	F	MP	MP	MG	F	[3.8, 4.8]
	S_2	F	MG	G	G	MG	[5.2, 7.0]
	S_3	G	G	G	MG	F	[5.4, 7.6]
	S_4	VG	G	MG	MG	G	[6.2, 8.0]
(v) *Delivery/reliability* (C_5)							
C_5	S_1	G	MG	G	G	MG	[5.6, 7.8]
	S_2	G	G	MG	F	G	[5.4, 7.6]
	S_3	F	MG	MG	MG	F	[4.6, 5.6]
	S_4	G	MG	VG	VG	G	[7.0, 8.8]
(vi) *Long-term relationship* (C_6)							
C_6	S_1	MG	MG	G	G	MG	[5.4, 7.2]
	S_2	G	G	VG	VG	G	[7.2, 9.4]
	S_3	F	MG	G	G	MG	[5.2, 7.0]
	S_4	G	G	G	MG	F	[5.4, 7.6]

Table V. Ratings of suppliers for different attributes

S_i	C_1	C_2	C_3	C_4	C_5	C_6
S_1	[5.4, 7.6]	[5.0, 6.4]	[4.0, 5.0]	[3.8, 4.8]	[5.6, 7.8]	[5.4, 7.2]
S_2	[4.6, 5.6]	[4.4, 5.4]	[5.4, 7.6]	[5.2, 7.0]	[5.4, 7.6]	[7.2, 9.4]
S_3	[6.4, 8.6]	[6.6, 9.2]	[7.0, 8.8]	[5.4, 7.6]	[4.6, 5.6]	[5.2, 7.0]
S_4	[7.0, 8.8]	[6.0, 7.4]	[5.0, 6.4]	[6.2, 8.0]	[7.0, 8.8]	[5.4, 7.6]

Table VI. Grey decision table

S_i	C_1	C_2	C_3	C_4	C_5	C_6
S_1	[0.614, 0.864]	[0.688, 0.88]	[0.455, 0.568]	[0.475, 0.6]	[0.636, 0.886]	[0.575, 0.766]
S_2	[0.523, 0.636]	[0.815, 1.0]	[0.614, 0.864]	[0.65, 0.875]	[0.614, 0.864]	[0.766, 1.0]
S_3	[0.727, 0.977]	[0.478, 0.667]	[0.795, 1.0]	[0.675, 0.95]	[0.523, 0.636]	[0.553, 0.745]
S_4	[0.796, 1.0]	[0.595, 0.733]	[0.568, 0.727]	[0.775, 1.0]	[0.796, 1.0]	[0.575, 0.809]

Table VII. Normalized grey decision table

Step 6. According to Equation (8), ideal supplier S^{max} a referential alternative is calculated as follows:

$$S^{max} = \{[0.573, 0.94], [0.375, 0.56], [0.668, 0.98], [0.357, 0.56], [0.573, 0.94], [0.398, 0.70]\}$$

According Equation (10), we have calculated the grey possibility degree between the four set of alternative suppliers ($S_i = S_1$, S_2, S_3, S_4) and the ideal referential supplier alternative S^{max} and the detailed calculations are given in the end of this paper:

$$P[S_1 \leqslant S^{max}] = \frac{1}{6}[P\{[0.442, 0.812] \leqslant [0.573, 0.94]\} + P\{[0.317, 0.493] \leqslant [0.375, 0.56]\} + P\{[0.382, 0.557] \leqslant [0.668, 0.98]\} + P\{[0.219, 0.336] \leqslant [0.357, 0.56]\} + P\{[0.457, 0.833] \leqslant [0.572, 0.94]\} + P\{[0.299, 0.536] \leqslant [0.398, 0.70]\}] \quad (11)$$

$$P[S_2 \leqslant S^{max}] = \frac{1}{6}[P\{[0.377, 0.598] \leqslant [0.573, 0.94]\} + P\{[0.375, 0.56] \leqslant [0.375, 0.56]\} + P\{[0.516, 0.847] \leqslant [0.668, 0.98]\} + P\{[0.299, 0.49] \leqslant [0.357, 0.56]\} + P\{[0.442, 0.812] \leqslant [0.572, 0.94]\} + P\{[0.398, 0.70] \leqslant [0.398, 0.70]\}] \quad (12)$$

$$P[S_3 \leqslant S^{max}] = \frac{1}{6}[P\{[0.523, 0.918] \leqslant [0.573, 0.94]\} + P\{[0.219, 0.374] \leqslant [0.375, 0.56]\} + P\{[0.668, 0.98] \leqslant [0.668, 0.98]\} + P\{[0.311, 0.532] \leqslant [0.357, 0.56]\} + P\{[0.377, 0.598] \leqslant [0.572, 0.94]\} + P\{[0.288, 0.522] \leqslant [0.398, 0.70]\}] \quad (13)$$

$$P[S_4 \leqslant S^{max}] = \frac{1}{6}[P\{[0.573, 0.94] \leqslant [0.573, 0.94]\} + P\{[0.274, 0.411] \leqslant [0.375, 0.56]\} + P\{[0.477, 0.713] \leqslant [0.668, 0.98]\} + P\{[0.357, 0.56] \leqslant [0.357, 0.56]\} + P\{[0.572, 0.94] \leqslant [0.572, 0.94]\} + P\{[0.299, 0.566] \leqslant [0.398, 0.70]\}] \quad (14)$$

Table VIII. Grey weighted normalized decision table

S_i	C_1	C_2	C_3	C_4	C_5	C_6
S_1	[0.442, 0.812]	[0.317, 0.493]	[0.382, 0.557]	[0.219, 0.336]	[0.458, 0.833]	[0.299, 0.536]
S_2	[0.377, 0.598]	[0.375, 0.56]	[0.516, 0.847]	[0.299, 0.49]	[0.442, 0.812]	[0.398, 0.70]
S_3	[0.523, 0.918]	[0.22, 0.374]	[0.668, 0.98]	[0.311, 0.532]	[0.377, 0.598]	[0.288, 0.522]
S_4	[0.573, 0.94]	[0.274, 0.411]	[0.477, 0.713]	[0.357, 0.56]	[0.573, 0.94]	[0.299, 0.566]

7. Results and discussion

So, the results of grey possibility degree are:

$$P\left[S_1 \leqslant S^{max}\right] = 0.790 \quad P\left[S_2 \leqslant S^{max}\right] = 0.67$$

$$P\left[S_3 \leqslant S^{max}\right] = 0.727 \quad P\left[S_4 \leqslant S^{max}\right] = 0.669$$

Supplier alternatives are ranked as per the values of grey possibility degree: when $P[S \leqslant S^{max}]$ is smaller, the ranking order of S is better. Otherwise, the ranking order is worse. The ranking of the various suppliers as per their score is given as below:

$$S_4 > S_2 > S_3 > S_1$$

Therefore, we can infer that S_4 is the best supplier out of the various alternatives available and S_2 is the next best option, as reflected in the Figure 5. Grey theory based

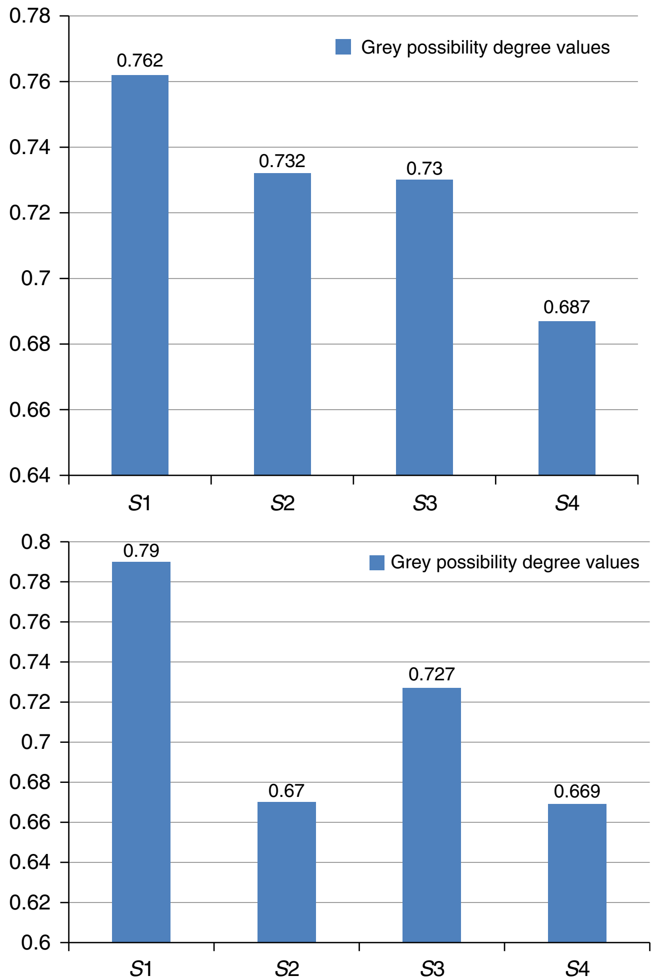


Figure 5.
Grey possibility degree chart

supplier selection model in banking industry for outsourcing the services of "optimizing digital banking" can solve the problem of supplier selection with incomplete information. The grey theory model has universal significance in supplier selection problems under insufficient information and includes the evaluation indicators, both quantitative and qualitative environment.

8. Future research directions and conclusion

To select the supply chain partners is the most important process for any organization, hence, it must be considered logically and rationally. This is the only reason that for many years supplier selection has been evaluated by researchers using various experimental and analytical techniques.

8.1 Practical implications

This paper proposed an MADM model based on grey theory for optimal supplier selection in context of Indian banking industry. This optimal selection helps a lot to provide the best supplier for "optimizing digital banking" services under uncertainty. Since the infrastructure of Indian banking, system is not so strong due to the lack of implementation of latest technology, hence, it is very much desirable to outsource the digital banking system to some external partner. This paper is very close to the actual implementation of grey theory in supplier selection, where we can select the best single alternative. Since, in India the outsourcing in this field has not been explored fully, so we do not have the full information about the selection process, vendors and factors of selection. Hence, grey theory approach is the best methodology in the situation like this where we do not have enough information and we have to make decision in uncertainty.

8.2 Future research direction

This paper can be extended into the field where multiple-supplier selection is required, like in manufacturing sector where we cannot rely always on single supplier. Therefore, in that case we need to pick more than one best alternatives. Moreover, sensitivity analysis can be done in order to find out the influence of criteria weights on the best alternate and can see the variations in the preferences order by changing the weights of the criteria.

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Appendix

$$P\left[S_1 \leqslant S^{max}\right] = \frac{1}{6}\Big[P\{[0.442, 0.812] \leqslant [0.573, 0.94]\} + P\{[0.495, 0.827] \leqslant [0.495, 0.827]\} + P\{[0.382, 0.557] \leqslant [0.668, 0.98]\} + P\{[0.219, 0.336] \leqslant [0.357, 0.56]\} + P\{[0.457, 0.833] \leqslant [0.572, 0.94]\} + P\{[0.299, 0.536] \leqslant [0.398, 0.70]\}\Big] \tag{A1}$$

$$= \frac{1}{6}\left[\frac{max(0, 0.737 - max(0, 0.239)}{0.737} + \frac{max(0, 0.361 - max(0, 0.118)}{0.361} + \frac{max(0, 0.487 - max(0, -0.423)}{0.487} + \frac{max(0, 0.32 - max(0, -0.021)}{0.32} + \frac{max(0, 0.744 - max(0, 0.261)}{0.744} + \frac{max(0, 0.539 - max(0, 0.138)}{0.539}\right]$$

$$= \frac{1}{6}[0.676 + 0.673 + 1 + 1 + 0.649 + 0.744] = 0.790]$$

$$P\left[S_2 \leqslant S^{max}\right] = \frac{1}{6}\Big[P\{[0.377, 0.598] \leqslant [0.573, 0.94]\} + P\{[0.375, 0.56] \leqslant [0.375, 0.56]\} + P\{[0.516, 0.847] \leqslant [0.668, 0.98]\} + P\{[0.299, 0.49] \leqslant [0.357, 0.56]\} + P\{[0.442, 0.812] \leqslant [0.572, 0.94]\} + P\{[0.398, 0.70] \leqslant [0.398, 0.70]\}\Big] \tag{A2}$$

$$
\begin{aligned}
&= \frac{1}{6}\left[\frac{max(0, 0.588 - max(0, 0.025)}{0.588} + \frac{max(0, 0.37 - max(0, 0.185)}{0.37}\right.\\
&\quad + \frac{max(0, 0.643 - max(0, -0.179)}{0.643} + \frac{max(0, 0.394 - max(0, -0.133)}{0.394}\\
&\quad \left. + \frac{max(0, 0.738 - max(0, 0.24)}{0.738} + \frac{max(0, 0.604 - max(0, 0.302)}{0.604}\right]\\
&= \frac{1}{6}[0.958 + 0.5 + 0.722 + 0.662 + 0.675 + 0.5] = 0.67
\end{aligned}
$$

$$
\begin{aligned}
P\left[S_3 \leqslant S^{max}\right] = \frac{1}{6}\Big[& P\{[0.523, 0.918] \leqslant [0.573, 0.94]\} + P\{[0.219, 0.374]\\
&\leqslant [0.375, 0.56]\} + P\{[0.668, 0.98] \leqslant [0.668, 0.98]\}\\
&+ P\{[0.311, 0.532] \leqslant [0.357, 0.56]\} + P\{[0.377, 0.598]\\
&\leqslant [0.573, 0.94]\} + P\{[0.288, 0.522] \leqslant [0.398, 0.70]\}\Big] \qquad \text{(A3)}
\end{aligned}
$$

$$
\begin{aligned}
&= \frac{1}{6}\left[\frac{max(0, 0.762 - max(0, 0.345)}{0.762} + \frac{max(0, 0.339 - max(0, -0.001)}{0.339}\right.\\
&\quad + \frac{max(0, 0.624 - max(0, -0.312)}{0.624} + \frac{max(0, 0.424 - max(0, -0.175)}{0.424}\\
&\quad \left. + \frac{max(0, 0.589 - max(0, 0.026)}{0.589} + \frac{max(0, 0.536 - max(0, 0.124)}{0.536}\right]\\
&= \frac{1}{6}[0.547 + 1 + 0.587 + 0.956 + 0.769 + 0.5] = 0.727
\end{aligned}
$$

$$
\begin{aligned}
P\left[S_4 \leqslant S^{max}\right] = \frac{1}{6}\Big[& P\{[0.573, 0.94] \leqslant [0.573, 0.94]\} + P\{[0.274, 0.411]\\
&\leqslant [0.375, 0.56]\} + P\{[0.477, 0.713] \leqslant [0.668, 0.98]\}\\
&+ P\{[0.357, 0.56] \leqslant [0.357, 0.56]\} + P\{[0.572, 0.94]\\
&\leqslant [0.572, 0.94]\} + P\{[0.299, 0.566] \leqslant [0.398, 0.70]\}\Big]. \qquad \text{(A4)}
\end{aligned}
$$

$$
\begin{aligned}
&= \frac{1}{6}\left[\frac{max(0, 0.734 - max(0, 0.367)}{0.734} + \frac{max(0, 0.322 - max(0, 0.036)}{0.322}\right.\\
&\quad + \frac{max(0, 0.548 - max(0, -0.045)}{0.548} + \frac{max(0, 0.406 - max(0, -0.203)}{0.406}\\
&\quad \left. + \frac{max(0, 0.736 - max(0, 0.368)}{0.736} + \frac{max(0, 0.569 - max(0, 0.168)}{0.569}\right]\\
&= \frac{1}{6}[0.5 + 0.888 + 0.918 + 0.5 + 0.5 + 0.705] = 0.669
\end{aligned}
$$

Therefore, the results of grey possibility degree are:

$$P\left[S_1 \leqslant S^{max}\right] = 0.79 \quad P\left[S_2 \leqslant S^{max}\right] = 0.67$$

$$P\left[S_3 \leqslant S^{max}\right] = 0.727 \quad P\left[S_4 \leqslant S^{max}\right] = 0.669$$

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