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A modified grey-based decision-making approach to the supplier selection problem for the automobile industry

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ABSTRACT

BACKGROUND AND OBJECTIVES: In the manufacturing sector, selecting the most suitable supplier is a critical strategic decision. In today's context, where sustainability has become a key performance indicator, the automotive industry emphasises supplier selection strategies that align with traditional economic criteria, as well as environmental and social sustainability. Sustainable supplier selection is a complex decision-making process. The objective of this article is to simplify the selection of a supplier, considering all three sustainability factors as important through the expertise of experts.

METHODS: In this study, a grey-based decision-making approach is employed. To address ambiguity and capture subjective judgments effectively, a linguistic scale-based questionnaire is utilized for both supplier evaluation and criteria weight determination. The model converts the expert rating into a grey number-based rating for the criteria weight and the supplier performance rating on each of the identified criteria. The proposed method computes the relative closeness index. The evaluated relative closeness index ranks the best suppliers that are closest to the ideal positive supplier. To demonstrate the applicability and effectiveness of the proposed methodology, a case study from the automotive industry is presented.

FINDINGS: The proposed method employs grey numbers to evaluate the criteria weights and grey numbers for supplier rating. Using modified grey relational analysis, the suppliers are ranked. The criteria identified by the experts were both quantitative and qualitative. The best sustainable supplier is supplier 4, with the relative closeness index farthest from the possibility degree 0.5, with a value of 0.7622. A comparative analysis was conducted, revealing that the top three ranked suppliers demonstrated consistent positions across the evaluated methods.

CONCLUSION: Suppliers from the automobile sector were evaluated using distinct criteria. Industry experts prioritized traditional operational factors such as technical capability, product quality, delivery reliability, workplace safety, and employee health. Furthermore, environmental performance and sustainability were also rated favourably, highlighting the growing importance of environmentally sustainable practices. The study emphasizes the reduction in computational complexity associated with making informed decisions in complex scenarios.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
33	2	15

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INTRODUCTION

Supply chain management plays a vital role in an organisation (Gede, 2025). In response to escalating environmental challenges and the global call for sustainable development, organisations are increasingly prioritising environmentally responsible practices across their operations. One critical area experiencing this shift is supply chain management (Wu *et al*., 2021). Sustainability is achieved through an optimal balance among economic, environmental, and social dimensions, all of which must align with and support the overarching goals of the organization (Afrasiabi *et al*., 2022). The initial phase in SCM is the selection of appropriate suppliers, a process that necessitates the collective identification and evaluation of relevant environmental, social, and economic criteria by decision-makers (Aslani *et al*., 2020). Post-pandemic period, purchasing managers have increasingly incorporated Environmental Management Systems (EMS) as a critical evaluation criterion (Govindan *et al*., 2012). Growing environmental concerns—such as pollution reduction, energy efficiency, and long-term ecological sustainability—have further driven the adoption of Green Supply Chain Management (GSCM) practices within procurement processes (Zimmer *et al*., 2015). The integration of social and environmental sustainability-related criteria alongside traditional supplier selection parameters is increasingly being aligned with an organization's Sustainable Development Goals (SDGs), often guided by expert input and strategic recommendations (Chauhan *et al.,* 2022). The formulation and execution of strategic supply chain decisions like supplier selection typically involve contributions from multiple stakeholders, reflecting a diversity of professional perspectives and expertise (Shepherd *et al.,* 2024). One of the techniques used by researchers and practitioners from 1970 to date is the Multi-Criteria Decision-Making (MCDM) method, which has been extensively employed across diverse research domains due to its effectiveness in handling complex evaluation problems involving multiple criteria. (Chen & Yang, 2011). Many researchers have supported the use of MCDM in making the right decision in various domains, like employee recruitment selection process using a weighted method and grey relational analysis (Megawaty *et al.,* 2025), in ranking the factors that affect social media marketing in urban cyberspace (M. Montezarhojat, Y. Vakil Alroaia, A. Rashidi), in selecting a reverse logistics provider in a closed loop supply chain (Khodaverdi & Hashemi, 2015). These methods have proven to be consistently reliable and effective, offering a range of ranked solutions tailored to specific decision-making problems, each reflecting varying levels of significance. This technique helps in selecting the best-ranked supplier among multiple suppliers, evaluating the alternatives, and ranking them. There are various techniques like Analytical Hierarchy Process (AHP), TOPSIS, SAW, MOORA, VIKOR, ELECTRE, GRA, and many more. It is used in many sectors where decision support is needed. Yang & Chen. (2006), Integrated AHP and Grey Relational Analysis (GRA) to develop a method combining the qualitative and quantitative methods to select the best supplier. Eshghizadeh. (2017) used AHP and ANP to estimate the potential of flooding. Research conducted by Kuo *et al.,* (2008) has combined Data Envelopment Analysis (DEA) and GRA for the facility layout and dispatch rules selection problem. The approach is based on Intuitionistic Fuzzy Set (IFS) and GRA to select green suppliers in an uncertain environment. (Bali *et al.,* 2013; Ahmadi *et al*., 2016) integrated AHP and GRA for the telecom industry to evaluate the sustainable supplier. According to De Oliveira *et al*., (2023), decision-making could be influenced by decision makers' vagueness, so a Hesitant Fuzzy Linguistic VIKOR (HFLVIKOR) method is used to evaluate the supplier. Ali & Zhang. (2023) proposed Fuzzy Analytical Hierarchy Process (FAHP), Multi-Objective Linear Programming (MOLP), and Fuzzy Compromise Programming (FCP) to understand the economic and environmental aspects, including foreign transportation risk post-COVID in the textile industry. Sudarsanam *et al.,* (2022) integrated expert opinion in criteria weights computed with AI and rated the supplier on seven KPIS; the top ten suppliers are identified for the automobile industry. K.Fahimi *et al.,* (2023) integrated TOPSIS and AHP to construct the organizational excellence model. A review of the existing literature reveals that numerous researchers have proposed various Multi-Criteria Decision-Making (MCDM) methods to facilitate the selection of suitable suppliers. While methods such as the AHP enable comparative evaluation of alternatives, many integrated frameworks combining two or more MCDM techniques have also been developed, which often lead to increased computational complexity.

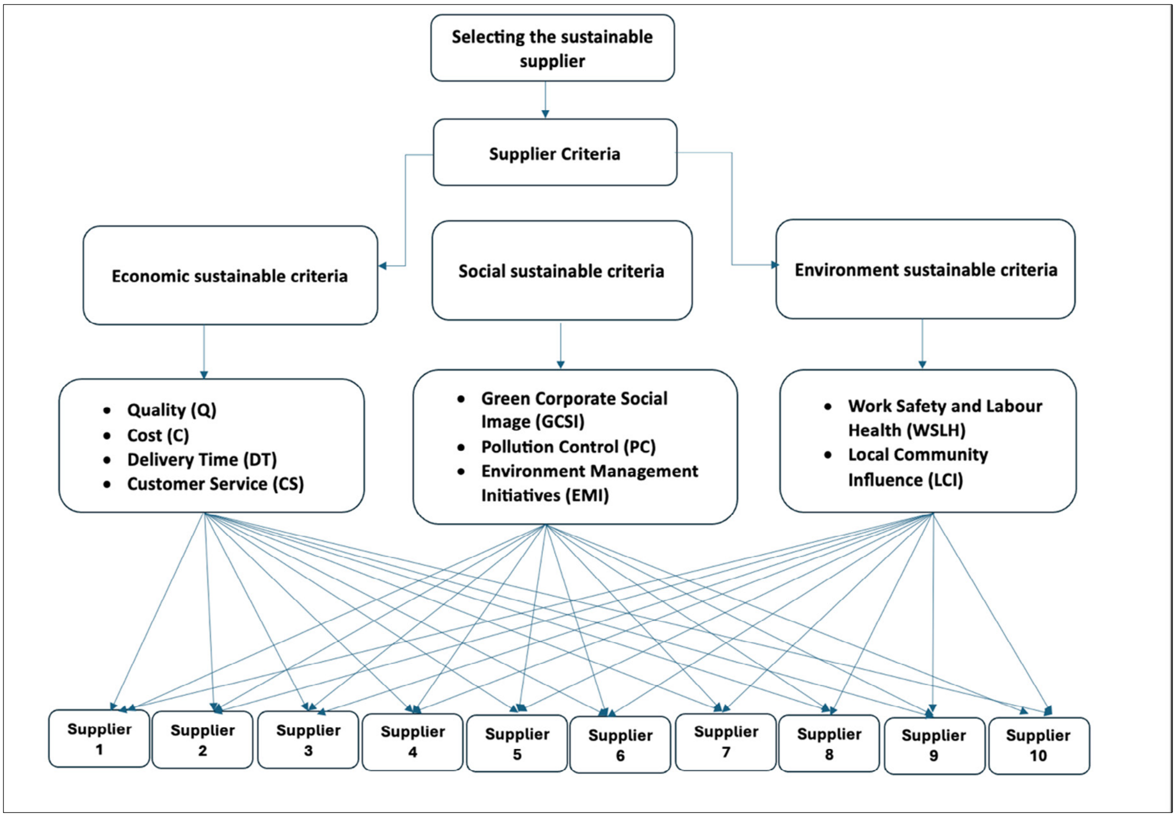

Fig. 2: Proposed Framework for criteria

Although fuzzy set theory has been applied to address uncertainties in decision-making, its implementation tends to be computationally intensive. To overcome these limitations, the present study employs grey set theory, which offers a reduction in ambiguity through the use of linguistic ratings, while also ensuring lower computational effort and greater methodological flexibility. The proposed approach utilises grey-based computation for determining criteria weights and ranking suppliers, thereby providing an efficient and effective supplier evaluation model. In this study, Fig. 1. The framework identifies the most suitable sustainable supplier for the selected industry based on environmental management systems. Relevant criteria for supplier evaluation are determined through expert input and a review of existing literature.

MATERIALS AND METHODS

Study area

The study was conducted on 17th March 2025, in the renowned automobile industry in Chennai city, Tamil Nadu, India. It is one of the development centres and is engaged in shared development services.

Survey design and data collection

The selection of the most suitable supplier remains a critical aspect of the evaluation process. This study employs expert input to identify relevant selection criteria through direct interviews. A purposive sampling technique is adopted, targeting decision-makers from the supply chain department. To minimize ambiguity in responses, a linguistic scale-based questionnaire is utilised during data collection. The experts evaluate the suppliers based on the criteria they have identified.

Sustainability criteria approach

In 1966, Dickson proposed 23 important criteria in vendor selection, and for a long period, supplier selection has predominantly focused on conventional criteria such as cost, delivery performance, and

Table 1: Sustainable supplier selection criteria

S No	Sustainability Selection	Criteria
1	Economical sustainability	Q
		C
		DT
		TC
2	Environmental sustainability	GCSI
		PC
		EMI
3	Social sustainability	WSLH
		LCI

material quality in economic sustainability. Later research identified various other criteria, like supplier reserve capacity, process capability (Kannan and Tan, 2002), and Technology development (Day,1994) that would support one of the pillars of sustainability. To achieve social sustainability, an organization must adopt social responsibility in supporting all its stakeholders. Safety regulations for the employees, health concerns, community involvement, and protecting the environment. (Carter and Jennings 2002). This study categorises sustainable supplier criteria into three key dimensions: economic, environmental, and social sustainability. Economic sustainability criteria assess the supplier's capabilities and financial performance. Social sustainability criteria focus on both internal and external social practices implemented by the supplier. Environmental sustainability selection criteria are about the environmental performance and practices that the supplier is aware of to protect the environment (Zimmer *et al*., 2015). Supplier assessments began to consider all three pillars of sustainability in the decision-making process. The criteria for selecting the best supplier were identified by the experts based on the Triple Bottom Line (TBL) framework, incorporating social, environmental, and economic dimensions into the evaluation of sustainability (Zimmer *et al.,* 2015). Many researchers identified the significance of the Quality (Q), Cost (C), and Delivery Time (DT) (Afrasiabi *et al*., 2022; Flores, 2021; Menon and Ravi, 2022; Althaqafi, 2023). Technology Capability (Govindan *et al.*, 2012; Haseli et al., 2021; Flores, 2021) is a vital economic indicator in evaluating the suppliers in their study. Zimmer *et al*., (2015) reviewed publications between 1977 and 2014, focusing on sustainable supplier management, where around 60 papers developed a conceptual framework on environmental supplier selection. Green Corporate Social Image (GCSI), Ahmadi *et al.,* (2016), is an approach towards the environmental sustainability of supplier selection based on the reputation they are ready to build in the corporate image and social agreement. Emroozi *et al.,* (2023) suggest that Pollution Control (PC) is one of the most important criteria in environmental stability, where the air quality, water waste, and chemical emission of the supplier are considered. Environmental Management Initiatives (EMI) (Haseli *et al.,* 2021; Flores, 2021; Menon and Ravi, 2022) are innovative initiatives of the supplier for the well-being of the stakeholder and the support activities that show the commitment towards the environment. Work Safety and Labour Health (WSLH) (Ahmadi *et al.,* 2016; Govindan *et al.,* 2012) considers safety management and stakeholders' rights in social factors. (Aslani *et al.,* 2020; Govindan *et al.,* 2012) studies demonstrated the importance of the welfare of the local community through healthcare, community projects, and economic welfare that could uplift the stakeholders of the community through the criteria Local Community Influence (LCI). Table 1 contains the sustainable supplier criteria. In this study, Fig. 2. The framework identifies the most suitable sustainable supplier criteria identified by the experts.

GRA

In 1982, Deng proposed the grey system theory; the essential content of grey set theory is grey generating space, grey forecasting, grey decision making, and so on (Deng, 1989) In grey relational analysis, grey generally represents the unknown information, where black represents that not all the information is available, and white is when there is all the needed information is available. Missed or fuzzy, poor, or incomplete information is

Table 2: Basic operations

S No	Basic Operation		Equation
1	Addition	$\otimes Gr_1 + \otimes Gr_2 = [\underline{Gr_1} + \underline{Gr_2}, \overline{Gr_1} + \overline{Gr_2}]$	(5)
2	Subtraction	$\otimes Gr_1 - \otimes Gr_2 = [\underline{Gr_1} - \overline{Gr_2}, \overline{Gr_1} - \underline{Gr_2}]$	(6)
3	Multiplication	$\otimes Gr_1 \times \otimes Gr_2 = [\min(\underline{Gr_1 Gr_2}, \underline{Gr_1}\overline{Gr_2}, \overline{Gr_1}\underline{Gr_2}, \overline{Gr_1 Gr_2}), \max(\underline{Gr_1 Gr_2}, \underline{Gr_1}\overline{Gr_2}, \overline{Gr_1}\underline{Gr_2}, \overline{Gr_1 Gr_2})]$	(7)
4	Division	$\otimes Gr_1 \div \otimes Gr_2 = [\underline{Gr_1}, \overline{Gr_1}] \times \left[\frac{1}{\underline{Gr_2}}, \frac{1}{\overline{Gr_2}}\right]$	(8)

Table 3 Scenarios on their relationships

S No	Scenario	Meaning	Denoted as	Possibility Degree
1	$\underline{Gr_1} = \underline{Gr_2}$ and $\overline{Gr_1} = \overline{Gr_2}$	$\otimes Gr_1$ is absolutely equal to $\otimes Gr_2$	$\otimes Gr_1 \cong \otimes Gr_2$.	$P\{\otimes Gr_1 \leq \otimes Gr_2\} = 0.5$
2	$\underline{Gr_2} > \overline{Gr_1}$	$\otimes Gr_2$ is larger than $\otimes Gr_1$.	$\otimes Gr_2 > \otimes Gr_1$	$P\{\otimes Gr_1 \leq \otimes Gr_2\} = 1$
3	$\overline{Gr_2} < \underline{Gr_1}$	$\otimes Gr_2$ is smaller than $\otimes Gr_1$.	$\otimes Gr_2 < \otimes Gr_1$	$P\{\otimes Gr_1 \leq \otimes Gr_2\} = 0$
4	If grey numbers have an overlapping intervals	$\otimes Gr_2$ is larger than $\otimes Gr_1$ $\otimes Gr_2$ is smaller than $\otimes Gr_1$	$\otimes Gr_2 > \otimes Gr_1$. $\otimes Gr_2 < \otimes Gr_1$.	$P\{\otimes Gr_1 \leq \otimes Gr_2\} > 0.5$ $P\{\otimes Gr_1 \leq \otimes Gr_2\} < 0.5$

called the grey system (Chakraborty *et al.,* 2023). It measures the relational degree of the factors. In GRA, the grey relational grade (GRG) is represented as the correlation between a set of experimental results and the ideal value for multiple performance characteristics. The higher the GRG, the stronger the correlation (Chakraborty *et al.,* 2023). Multi-attribute decision making is converted into a single-attribute decision-making problem, so the comparison of the attributes is turned into a single value. In Table 4. The GRA method is used in various sectors like facility layout problems, dispatching rule selection problems, and time series data (Kuo *et al.,* 2008). Grey theory considers the condition of vagueness and fuzziness. (G. Li *et al.*, 2007).

Definition 1: Grey theory is applied when information is known, and some information is unknown. The unknown information is described in terms of grey numbers. A grey number operation is defined on sets of intervals instead of individual real numbers.

Definition 2: The grey number is a number having uncertain information. The numbers are represented in the interval [a,b] where ‘a’ is the lower limit and ‘b’ is the upper limit. The interval represents the possible range of values for the uncertain data. A degree of uncertainty is associated with linguistic ratings, and they can be converted into interval values, such as grey numbers. It is generally represented as

$\otimes G$, where $\otimes G = G|_{\underline{\mu}}^{\bar{\mu}}$ (1)

Definition 3: The definition of the lower limit grey number is

$\otimes G_l = [\underline{G}, \infty)$ (2)

Definition 4: The upper limit grey number is described as

$\otimes G_u = (-\infty, \overline{G}]$ (3)

Definition 5: With estimations of the lower limit of G and upper limit of G available, a grey number can be represented as a grey number interval as

$\otimes G = [\underline{G}, \overline{G}]$ (4)

Definition 6: The grey number operations, such as addition, subtraction, multiplication, and division, are performed on the interval-valued grey numbers. G.Li *et al.*, (2006) defined the operations on grey numbers where $\otimes Gr_1 = [\underline{Gr_1}, \overline{Gr_1}]$ and $\otimes Gr_2 = [\underline{Gr_2}, \overline{Gr_2}]$ are grey numbers, and the basic operations are shown in

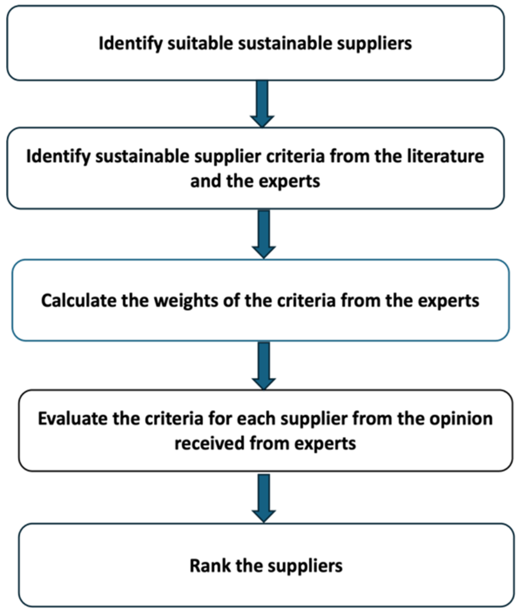

Fig. 1: Sustainable Supplier Framework

Table 2.

Definition 7: The length of grey number ⊗ G is

$$L(\otimes G) = \overline{G} - \underline{G} \quad (9)$$

Definition 8:The possibility degree between two grey numbers

$\otimes Gr_1 = [\underline{Gr_1}, \overline{Gr_1}]$ and $\otimes Gr_2 = [\underline{Gr_2}, \overline{Gr_2}]$

$$P\{\otimes Gr_1 \leq \otimes Gr_2\} = \frac{\max\left((0,\ L^* - \max\left(0,\ \overline{Gr_1} - \underline{G_{r2}}\right)\right)}{L^*} \quad (10)$$

where $L^* = L(\otimes Gr_1) + L(\otimes Gr_2)$.

Based on the position of grey number intervals $\otimes Gr_1, \otimes Gr_2$, there could be four different scenarios in the relationship between them, which are described in Table 3.

Proposed methodology

Modified GRA

The objective of modified grey relational analysis is to simply the computation and order the preference of the best supplier by using relative closeness to the positive ideal and negative ideal suppliers. The RC_i^* denotes the relative closeness to the positive ideal solution, indicating a greater distance from the minimum ideal possibility degree (0.5), and to the negative ideal solution, indicating a closer proximity to the maximum possibility degree (0.5). The grey possibility degree between each of the suppliers against the ideal supplier and the negative ideal supplier is computed. A positive ideal solution is considered the best performance value, and the negative ideal solution is considered the worst performance value.

GRA is robust to data variability and less sensitive to outliers, ensuring reliability in real-world applications. It captures subjective judgments; the research aims to prioritise suppliers based on both quantitative and qualitative factors. This combination enhances the decision-making process by providing a systematic approach to ranking alternatives and identifying the most promising supplier.

In this research, to select the best supplier, a modified grey relational analysis is proposed. Let SS = $\{SS_1, SS_2, \ldots, SS_m\}$ be a collection of m potential suppliers, and let C = $\{C_1, C_2, \ldots, C_n\}$ be a collection of n supplier evaluation factors. The decision makers provide ratings on the linguistic scale to the evaluation criteria and the supplier. Also, the decision makers rate each of the suppliers for each of the criteria on a

Table 4: The scale of supplier selection evaluation criteria weights ⊗w (G. Li *et al*., 2006)

Linguistic Scale	⊗w (Grey Number Scale)
Very low (VL)	[0.0, 0.1]
Low (VL)	[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 5: Supplier evaluation criteria rating scale

Linguistic Scale	⊗ G (Grey Number)
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]

linguistic scale. The linguistic scale is converted into a grey number scale in Table 4.

The decision makers provide linguistic scale values for the criteria weights. The supplier selection evaluation criteria ratings in a linguistic scale can be converted into a grey numbers scale, given in Table 5.

The Modified Grey-based Multi-Criteria Decision-Making method involves the following ten steps.

Step 1: The criteria weight of the criteria C_j , assuming a group of K decision makers, can be calculated as follows:

$$\otimes\ C_j = \frac{1}{K}\ [\otimes C_j^1 + \otimes C_j^2 + \ldots + \otimes C_j^k] \tag{11}$$

Where $\otimes C_j^k\left(j=1,2,\ldots,n\right)$ is the kth decision maker's criterion weight, which is represented by the grey number $\otimes C_j^k$ = [$\underline{C_j^k}, \overline{C_j^k}$].

Step 2: Decision makers provide linguistic ratings to each of the criteria, for each of the supplier ratings is converted into the grey scale as given in Table 7.

The grey scale rating of the i[th] supplier alternative for the j[th] criterion is given by:

$$\otimes G_{ij} = \frac{1}{K}\ [\otimes G_{ij}^1 + \otimes G_{ij}^2 + \ldots + \otimes G_{ij}^K] \tag{12}$$

where $\otimes G_{ij}^K$ (i = 1, 2, . . . , m; j = 1, 2, . . . , n) is the criterion rating value of the K[th] decision maker.

It is represented by the grey number as $\otimes G_{ij}^K$ = [$\underline{G_{ij}^K}, \overline{G_{ij}^K}$].

Step 3: Develop the grey decision matrix

$$D = \begin{bmatrix} \otimes G_{11} & \cdots & \otimes G_{1n} \\ \vdots & \ddots & \vdots \\ \otimes G_{m1} & \cdots & \otimes G_{mn} \end{bmatrix} \tag{13}$$

where $\otimes G_{ij}$ provides the grey scale rating of the i[th] supplier alternative for the j[th] criterion.

Step 4: Normalisation of the grey decision matrix

$$D^* = \begin{bmatrix} \otimes G_{11}^* & \cdots & \otimes G_{1n}^* \\ \vdots & \ddots & \vdots \\ \otimes G_{m1}^* & \cdots & \otimes G_{mn}^* \end{bmatrix} \tag{14}$$

where for a benefit attribute $\otimes G_{ij}^*$ = $\left[\frac{\underline{G_{ij}}}{G_j^{max}}, \frac{\overline{G_{ij}}}{G_j^{max}}\right]$ with G_j^{max} = $max_{1\le i\le m}\{G_{ij}\}$;

for a cost attribute $\otimes G_{ij}^*$ = $\left[\frac{G_j^{min}}{\overline{G_{ij}}}, \frac{G_j^{min}}{\underline{G_{ij}}}\right]$ with G_j^{min} = $min_{1\le i\le m}\{G_{ij}\}$;

Step 5: This step involves computing the weighted normalisation table considering the criteria weights.

$$D_w^* = \begin{bmatrix} \otimes V_{11}^* & \cdots & \otimes V_{1n}^* \\ \vdots & \ddots & \vdots \\ \otimes V_{m1}^* & \cdots & \otimes V_{mn}^* \end{bmatrix} \tag{15}$$

where $\otimes V_{ij}^*$ = $\otimes G_{ij}^*$ x $\otimes\ C_j$

Step 6: For m possible supplier alternatives SS=

$\{SS_1, SS_2, \ldots, SS_m\}$, the ideal supplier alternative is defined as $SS_{max} = \{G_1^{max}, G_2^{max}, \ldots, G_n^{max}\}$ where SS_{max} is computed as

$$\{\left[\max_{1\le i\le m} \underline{V_{i1}}, \quad \max_{1\le i\le m} \overline{V_{i1}}\right], \left[\max_{1\le i\le m} \underline{V_{i2}}, \quad \max_{1\le i\le m} \overline{V_{i2}}\right], \ldots, \left[\max_{1\le i\le m} \underline{V_{in}}, \quad \max_{1\le i\le m} \overline{V_{in}}\right]\} \quad (16)$$

Step 7: Compute the grey possibility degree between the compared supplier alternatives set

$SS_{max} = \{SS_1, SS_2, \ldots, SS_m\}$ and ideal supplier alternative SS_{max}.

$$L_i^+ = P\{SS_i \le SS_{max}\} = \frac{1}{n}\sum_{j=1}^{n} P\left\{\otimes V_{ij} \le \otimes G_j^{max}\right\} \quad (17)$$

Step 8: Compute the grey possibility degree between the negative ideal supplier SS_{min} and the supplier alternatives. It is defined as

$$L_i^- = P\{SS_{min} \le SS_i\} = \frac{1}{n}\sum_{j=1}^{n} P\left\{\otimes G_j^{min} \le \otimes V_{ij}\right\} \quad (18)$$

Step 9: Calculate the relative closeness index, which provides the closeness of the supplier to the ideal supplier using the following equation

$$RC_i^* = \frac{L_i^-}{L_i^- + \left(1 - L_i^+\right)} \quad (19)$$

Step 10: Rank the supplier in descending order of the relative closeness index. The higher the RC_i^* for a particular supplier better the ranking of the supplier. The supplier with the highest relative closeness index is selected as the supplier.

RESULT AND DISCUSSION

Following the initial screening, ten suppliers were shortlisted for further evaluation based on criteria defined by industry experts. A panel of four supply chain experts assessed the potential suppliers and the key criteria for selecting the most suitable one. These experts, each possessing substantial experience in supply chain management, were instrumental in identifying industry-relevant evaluation parameters.

Expert 1, with 15 years of experience, serves as the Divisional Manager in the Supplier Management Division.

Expert 2 has 12 years of experience and currently holds the position of Manager in the Part Control Division.

Expert 3, with 18 years of expertise in the Supplier Quality Division, is designated as Deputy General Manager.

Expert 4, with 16 years of experience, manages the Scheduling and Procurement Division. To mitigate ambiguity in the evaluation process, the experts employed linguistic terms for assessing supplier performance.

Application of grey-based methodology

Step 1: The criteria weights were evaluated from 4 experts, and the criteria weights were linguistic variables in GRA. Table 6. provides the linguistic value of the experts. Each decision maker k assigns a grey weight to each criterion C_j. The overall weight for each criterion C_j is obtained by averaging across all K decision makers, which yields a combined grey weight for each criterion.

Step 2: The rating of each supplier for the selected criteria is calculated from 4 experts using linguistic variables. The given ratings are converted into grey numbers. Table 7. Provides the value of the supplier

Table 6: Criteria Weights of the decision maker

Criteria	Exprt 1	Exprt 2	Exprt 3	Exprt 4	Criteria Weights	
Q	H	VH	VH	MH	0.725	0.875
C	MH	H	MH	M	0.500	0.650
DT	M	H	H	H	0.550	0.800
TC	VH	H	VH	H	0.750	0.950
GCSI	M	MH	H	MH	0.450	0.650
PC	ML	M	MH	H	0.450	0.600
EMI	M	MH	H	MH	0.500	0.650
WSLH	H	VH	VH	H	0.750	0.950
LCI	ML	M	MH	M	0.400	0.500

Table 7: Supplier ratings by the experts

Criteria	Suppliers	Exprt 1	Exprt 2	Exprt 3	Exprt 4	Grey Ratings	
Q	Sl1	G	MG	VG	F	6.0	7.5
	Sl2	MG	G	F	MP	4.5	6.0
	Sl3	VG	VG	G	MG	7.3	8.8
	Sl4	MP	P	F	MG	3.3	4.5
	Sl5	G	G	MG	G	5.8	8.3
	Sl6	F	MG	G	VG	6.0	7.5
	Sl7	VG	G	G	MG	6.5	8.5
	Sl8	P	MP	F	G	3.5	5.3
	Sl9	MG	VG	G	F	7.3	7.5
	Sl10	G	F	MG	VG	6.0	7.5
C	Sl1	F	MG	G	VG	6.0	7.5
	Sl2	VG	G	MG	F	6.0	7.5
	Sl3	G	MG	VG	P	5.3	7.0
	Sl4	MP	F	P	G	3.5	5.3
	Sl5	G	VG	G	MG	6.5	8.5
	Sl6	P	MP	F	MG	3.3	4.5
	Sl7	VG	G	MG	G	6.5	8.5
	Sl8	MP	P	F	VG	4.3	5.5
	Sl9	G	MG	VG	P	5.3	7.0
	Sl10	MG	G	F	VG	6.0	7.5
DT	Sl1	MG	G	VG	P	5.3	7.0
	Sl2	F	MP	G	MG	4.5	6.0
	Sl3	VG	G	MG	F	6.0	7.5
	Sl4	P	F	MP	G	3.5	5.3
	Sl5	G	MG	VG	MP	5.8	7.3
	Sl6	VG	G	F	MG	6.0	7.5
	Sl7	MP	F	G	VG	5.5	7.0
	Sl8	P	MG	G	G	4.5	6.8
	Sl9	VG	G	MG	F	6.0	7.5
	Sl10	G	VG	MG	F	6.0	7.5
TC	Sl1	VG	G	MG	F	6.0	7.5
	Sl2	F	MP	G	VG	5.5	7.0
	Sl3	G	MG	VG	P	5.3	7.0
	Sl4	MP	F	P	G	3.5	5.3
	Sl5	G	VG	G	MG	6.5	8.5
	Sl6	P	MP	F	MG	3.3	4.5
	Sl7	VG	G	MG	G	6.5	8.5
	Sl8	MP	P	F	VG	4.3	5.5
	Sl9	G	MG	VG	P	5.3	7.0
	Sl10	MG	G	F	VG	6.0	7.5
GCSI	Sl1	P	G	F	MP	3.5	5.3
	Sl2	G	F	G	G	5.0	7.0
	Sl3	VG	G	G	F	6.3	8.3
	Sl4	MP	P	F	G	3.5	5.3
	Sl5	F	F	G	VG	5.8	7.3
	Sl6	G	G	G	MP	5.3	7.8
	Sl7	G	MP	MP	G	4.5	6.5
	Sl8	P	F	F	G	3.8	5.5
	Sl9	P	G	F	MP	3.5	5.3
	Sl10	VG	G	MG	G	6.5	8.5
PC	Sl1	G	G	F	MP	4.8	6.8
	Sl2	VG	MG	G	F	6.0	7.5
	Sl3	P	P	F	G	3.0	5.0
	Sl4	G	MG	F	G	5.3	7.3
	Sl5	MP	G	G	F	4.8	6.8
	Sl6	VG	G	F	MG	6.0	7.5
	Sl7	G	G	P	F	4.3	6.5
	Sl8	F	G	MG	MG	5.0	6.5
	Sl9	VG	G	MG	F	6.0	7.5
	Sl10	MP	F	G	VG	5.5	7.0
EMI	Sl1	G	F	G	G	5.5	8.0
	Sl2	MP	MG	MP	F	3.8	4.8
	Sl3	MG	G	VG	F	6.0	7.5

Table 7: Supplier ratings by the experts

Criteria	Suppliers	Exprt 1	Exprt 2	Exprt 3	Exprt 4	Grey Ratings	
	Sl4	G	F	P	F	3.8	5.5
	Sl5	G	F	G	G	5.5	8.0
	Sl6	MG	VG	VG	G	7.3	8.8
	Sl7	G	MP	MP	G	4.5	6.5
	Sl8	VG	G	G	G	6.8	9.3
	Sl9	G	F	F	MG	4.8	6.3
	Sl10	MG	G	G	VG	6.5	8.5
WSLH	Sl1	MP	P	F	MP	2.8	4.0
	Sl2	F	F	MG	G	4.8	6.3
	Sl3	G	G	VG	F	6.3	8.3
	Sl4	G	MP	G	G	5.3	7.8
	Sl5	P	F	VG	F	4.5	5.8
	Sl6	P	G	P	G	3.5	6.0
	Sl7	MG	G	G	MG	5.5	7.5
	Sl8	VG	G	MP	F	5.5	7.0
	Sl9	F	G	VG	G	6.3	8.3
	Sl10	MG	G	G	G	5.8	8.3
LCI	Sl1	G	G	MG	F	5.3	7.3
	Sl2	P	F	G	VG	5.0	6.8
	Sl3	F	MG	G	G	5.3	7.3
	Sl4	G	F	G	MG	5.3	7.3
	Sl5	G	G	VG	F	6.5	8.3
	Sl6	MG	VG	MP	F	5.3	6.3
	Sl7	MP	G	G	VG	6.0	8.0
	Sl8	G	MP	G	MP	4.5	6.5
	Sl9	F	G	VG	G	6.3	8.3
	Sl10	G	F	G	F	5.0	7.0

Table 8: Grey decision matrix

Criteria/ Supplier	Sl1	Sl2	Sl3	Sl4	Sl5	Sl6	Sl7	Sl8	Sl9	Sl10
Q	6.0	4.5	7.3	3.3	5.8	6.0	6.5	3.5	7.3	6.0
	7.5	6.0	8.8	4.5	8.3	7.5	8.5	5.3	7.5	7.5
C	6.0	6.0	5.3	3.5	6.5	3.3	6.5	4.3	5.3	6.0
	7.5	7.5	7.0	5.3	8.5	4.5	8.5	5.5	7.0	7.5
DT	5.3	4.5	6.0	3.5	5.8	6.0	5.5	4.5	6.0	6.0
	7.0	6.0	7.5	5.3	7.3	7.5	7.0	6.8	7.5	7.5
TC	6.0	5.5	5.3	3.5	6.5	3.3	6.5	4.3	5.3	6.0
	7.5	7.0	7.0	5.3	8.5	4.5	8.5	5.5	7.0	7.5
GCSI	3.5	5.0	6.3	3.5	5.8	5.3	4.5	3.8	3.5	6.5
	5.3	7.0	8.3	5.3	7.3	7.8	6.5	5.5	5.3	8.5
PC	4.8	6.0	3.0	5.3	4.8	6.0	4.3	5.0	6.0	5.5
	6.8	7.5	5.0	7.3	6.8	7.5	6.5	6.5	7.5	7.0
EMI	5.5	3.8	6.0	3.8	5.5	7.3	4.5	6.8	4.8	6.5
	8.0	4.8	7.5	5.5	8.0	8.8	6.5	9.3	6.3	8.5
WSLH	2.8	4.8	6.3	5.3	4.5	3.5	5.5	5.5	6.3	5.8
	4.0	6.3	8.3	7.8	5.8	6.0	7.5	7.0	8.3	8.3
LCI	5.3	5.0	5.3	5.3	6.5	5.3	6.0	4.5	6.3	5.0
	7.3	6.8	7.3	7.3	8.3	6.3	8.0	6.5	8.3	7.0

rating. The ratings from all the decision makers are averaged to get a combined rating.

Step 3: Develop the grey decision matrix, which is shown in Table 8. A grey decision matrix D is formed, where each element is the grey rating $\otimes G_{ij}$, supplier *i* for criterion *j*.

Step 4: Normalization of the grey decision matrix is provided in Tables 9 and 10. Normalization ensures comparability across criteria by transforming the ratings into a [0,1] range. This yields a normalized grey decision matrix D*

Step 5: A Grey weighted normalization matrix is

Table 10: Normalized grey decision matrix

Criteria/ Supplier	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
(Q)	0.5417	0.7222	0.4483	1.0000	0.5652	0.5417	0.5000	0.9286	0.4483	0.5417
	0.4333	0.5417	0.3714	0.7222	0.3939	0.4333	0.3824	0.6190	0.4333	0.4333
(C)	0.5417	0.5417	0.6190	0.9286	0.5000	1.0000	0.5000	0.7647	0.6190	0.5417
	0.4333	0.4333	0.4643	0.6190	0.3824	0.7222	0.3824	0.5909	0.4643	0.4333
(DT)	0.6667	0.7778	0.5833	1.0000	0.6087	0.5833	0.6364	0.7778	0.5833	0.5833
	0.5000	0.5833	0.4667	0.6667	0.4828	0.4667	0.5000	0.5185	0.4667	0.4667
(TC)	0.5417	0.5909	0.6190	0.9286	0.5000	1.0000	0.5000	0.7647	0.6190	0.5417
	0.4333	0.4643	0.4643	0.6190	0.3824	0.7222	0.3824	0.5909	0.4643	0.4333
(GCSI)	1.0000	0.7000	0.5600	1.0000	0.6087	0.6667	0.7778	0.9333	1.0000	0.5385
	0.6667	0.5000	0.4242	0.6667	0.4828	0.4516	0.5385	0.6364	0.6667	0.4118
(PC)	0.6316	0.5000	1.0000	0.5714	0.6316	0.5000	0.7059	0.6000	0.5000	0.5455
	0.4444	0.4000	0.6000	0.4138	0.4444	0.4000	0.4615	0.4615	0.4000	0.4286
(EMI)	0.6818	1.0000	0.6250	1.0000	0.6818	0.5172	0.8333	0.5556	0.7895	0.5769
	0.4688	0.7895	0.5000	0.6818	0.4688	0.4286	0.5769	0.4054	0.6000	0.4412
(WSLH)	1.0000	0.5789	0.4400	0.5238	0.6111	0.7857	0.5000	0.5000	0.4400	0.4783
	0.6875	0.4400	0.3333	0.3548	0.4783	0.4583	0.3667	0.3929	0.3333	0.3333
(LCI)	0.8571	0.9000	0.8571	0.8571	0.6923	0.8571	0.7500	1.0000	0.7200	0.9000
	0.6207	0.6667	0.6207	0.6207	0.5455	0.7200	0.5625	0.6923	0.5455	0.6429

Table 11: Normalized grey decision matrix

Criteria/ Supplier	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
(Q)	0.6857	0.5143	0.8286	0.3714	0.6571	0.6857	0.7429	0.4000	0.8286	0.6857
	0.8571	0.6857	1.0000	0.5143	0.9429	0.8571	0.9714	0.6000	0.8571	0.8571
(C)	0.7059	0.7059	0.6176	0.4118	0.7647	0.3824	0.7647	0.5000	0.6176	0.7059
	0.8824	0.8824	0.8235	0.6176	1.0000	0.5294	1.0000	0.6471	0.8235	0.8824
(DT)	0.7000	0.6000	0.8000	0.4667	0.7667	0.8000	0.7333	0.6000	0.8000	0.8000
	0.9333	0.8000	1.0000	0.7000	0.9667	1.0000	0.9333	0.9000	1.0000	1.0000
(TC)	0.7059	0.6471	0.6176	0.4118	0.7647	0.3824	0.7647	0.5000	0.6176	0.7059
	0.8824	0.8235	0.8235	0.6176	1.0000	0.5294	1.0000	0.6471	0.8235	0.8824
(GCSI)	0.4118	0.5882	0.7353	0.4118	0.6765	0.6176	0.5294	0.4412	0.4118	0.7647
	0.6176	0.8235	0.9706	0.6176	0.8529	0.9118	0.7647	0.6471	0.6176	1.0000
(PC)	0.6333	0.8000	0.4000	0.7000	0.6333	0.8000	0.5667	0.6667	0.8000	0.7333
	0.9000	1.0000	0.6667	0.9667	0.9000	1.0000	0.8667	0.8667	1.0000	0.9333
(EMI)	0.5946	0.4054	0.6486	0.4054	0.5946	0.7838	0.4865	0.7297	0.5135	0.7027
	0.8649	0.5135	0.8108	0.5946	0.8649	0.9459	0.7027	1.0000	0.6757	0.9189
(WSLH)	0.3333	0.5758	0.7576	0.6364	0.5455	0.4242	0.6667	0.6667	0.7576	0.6970
	0.4848	0.7576	1.0000	0.9394	0.6970	0.7273	0.9091	0.8485	1.0000	1.0000
(LCI)	0.6364	0.6061	0.6364	0.6364	0.7879	0.6364	0.7273	0.5455	0.7576	0.6061
	0.8788	0.8182	0.8788	0.8788	1.0000	0.7576	0.9697	0.7879	1.0000	0.8485

computed as in Eq.15 and is listed below in Tables 11 and 12. Each normalized grey value is multiplied by its criterion weight to reflect importance. This results in a weighted normalized matrix that integrates both ratings and criteria weights.

Step 6: The ideal supplier is one of the best performers in all criteria. SS_{max} is computed.

SS_{max} ={[0.600, 0.875], [0.382, 0.650], [0.440, 0.800],[0.573, 0.950], [0.344, 0.655], [0.360,0.600], [0.391, 0.650], [0.568, 0.950], [0.315, 0.500]}

Step 7: The grey possibility degree between the supplier alternatives SS_i {I=1,2,3,..10}. This step calculates how close each supplier SS_i is to the ideal supplier. According to Eq. 17, the values are listed below in Table 13. The function P represents the possibility degree measuring the overlap or closeness between intervals

Step 8: The grey possibility degree between

Table 11: Grey weighted normalization table

Criteria/ Supplier	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
(Q)	0.3927	0.5236	0.3250	0.7250	0.4098	0.3927	0.3625	0.6732	0.3250	0.3927
	0.3792	0.4740	0.3250	0.6319	0.3447	0.3792	0.3346	0.5417	0.3792	0.3792
(C)	0.2708	0.2708	0.3095	0.4643	0.2500	0.5000	0.2500	0.3824	0.3095	0.2708
	0.2817	0.2817	0.3018	0.4024	0.2485	0.4694	0.2485	0.3841	0.3018	0.2817
(DT)	0.3667	0.4278	0.3208	0.5500	0.3348	0.3208	0.3500	0.4278	0.3208	0.3208
	0.4000	0.4667	0.3733	0.5333	0.3862	0.3733	0.4000	0.4148	0.3733	0.3733
(TC)	0.4063	0.4432	0.4643	0.6964	0.3750	0.7500	0.3750	0.5735	0.4643	0.4063
	0.4117	0.4411	0.4411	0.5881	0.3632	0.6861	0.3632	0.5614	0.4411	0.4117
(GCSI)	0.4500	0.3150	0.2520	0.4500	0.2739	0.3000	0.3500	0.4200	0.4500	0.2423
	0.4333	0.3250	0.2758	0.4333	0.3138	0.2935	0.3500	0.4136	0.4333	0.2676
(PC)	0.2842	0.2250	0.4500	0.2571	0.2842	0.2250	0.3176	0.2700	0.2250	0.2455
	0.2667	0.2400	0.3600	0.2483	0.2667	0.2400	0.2769	0.2769	0.2400	0.2571
(EMI)	0.3409	0.5000	0.3125	0.5000	0.3409	0.2586	0.4167	0.2778	0.3947	0.2885
	0.3047	0.5132	0.3250	0.4432	0.3047	0.2786	0.3750	0.2635	0.3900	0.2868
(WSLH)	0.7500	0.4342	0.3300	0.3929	0.4583	0.5893	0.3750	0.3750	0.3300	0.3587
	0.6531	0.4180	0.3167	0.3371	0.4543	0.4354	0.3483	0.3732	0.3167	0.3167
(LCI)	0.3429	0.3600	0.3429	0.3429	0.2769	0.3429	0.3000	0.4000	0.2880	0.3600
	0.3103	0.3333	0.3103	0.3103	0.2727	0.3600	0.2813	0.3462	0.2727	0.3214

Table 12: Grey weighted normalization table

Criteria/ Supplier	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
(Q)	0.4740	0.6319	0.3922	0.8750	0.4946	0.4740	0.4375	0.8125	0.3922	0.4740
	0.3142	0.3927	0.2693	0.5236	0.2856	0.3142	0.2772	0.4488	0.3142	0.3142
(C)	0.3521	0.3521	0.4024	0.6036	0.3250	0.6500	0.3250	0.4971	0.4024	0.3521
	0.2167	0.2167	0.2321	0.3095	0.1912	0.3611	0.1912	0.2955	0.2321	0.2167
(DT)	0.5333	0.6222	0.4667	0.8000	0.4870	0.4667	0.5091	0.6222	0.4667	0.4667
	0.2750	0.3208	0.2567	0.3667	0.2655	0.2567	0.2750	0.2852	0.2567	0.2567
(TC)	0.5146	0.5614	0.5881	0.8821	0.4750	0.9500	0.4750	0.7265	0.5881	0.5146
	0.3250	0.3482	0.3482	0.4643	0.2868	0.5417	0.2868	0.4432	0.3482	0.3250
(GCSI)	0.6500	0.4550	0.3640	0.6500	0.3957	0.4333	0.5056	0.6067	0.6500	0.3500
	0.3000	0.2250	0.1909	0.3000	0.2172	0.2032	0.2423	0.2864	0.3000	0.1853
(PC)	0.3789	0.3000	0.6000	0.3429	0.3789	0.3000	0.4235	0.3600	0.3000	0.3273
	0.2000	0.1800	0.2700	0.1862	0.2000	0.1800	0.2077	0.2077	0.1800	0.1929
(EMI)	0.4432	0.6500	0.4063	0.6500	0.4432	0.3362	0.5417	0.3611	0.5132	0.3750
	0.2344	0.3947	0.2500	0.3409	0.2344	0.2143	0.2885	0.2027	0.3000	0.2206
(WSLH)	0.9500	0.5500	0.4180	0.4976	0.5806	0.7464	0.4750	0.4750	0.4180	0.4543
	0.5156	0.3300	0.2500	0.2661	0.3587	0.3438	0.2750	0.2946	0.2500	0.2500
(LCI)	0.4286	0.4500	0.4286	0.4286	0.3462	0.4286	0.3750	0.5000	0.3600	0.4500
	0.2483	0.2667	0.2483	0.2483	0.2182	0.2880	0.2250	0.2769	0.2182	0.2571

the negative ideal supplier SS_{min} and the supplier alternative SS_i {I=1,2,3,..10}. According to Eq. 18, the values are listed below in Table 14. The negative ideal supplier SS_{min} has the worst performance across criteria. This step calculates how far a supplier is from this negative ideal.

Step 9: According to Eq. 19 relative closeness index is computed, and the values are listed below in Table 15. The closeness index reflects how close a supplier is to the ideal and how far from the anti-ideal. A higher RC_i^* means the supplier is closer to the ideal solution.

Step 10: Sorting the relative closeness index in descending order. The RC_i^* represents the distance to the positive ideal solution (L_i^+), where it is farther from the minimum ideal possibility degree 0.5 and the negative ideal solution ($.L_i^-$) where it is closer to a maximum of 0.5. The supplier with the highest

Table 13: Grey Possibility degree of layout alternatives with ideal supplier

L_1^+	$P(SS_1 <= SS_{max})$	0.6499
L_2^+	$P(SS_2 <= SS_{max})$	0.6674
L_3^+	$P(SS_3 <= SS_{max})$	0.5749
L_4^+	$P(SS_4 <= SS_{max})$	0.7711
L_5^+	$P(SS_5 <= SS_{max})$	0.5371
L_6^+	$P(SS_6 <= SS_{max})$	0.6539
L_7^+	$P(SS_7 <= SS_{max})$	0.5377
L_8^+	$P(SS_8 <= SS_{max})$	0.6859
L_9^+	$P(SS_9 <= SS_{max})$	0.5897
L_{10}^+	$P(SS_{10} <= SS_{max})$	0.5374

Table 14: Grey Possibility degree of the negative ideal supplier with the supplier alternative

L_1^-	$P(SS_{min} <= SS_1)$	0.6517
L_2^-	$P(SS_{min} <= SS_2)$	0.6682
L_3^-	$P(SS_{min} <= SS_3)$	0.5047
L_4^-	$P(SS_{min} <= SS_4)$	0.7336
L_5^-	$P(SS_{min} <= SS_5)$	0.5602
L_6^-	$P(SS_{min} <= SS_6)$	0.7253
L_7^-	$P(SS_{min} <= SS_7)$	0.5764
L_8^-	$P(SS_{min} <= SS_8)$	0.6779
L_9^-	$P(SS_{min} <= SS_9)$	0.5700
L_{10}^-	$P(SS_{min} <= SS_{10})$	0.5300

Table 15: Relative closeness index of the supplier's alternative

RC_1^*	0.6506
RC_2^*	0.6676
RC_3^*	0.5428
RC_4^*	0.7622
RC_5^*	0.5476
RC_6^*	0.6770
RC_7^*	0.5550
RC_8^*	0.6834
RC_9^*	0.5814
RC_{10}^*	0.5340

relative closeness index RC_i^* is selected as the best supplier, as it is nearer to 1. The findings indicate that all suppliers demonstrate satisfactory performance, with the maximum relative closeness value observed being 0.76, and the minimum relative closeness value observed is 0.53. This reflects a highly competitive environment among the evaluated suppliers. More comprehensive by comparing both proximity to the best and distance from the worst. Table 15. The ranking order of the suppliers is as follows. *S4 > S8 > S6 > S2 > S1 > S9 > S7 > S5 > S3 > S10.* Hence, the research concludes that the supplier has the best sustainability performance in all three economic, environmental, and social sustainability based on the experts' opinions. To check the robustness of the model, a comparative analysis with another MCDM method, TOPSIS, is applied, and the ranking suggests that the first three suppliers are supplier 4, supplier 8, and supplier 6, and there was a variation in the other supplier ranking.

CONCLUSION

Sustainable supplier selection is a complex process. This method facilitates a thorough evaluation of suppliers, delivering meaningful insights for decision-makers in the automobile sector. This comprehensive evaluation framework reflects an integrated approach that balances conventional performance indicators with contemporary sustainability considerations in supplier selection. The objective of the modified grey relational analysis is to simplify decision making and less time-consuming by converting the linguistic ratings into a grey number, and the method compares each supplier against an ideal supplier and a negative ideal supplier. The grey possibility degree between each of the suppliers against the ideal supplier and the negative ideal supplier is computed. The supplier with the highest relative closeness index is selected as the best supplier. This method is robust to data variability and less sensitive to outliers. It ultimately establishes a strong framework for selecting suppliers that adhere to sustainability principles while enhancing procurement efficiency. The selection alternative is based on the distance closest to the positive ideal supplier and farthest from the negative ideal supplier. Suppliers with an RCi* value below 0.5 should be excluded from consideration. One of the limitations of this study lies in the selection of evaluation criteria, which, although intended to provide a comprehensive assessment of supplier sustainability performance, may not fully encompass all relevant dimensions. Future research could expand the scope by incorporating additional criteria to enhance the robustness of supplier selection. As the identification of criteria represents the initial and crucial step in the evaluation process, it significantly influences the outcome. Furthermore, analysis of the responses indicated that the selected criteria were not uniformly influenced by the three pillars of sustainability—economic, environmental, and social—highlighting the need for a more balanced approach in future investigations. Future research may explore the integration of advanced multi-criteria decision-making (MCDM) techniques, such as Intuitionistic Fuzzy Sets, Fuzzy Rough Sets, and Interval-Valued Fuzzy Sets. These methodologies offer robust capabilities for handling uncertainty and can be effectively applied across diverse decision-making contexts. Evaluation can be made for a dynamic environment considering possible events. Potential applications include supplier selection in the manufacturing sector, project or portfolio selection in construction, equipment selection in warehouse operations, risk interaction assessment in green supply chain environments, evaluation of green port factors, and other strategic decisions within production and operations management. Furthermore, the proposed model can be enhanced by incorporating industry-specific evaluation criteria, enabling comparative analysis of outcomes across different domains.

AUTHOR CONTRIBUTIONS

Sai Keerthana.N carried out the idea development, methodology, software, review of literature, and manuscript preparation. Sudarsanam.S.K and Neelanarayanan.V corrected data, reviewed, and edited it, tested the software, and validated it.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the authors have witnessed ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy.

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ABBREVIATIONS (NOMENCLATURE)

$\underline{G}$, $\overline{G}$	Lower and upper bounds of grey number
$\bar{\mu}$	Upper Limit
∞	Infinity
$\otimes$	Grey operator
$\otimes C_j^k \left(j=1,2,\ldots,n \right)$	K^{th} decision maker's criterion weight
$\otimes G_{ij}^K$ (i = 1, 2, . . . , m; j = 1, 2, . . . , n)	criterion rating value of the K^{th} decision maker.
$\otimes V_{ij}^*$	Weighted and normalized grey value
$\otimes$G	Grey Number
ADGRA	Absolute Grey Relational Analysis
AHP	Analytical Hierarchy Process
ANP	Analytics Network Process
C	Cost
DEA	Data Envelopment Analysis
DEMATEL	Decision-Making Trial and Evaluation Laboratory
DGRA	Dynamic Grey Relational Analysis
DT	Delivery Time
ELECTRE	Elimination and Choice Expressing Reality
EMI	Environmental Management Initiatives
EMS	Environmental Management System
Eq	Equation
ESE Sustainability	Economic, Social, Environmental sustainability
FAHP	Fuzzy Analytical Hierarchy Process
FBWM	Fuzzy Best Worst Method
FCP	Fuzzy Compromise Programming
GCSI	Green Corporate Social Image
GIFSS	Generalised Intuitionistic Fuzzy Soft Set
GRA	Grey Relational Analysis
HFLVIKOR	Hesitant Fuzzy Linguistic VIKOR
IFS	Intuitionistic Fuzzy Set
IFSS	Intuitionistic Fuzzy Soft Set
L*	Length of grey number
LCI	Local Community Influence
MCDM	Multi-Criteria Decision Making
MOLP	Multi-Objective Linear Programming
MOORA	Multi-Objective Optimization based on Ratio Analysis
P	Possibility degree
PC	Pollution Control
Q	Quality
RC_i^*	Relative Closeness Index
SAW	Simple Additive Weighting
SSGRA	Second Synthetic Grey Relational Analysis
SS^{max}	Positive ideal Supplier
SS^{min}	Negative ideal supplier
TBL	Triple Bottom Line
TC	Technology Capabilities
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VIKOR	VIseKriterijumska Optimizacija I Kompromisno Resenje
WSLH	Work Safety and Labour Health
$\underline{\mu}$	Lower Limit

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