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An extended grey relational analysis based on COPRAS method for sustainable supplier selection in project procurement problems

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Abstract *– The sustainable supplier selection (SSS) problem is an integral part of project procurement management. In this paper, a new extended grey relational analysis (GRA) based on the complex proportional assessment (COPRAS) is applied for SSS problems for using the merits of these two methods simultaneously. Furthermore, a new multi-objective optimization model (MOOM) is developed to obtain the objective weights of criteria. Moreover, to illustrate the uncertainty of real SSS problems and derived uncertainty of experts' judgments, grey numbers are employed. To reduce the reliance on the experts, a new MOOM is developed for criteria' weights determination. Finally, the performance of the introduced method is demonstrated by solving a numerical example.*

Keywords*– COPRAS method, GRA method, Grey numbers, Multi-objective optimization model, Project procurement management, Sustainable supplier selection.*

I. INTRODUCTION

By increasing the decision-making complexity in practical conditions, the uncertainty of evaluations has increased. Due to a lack of data in realistic circumstances, the judgment of experts is gathered for decision-making procedures. In this situation, it is very tough for experts to explain their assessments by using deterministic numbers. To solve this problem, grey numbers or interval numbers have been introduced. By using the grey numbers, experts can express their opinions and feelings reasonably and realistically. Hence, in this paper, a new group decision model is developed under the grey numbers.

The grey system theory was initially introduced by (Julong, 1982). Grey number is categorized as a specific kind of fuzzy number, but the computation of grey numbers is much easier than fuzzy numbers (Lin et al., 2008). The advent of the concept of interval numbers was related to (Young, 1931). Afterward, many scholars and researchers have concentrated on the interval numbers (Moore, 1979; Ishihuchi and Tanaka, 1990). Then, the grey relational analysis (GRA) has proposed by using the concept of grey system theory by (Lin et al. 1998).

The GRA method can be considered impressively the complex inter-relationships among criteria. It takes the correlation of reference sequence and analogical sequence and ranks the alternatives based on the correlation and makes the right decisions (Chen, 2019). Furthermore, the GRA method ranks alternatives based on the various criteria by

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using a global preference relation (Kahraman and Karaşan, 2018). It is subsumed as a recognized multi-criteria decision-making (MCDM) method and has been applied in many problems in recent years (Baudry et al., 2018).

Mousavi et al. (2016) extended a VIKOR method based on intuitionistic fuzzy sets and developed a ranking index to solve the multiple attributes group decision making (MAGDM) problems. Mohagheghi et al. (2016) presented a model to predict project cash flow based on interval type-2 fuzzy. Gitinavard et al. (2016) used a group decision-making (GDM) approach based on interval-valued hesitant fuzzy sets (IVHFSs) and compromise ranking method for multiple criteria decision-making problem. Mousavi and Vahdani (2016) proposed a cross-docking location selection problem by using intuitionistic fuzzy hierarchical group decision-making (IFHGDM) model. Ebrahimnejad et al. (2015) developed an interval-valued intuitionistic fuzzy multi-criteria model for the outsourcing provider selection problem. Dorfeshan et al. (2018) developed a new MCDM problem for project-critical path selecting. The presented method is an extended version of MULTIMOORA and MOOSRA in the fuzzy environment. Stevic et al. (2020) have extended a measurement alternatives and ranking according to compromise solution (MARCOS) method for SSS problem in the real-world.

In connection with the application of MCDM methods in the production projects, Zolghadri et al. (2011) used the customer perspective to select a supplier and provided a method to enlisting customer feedback on potential suppliers. Luzon and Sayegh (2016) provided a method to choose suppliers for oil and gas projects. In this study, 10 criteria were classified into two groups, and the alternatives were weighed and evaluated using analytical hierarchy process (AHP) and Delphi methods. To reduce project costs, Safa et al. (2014) considered an integrated construction materials management (ICMM) model and provided the TOPSIS method for selecting a supplier. Polat and Eray (2015) presented an integrated AHP and evidential reasoning (ER) approach for choosing a supplier for an intercity railway project. Yin et al. (2017) proposed a multi-criteria decision-making method for selecting green suppliers in construction projects.

One of the problems that are defined as an MCDM problem is sustainable supplier selection (SSS). Many scholars and researchers have applied the MCDM methods to the SSS problems in the last decade (Liu et al., 2019; Chen, 2019; Jiang et al., 2018).

The SSS plays a significant role in the development of economic. Yazdani et al. (2017) evaluated the environmental criteria by using an integrated method for the SSS. They considered interrelationship among customer requirements according to the combination of the decision-making trial and evaluation laboratory (DEMATEL) and complex proportional assessment (COPRAS). Hamdan and Cheaitou (2017) solved SSS and order allocation problems utilizing a decision-making methodology. Lu et al., (2018) extended a cloud-based decision methodology employing the possibility degree to SSS. Haeri and Rezaei (2018) introduced an SSS methodology based on the environmental and economic criteria under uncertainty. Furthermore, they proposed a weight determination method. Liu et al. (2019) combined partitioned Bonferroni mean and quality function deployment to select the SSS under uncertainty. Stevic et al. (2020) have extended a new MARCOS method for SSS problem in the real world.

The SSS problem in project procurement management has been received significant heed in recent years. Many researchers have concentrated on the GRA to choose the best supplier (Chen et al. 2019; Govindan et al. 2020; Kellner & Utz, 2019). In this paper, a combination of GRA-based COPRAS and MOOM methods is developed for the SSS problem. In other words, a new GRA-based COPRAS is extended for the ranking of alternatives, and a new version of MOOM is expanded for criteria’ weights determination.

Another useful MCDM approach is the COPRAS approach. The COPRAS method has been attracted much attention in recent years and successfully applied in many MCDM problems economics, construction management, and property management (Chatterjee et al., 2011; Zavadskas et al., 2003, 2008). In the COPRAS method, Alternatives is ranked with a direct and proportional ratio solution to the best solution by the ideal and worst solutions. Some other well-known techniques, such as TOPSIS, VIKOR, and AHP, could not provide the relative importance of distances from best and worst solutions (Valipour et al., 2017; Vahdani et al., 2014).

Table 1. Literature review

Researchers	*Uncertainty*			*Criteria weighting method*				*Ranking method*				
	Crisp	*Fuzzy*	*Grey*	*Mathematical optimization model*	*BWM*	*QFD*	*SWARA*	*GRA*	*COPRAS*	*TOPSIS*	*DEMATEL*	*MULTIMOORA*
Vahdani et al. (2014)		*							*			
Gitinavard et al. (2016)		*		*								
Valipour et al. (2017)	*						*		*			
Yazdani et al. (2017)		*				*		*				
Haeri & Rezaei (2018)			*		*			*				
Dorfeshan et al. (2018)		*										*
Chen (2019)		*								*	*	
Liu et al. (2019)		*		*				*				
Stevic et al. (2020)	*											
Proposed method			*	*				*	*			

In recent years, the COPRAS method has significantly been used as a multi-criteria decision-making method for the following reasons: simplicity of calculation method, low calculation time, using the quantitative and qualitative criteria simultaneously, the capability of calculating the positive and negative criteria separately in the evaluation process, estimating the degree of importance of each alternative in percentage terms to indicate the best or worst alternative. This method is employed for various planning, financial, accounting, and geography. This method was developed initially by Zavadskas and Kaklauskas (1994) to determine the priorities and the degree of effectiveness of the alternatives. COPRAS procedure is simple, practical, powerful, and does not require complicated mathematical operations to rank of alternatives (Pitchipo et al., 2014). Because of using the fuzzy approach to deal with uncertainty, grey systems theory has been overlooked, although it is an effective and useful method in uncertain environments, with small, discrete, and uncertain data (Deng, 1989). Grey systems theory is a superior method in comparison with the other methods in the mathematical analysis of systems with vague information (Li et al., 2007). Grey numbers help decision-makers to explain their assessment better. The grey system approach has two essential advantages over other methods; requiring the low data is the first advantage of this method; another critical benefit of this system is the ability to deal with uncertainty in real situations.

Using the multi-objective optimization model to calculate the criteria weights can be useful because the model gains the best weight for every criterion by maximizing the grey relational grade vector. These weights are used to develop the COPRAS-GRA model for the ranking of alternatives. The COPRAS-GRA method is a combined method for ranking the alternatives in the SSS problem for the project procurement. This method is developed to take advantage of both the COPRAS and GRA methods simultaneously.

By taking into account the above benefits of COPRAS, GRA, and grey numbers and using the benefits of COPRAS and GRA methods simultaneously for solving the SSS problems, this study is motivated to solve the SSS problem by using a combination of COPRAS and GRA methods under the grey numbers. Notably, the objective weight of criteria is determined by using a new MOOM model.

In other words, in this study, a new compromise solution method is developed that combines GRA and COPRAS methods. Grey numbers are used for uncertainty consideration. In the introduced model, the ratings of alternatives according to the conflict criteria are collected from experts by linguistic variables. Then, these linguistic variables are converted to grey numbers. To take the benefits of GRA and COPRAS methods simultaneously, a new extended decision model is introduced. The GRA method is developed by using the positive and negative ideal solutions that are adopted from the COPRAS method. Moreover, this paper is concentrated on the concept of negative and positive ideal solutions separately. Furthermore, to calculate the weight of conflict criteria, a new model is extended. In fact, by using a new multiple objective optimization model (MOOM), the accurate weight of essential criteria is computed. The proposed model for determining the weight of criteria is applied after calculating the final results of the introduced decision model based on the combination of the GRA and COPRAS.

The innovations of this paper are defined by: (1) The uncertainty of SSS problems is considered by employing the grey numbers; (2) A new extension of GRA-based the COPRAS method is introduced to achieve the merits of the GRA and COPRAS method concurrently; and (3) A new MOOM procedure is developed to the weight determination process under the grey environment.

The structure of this paper is expressed as follows. Section 2 explains the basic science of grey system theory. Section 3 introduces the proposed decision methodology. Section 4 offers a multi-objective optimization model for weight determination. Section 5 presents an example of an extended methodology. The conclusion remarks explain in section 6.

II. PRELIMINARIES

A. Grey system theory

A grey number $\otimes G$ is a number that real value is unknown but a range of which is known. A grey number is defined as an upper bound and a lower bound as $\otimes G = [G^L, G^U]$. The basic operations on the grey numbers are defined as follows, where $\otimes G_1$ and $\otimes G_2$ are two different grey numbers.

$$\otimes G_1 + \otimes G_2 = [G_1^L + G_2^L , G_1^U + G_2^U] \quad (1)$$

$$\otimes G_1 - \otimes G_2 = [G_1^L - G_2^U , G_1^U - G_2^L] \quad (2)$$

$$\otimes G_1 \times \otimes G_2 = [\min(G_1^L G_2^L , G_1^L G_2^U, G_1^U G_2^L, G_1^U G_2^U), \max(G_1^L G_2^L , G_1^L G_2^U, G_1^U G_2^L, G_1^U G_2^U)] \quad (3)$$

$$\otimes G_1 \div \otimes G_2 = [G_1^L, G_1^U] \times [\frac{1}{G_2^L}, \frac{1}{G_1^U}] \quad (4)$$

$$K.\otimes G = [k.G^L, k.G^U] \quad (5)$$

III. PROPOSED DECISION METHODOLOGY

Step 1. A group of decision-makers is constructed. Then, the evaluations of decision-makers on ratings of alternatives based on the criteria are collected. Their assessments are presented in the form of a matrix.

$$G_k = (\otimes G_{ij}^k)_{m\times n} = \begin{pmatrix} \otimes G_{11}^k & \cdots & \otimes G_{1n}^k \\ \vdots & \ddots & \vdots \\ \otimes G_{m1}^k & \cdots & \otimes G_{mn}^k \end{pmatrix} \quad (6)$$

In this matrix, $k, i,$ and j respectively present the decision-maker, alternative, and criteria indices where $1 \leq i \leq m$, $1 \leq j \leq n$, $1 \leq k \leq K$. $\otimes G_{mn}^{k}$ defines the grey estimation of the k^{th} expert about the i^{th} alternative concerning the j^{th} criterion.

Step 2. The average matrix $\bar{G}$ is formed via Eq. (7)

$$\bar{G} = (\otimes G_{ij})_{m\times n} \tag{7}$$

Where $\otimes G_{ij} = \left(\frac{\otimes G_{ij}^{1} + \otimes G_{ij}^{2} + \cdots + \otimes G_{ij}^{k}}{k}\right)$, $\otimes G_{ij}$ is a grey number.

Step 3. In this step, the normalized matrix is computed by using the following:

$$\otimes R_{ij} = (r_{ij}^{L}, r_{ij}^{U}) = \left(\frac{\otimes G_{ij}^{L}}{\otimes G^{*}}, \frac{\otimes G_{ij}^{U}}{\otimes G^{*}}\right) \quad , \qquad \otimes G^{*} = \max_j \otimes G_{ij}^{U} \qquad \text{where } C_j \in B. \tag{8}$$

$$\otimes R_{ij} = (r_{ij}^{L}, r_{ij}^{U}) = \left(\frac{\otimes G^{-}}{\otimes G_{ij}^{u}}, \frac{\otimes G^{-}}{\otimes G_{ij}^{L}}\right) \quad , \qquad \otimes G^{-} = \min_j \otimes G_{ij}^{L} \qquad \text{where } C_j \in C. \tag{9}$$

Step 4. Negative and positive ideal points are determined by Eqs. (10) and (11).

$$A^{*} = \otimes r_j^{*} = \max_i \otimes r_{ij}^{T}, \quad T \in [L, U] \quad , \forall j \tag{10}$$

$$A^{-} = \otimes r_j^{-} = \min_i \otimes r_{ij}^{T}, \quad T \in [L, U] \quad , \forall j \tag{11}$$

Step 5. In this step, the grey relational coefficient is calculated using positive and negative ideals.

$$\gamma^{*}{}_{(\otimes r_j^{*}, \otimes r_{ij})} = \frac{\delta_{min} + \vartheta\delta_{max}}{\delta_{ij} + \vartheta\delta_{max}} \quad , \qquad \forall i, j \tag{12}$$

Where $\delta_{ij}{}^{*} = \frac{\sqrt{((r_{ij}^{L} - r_j^{L^*})^2 + (r_{ij}^{U} - r_j^{U^*})^2/2}}{\sqrt{2}}$

$\delta_{min}{}^{*} = \min_i \delta_{ij}{}^{*} \qquad \forall j,$

$\delta_{max}{}^{*} = \max_i \delta_{ij}{}^{*} \qquad \forall j.$

And

$$\gamma^{-}{}_{(\otimes r_j^{-}, \otimes r_{ij})} = \frac{\delta_{min} + \vartheta\delta_{max}}{\delta_{ij} + \vartheta\delta_{max}} \quad , \qquad \forall i, j \tag{13}$$

Where $\delta_{ij}{}^{-} = \frac{\sqrt{((r_{ij}^{L} - r_j^{L^-})^2 + (r_{ij}^{U} - r_j^{U^-})^2/2}}{\sqrt{2}}$

$\delta_{min}{}^{-} = \min_i \delta_{ij}{}^{-} \qquad \forall j,$

$\delta_{max}{}^{-} = \max_i \delta_{ij}{}^{-} \qquad \forall j.$

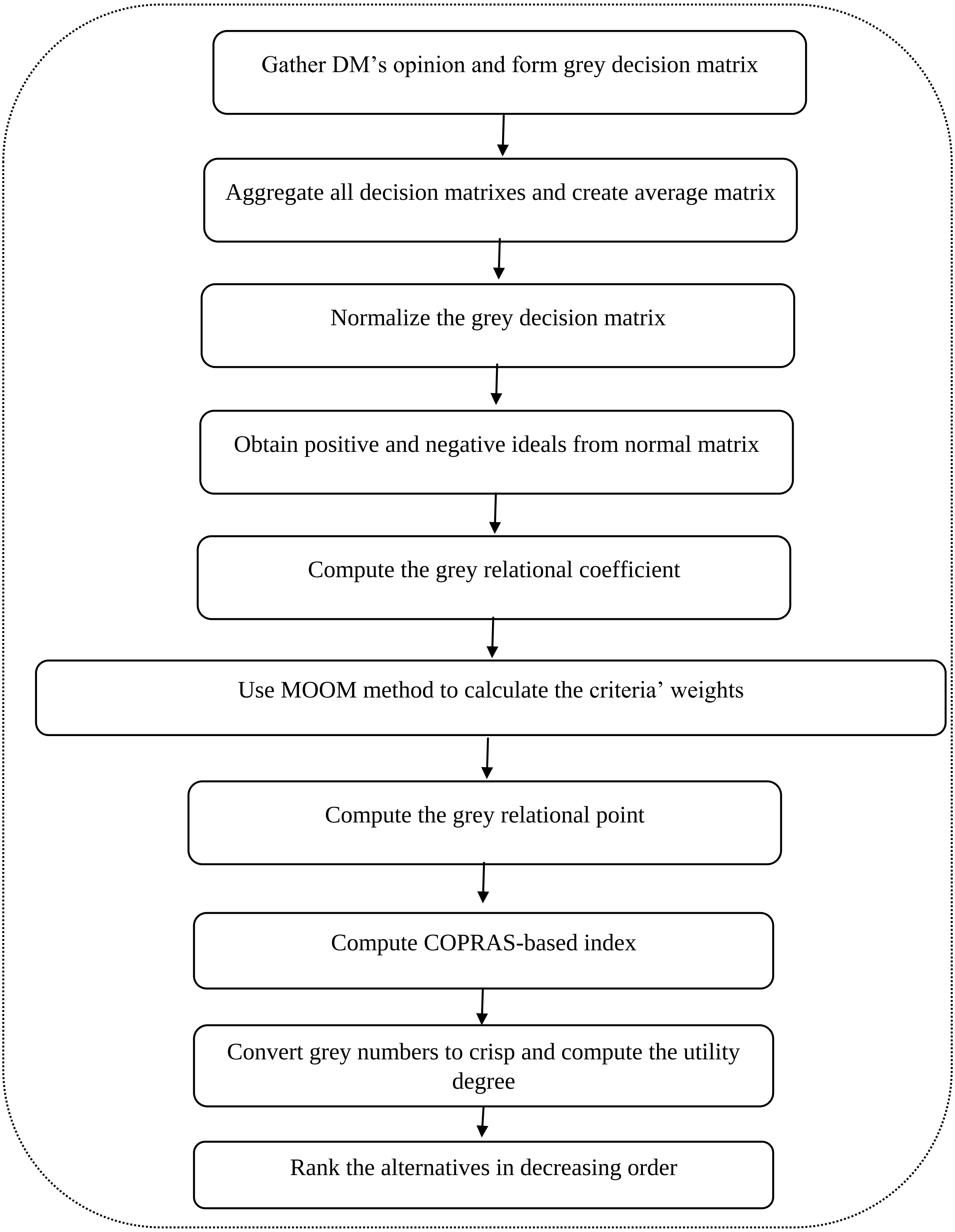

Figure 1. The framework of the extended method

Step 6. In this step, according to the proposed model by (Liu et al., 2017), the weights of criteria are obtained by a new MOOM model under the grey environment by using the following:

Step 6.1. In this step, a new MOOM is constructed to compute the criteria's weight. For this purpose, the obtained γ^* and γ^- values in step 5 are used as inputs for the MOOM as follows:

$$
\begin{aligned}
& max\ \Gamma(w) = (\gamma_1^*, \gamma_2^*, \dots, \gamma_m^*)\ ) \\
& s.t. \\
& \sum_j w_j = 1\ , \quad w_j \geq 0\ , \quad j = 1,2,\dots,n \\
& w_j \in \Delta
\end{aligned}
\tag{14}
$$

$$
\begin{aligned}
& max\ \Gamma(w) = (\gamma_1^-, \gamma_2^-, \dots, \gamma_m^-)\ ) \\
& s.t. \\
& \sum_j w_j = 1\ , \quad w_j \geq 0\ , \quad j = 1,2,\dots,n \\
& w_j \in \Delta
\end{aligned}
\tag{15}
$$

Step 6.2. There are many ways to solve multi-objective functions**.** Here the max-min operator (Chen, 2014) is used to convert multi-objective functions into a single objective by following Eqs:

$$
\begin{aligned}
& \mathbf{max}\ \ \mu \\
& s.t. \\
& \gamma^* \geq \mu, \quad i = 1,2,\dots,m \\
& \sum_j w_j = 1\ , w_j \geq 0\ , w_j \in\ \Delta \quad j = 1,2,\dots,n
\end{aligned}
\tag{16}
$$

$$
\begin{aligned}
& \mathbf{max}\ \ \mu \\
& s.t. \\
& \gamma^- \geq \mu, \quad i = 1,2,\dots,m \\
& \sum_j w_j = 1\ , w_j \geq 0\ , w_j \in\ \Delta \quad j = 1,2,\dots,n
\end{aligned}
\tag{17}
$$

In this step, weights of criteria are calculated by using Eq. (17) and (18) and used as the lower and upper bound of the grey number $\otimes w_j$, respectively.

The desired weight range is gathered from DM and is represented in the Δ set.

Step 7. In this step, the grey relation points are calculated by:

$$\otimes P_i = \sum_j \otimes w_j \, \gamma^* (\otimes r_j^*, \otimes r_{ij}) \tag{18}$$

$$\otimes R_i = \sum_j \otimes w_j \, \gamma^- (\otimes r_j^-, \otimes r_{ij}) \tag{19}$$

where $\otimes w_j = [w_j^L, w_j^U]$ is the grey weight of each criterion that computed in step 6.2.

Step 8. A new ranking index based on the COPRAS method is introduced in this step. The lower bound and upper bound of the proposed ranking index are computed via Eqs. (20-21).

$$Q_i^L = R_i^L + \frac{\sum_i P_i^L}{P_i^L \sum_i \left(\frac{1}{P_i^L} \right)} \tag{20}$$

$$Q_i^U = R_i^U + \frac{\sum_i P_i^U}{P_i^U \sum_i \left(\frac{1}{P_i^U} \right)} \tag{21}$$

Step 9. To compare the final values of alternatives, the grey numbers are converted to the crisp values, and then they are used to calculate the U_i .

$$Q_i = \frac{Q_i^L + Q_i^U}{2} \tag{22}$$

The utility degree of each alternative is calculated by using the following:

$$U_i = \frac{Q_i}{Q_{max}} \times 100 \quad , \quad Q_{max} = \max_i Q_i \tag{23}$$

The alternatives with the higher value, get a higher rank.

V. NUMERICAL EXAMPLE

A. Example

In this section, a numerical case from the literature (Memon et al. 2015) has been chosen and solved. This example is about sustainable supplier selection using the five criteria, quality (QL), delivery service level (SL), logistics service (LS), sustainability factor (SF), and risk factor (R). Three suppliers (S_1, S_2, S_3) are evaluated and compared against these criteria. Tables 2 and 3 are demonstrated the grey equivalent of the linguistic variables for the importance of criteria and ratings of alternatives. Tables 4 is depicted the opinions of the experts on the three alternatives against five criteria and the weight of each criterion. The steps of the developed method are performed sequentially, and the results of some of the steps are shown in Tables 5-9.

Table 2. Scale for evaluating alternatives against criteria

Linguistic variable	*L*	*U*
VP	0	1
P	1	3
MP	3	4
F	4	6
MG	6	7
G	7	9
VG	9	10

Table 3. Criteria weighing scale

Linguistic variable	*L*	*U*
VL	0	0.1
L	0.1	0.3
ML	0.3	0.4
M	0.4	0.6
MH	0.6	0.7
H	0.7	0.9
VH	0.9	1

Table 4. Experts opinions on supplier selection criteria

Alternative	*Criteria*	*Decision Maker*			
		DM_1	DM_2	DM_3	DM_4
S_1	QL	G	MG	F	MG
	SL	G	G	MG	G
	LS	G	MG	VG	VG
	SF	F	VG	F	MG
	R	G	MG	G	G
S_2	QL	F	MG	MG	F
	SL	MG	MG	G	G
	LS	MG	F	F	F
	SF	F	F	MG	F
	R	G	MG	F	MG
S_3	QL	G	MG	MG	G
	SL	G	MG	F	G
	LS	VG	VG	G	VG
	SF	MG	G	MG	VG
	R	MG	F	F	F

After gathering the linguistic variables from decision-makers and converting them to grey numbers based on Step 1, the average matrix is obtained via Eq. (7) as shown in Table 5.

Table 5. Averaged decision matrix

		$\otimes G_{ij}$	
Alternative	***Criteria***	***L***	***U***
S_1	QL	5.75	7.25
	SL	6.75	8.5
	LS	7.75	9
	SF	5.75	7.25
	R	6.75	8.5
S_2	QL	5	6.5
	SL	6.5	8
	LS	4.5	6.25
	SF	4.5	6.25
	R	5.75	7.25
S_3	QL	6.5	8
	SL	6	7.75
	LS	8.5	9.75
	SF	7	8.25
	R	4.5	6.25

The decision matrix is normalized by using Eqs. (8) and (9) which is depicted in Table 6.

Table 6. Normalized decision matrix

		$\otimes R_{ij}$	
Alternative	***Criteria***	***L***	***U***
S_1	QL	0.71875	0.90625
	SL	0.794118	1
	LS	0.794872	0.923077
	SF	0.69697	0.878788
	R	0.529412	0.666667
S_2	QL	0.625	0.8125
	SL	0.764706	0.941176
	LS	0.461538	0.641026
	SF	0.545455	0.757576
	R	0.62069	0.782609
S_3	QL	0.8125	1
	SL	0.705882	0.911765
	LS	0.871795	1
	SF	0.848485	1
	R	0.72	1

Grey's relational coefficients for positive and negative ideals solutions are calculated from step 5. The results are tabulated in Tables 7 and 8.

Table 7. Grey relational coefficient for positive ideal

Alternative	*Criteria*	$\gamma^{*}(\otimes r_j^{*}, \otimes r_{ij})$
S_1	QL	0.5
	SL	1
	LS	0.714738
	SF	0.5
	R	1
S_2	QL	0.333333
	SL	0.486833
	LS	0.333333
	SF	0.333333
	R	0.565419
S_3	QL	1
	SL	0.333333
	LS	1
	SF	1
	R	0.333333

Table 8. Grey relational coefficient for negative ideal

Alternative	*Criteria*	$\gamma^{-}(\otimes r_j^{-}, \otimes r_{ij})$
S_1	QL	0.5
	SL	0.333333
	LS	0.384321
	SF	0.5
	R	0.333333
S_2	QL	1
	SL	0.486833
	LS	1
	SF	1
	R	0.445457
S_3	QL	0.333333
	SL	1
	LS	0.333333
	SF	0.333333
	R	1

The computational steps for criteria' weight determination are done according to step 6, and the obtained results in Tables 7 and 8 are used as inputs for MOOM below:

For positive ideal:

$\max \mu$

S .t.

$0.5w_1 + w_2 + 0.71w_3 + 0.5w_4 + w_5 \geq \mu$

$0.33w_1 + 0.49w_2 + 0.33w_3 + 0.33w_4 + 0.56w_5 \geq \mu$

$w_1 + 0.33w_2 + w_3 + w_4 + 0.33w_5 \geq \mu$

$w_1 + w_2 + w_3 + w_4 + w_5 = 1$

$w_j \geq 0, w_j \in \Delta \quad j = 1,2, \dots ,5$

For negative ideal:

$\max \mu$

S .t.

$0.5w_1 + 0.33w_2 + 0.38w_3 + 0.5w_4 + 0.33w_5 \geq \mu$

$w_1 + 0.49w_2 + w_3 + w_4 + 0.44w_5 \geq \mu$

$0.33w_1 + w_2 + 0.33w_3 + 0.33w_4 + w_5 \geq \mu$

$w_1 + w_2 + w_3 + w_4 + w_5 = 1$

$w_j \geq 0, w_j \in \Delta \quad j = 1,2, \dots ,5$

$\Delta = 0.01 \leq w_1 \leq 0.2 , 0.2 \leq w_2 \leq 0.4, 0.15 \leq w_3 \leq 0.3, 0.1 \leq w_4 \leq 0.35, 0.1 \leq w_5 \leq 0.2.$

The above optimization models are solved by LINGO software, and the weights of five decision criteria are obtained below:

$w^- = (0.1,0.3,0.2,0.3,0.1)$ and $w^*(0.105,0.301,0.201,0.302,0.101)$.

These weights are used to calculate the grey relation points in Eqs. (18) and (19) in step 7. Afterward, the grey relation points are computed from step 7, Q_i and U_i are calculated in step 8, and the results are shown in Table 9.

Table 9. The ranking index for GRA-COPRAS method

Q_i	*L*	*U*	*Average*	U_i	*Rank*
S_1	0.897139	0.902757	0.899948	70.22413	3
S_2	1.277537	1.285536	1.281536	100	1
S_3	1.093325	1.099425	1.096375	85.55161	2

As can be seen in Table 9, the ratings are as follows:

$S_2 > S_3 > S_1$

B. Comparisons and discussion

To comparison MCDM methods, the result of the extended method in this paper is compared with the TOPSIS, VIKOR, COPRAS, and TOPSIS-GRA methods. The results of these methods are shown in Table 10.

Table 10. Comparative analysis

Alternative	*TOPSIS*	*VIKOR*	*COPRAS*	*TOPSIS-GRA*	*COPRAS-GRA*	*Rank*
S_1	0.27591	0.53297	71.6685	0.356032	70.22413	3
S_2	0.81434	1.36302	100	0.66282	100	1
S_3	0.3152	0.72016	77.0092	0.449502	85.55161	2

As can be seen, the results of all methods have confirmed the results of the proposed COPRAS-GRA methodology. Furthermore, the sensitivity analysis into the weight of the criteria is done. For this purpose, the criteria' weights are changed pair to pair, and the results are displayed in Table 11. Concerning the obtained results, except in two cases, the others have the same ranking. These results indicate that the weight of criteria does not have a significant impact on the final ranking. Ranking results are changed when the weights significantly differ from each other.

Table 11. Sensitivity analysis

Alternative	*Weights mutually changed*									
	QL-SL	*QL-LS*	*QL-SF*	*QL-R*	*SL-LS*	*SL-SF*	*SL-R*	*LS-SF*	*LS-R*	*SF-R*
S_1	70.2241	71.2383	70.2241	70.2241	68.4197	70.2241	70.9782	69.2074	72.3353	60.5078
S_2	100	100	100	100	100	100	100	100	99.6389	82.8967
S_3	85.5516	84.4928	85.5516	85.5516	73.1335	85.5516	86.2616	86.6296	100	100

As can be seen in Table 11, the alternatives have the same ranking ($S_2 > S_3 > S_1$) except in the last two columns of Table 11, which is indicated that changing the weights can be useful when the weights significantly differ from each other.

C. Managerial implications

Project managers can be used in the presented approach in this paper to select the appropriate supplier based on conflict criteria. Given that most information is not complete about some criteria in the realties. Depending on the type of data required, managers can use either fuzzy or grey data types. In real-world situations, because of the lack of information, grey numbers are a better option. To use this method, essential criteria must be considered, and several suppliers must be evaluated according to these criteria. It is advisable to gather the opinions of several decision-makers in this regard, then to integrate the decision-makers' judgments. After collecting the judgments, it is necessary to convert the linguistic data to a number. Defined grey data is used for this purpose. The calculations will be done based on the described method in the paper.

Moreover, project managers to reduce the dependence on the experts' opinions can be applied to the newly presented objective weight determination method in this paper based on a mathematical model. Sometimes the importance of the criteria may not be clear. In this condition, to obtain the weight of each criterion, a mathematical model is presented that can be easily used. A project manager will be able to select the best supplier and ordered project requirements after deploying the proposed method.

V. CONCLUSION

On the one hand, project completion time is directly influenced by project procurement management. On the other hand, an integral part of the project procurement is the sustainable supplier selection (SSS) problem. In this paper, to simultaneously use the advantages of GRA and COPRAS methods, a new GRA based on the COPRAS method has been extended and used for choosing the best sustainable supplier. Besides, a multi-objective optimization model was developed under the grey environment to calculate the objective weight of the criteria. Further, grey numbers have been used to cope with the derived uncertainty from the decision-makers' judgments. An adopted numerical example from the literature was solved to demonstrate the applicability of the proposed methodology. To investigate the applicability of the proposed method, the results of this example were compared with TOPSIS, VIKOR, COPRAS, and TOPSIS-GRA methods. The results of other methods have confirmed the validity of the proposed method. Furthermore, the weight of the criteria was changed to investigate the effect of the importance of the criteria on the ranking of alternatives. Changes in the weights of criteria only lead to different results when there is a significant difference in weights; otherwise, there is no significant difference in the results. This methodology can be applied to the MCDM problems (e.g., supplier selection, project procurement management, project logistics system selection, project portfolio evaluation, assessment of project transportation system), some subjective weighting methods (e.g., AHP and QFD) can be used for calculating the weights of criteria to enhance the proposed methodology.

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