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Abstract:

Materials are an important input in building construction. They account for a substantial proportion of investment capital and construction volume. However, as material prices are often affected by the market, choosing the right construction supplier is not an easy decision for contractors, especially for those materials required during the finishing phase of construction. As one of these finishing materials is paint, identifying core criteria for evaluating and selecting the best construction paint supplier is a crucial economic choice for construction contractors. Assessing the importance of these criteria is a complex multi-criteria decision-making problem. To reflect the risks and uncertainties in this problem, this paper presents a grey system theory approach to prioritize important criteria for selecting paint material suppliers in construction projects.

Keywords-construction management, project management, evaluation and selection criteria, material management, paint supplier, grey theory

I. INTRODUCTION

Material management is an essential task in the construction management of any civil engineering project because construction materials account for a high proportion of the total construction cost [1, 2]. In this regard, evaluating and selecting an efficient supplier of construction materials is the most important economic decision to help the contractor manage materials effectively [3]. One definition of an efficient supplier is a company that specializes in distributing high-quality products in the proper quantity, at the proper time, for a fair price [4].

In a construction project, one commonly required and evaluated material is construction paint. Determining the critical criteria in selecting the construction paint supplier is essential to choosing a materials supplier. However, traditional assessment methods (e.g., scoring methods) are often based on the subjective opinions of construction experts. They often do not consider uncertainty in their expert judgments or opinions. This results in a final decision that is often irrational and sometimes inconsistent with reality. To improve this shortcoming, this paper proposes a new quantitative model for prioritizing paint supplier evaluation and selection criteria based on the grey system theory.

II. RESEARCH BACKGROUND

Construction paint in civil engineering projects is available in liquid, paste, or powder form. It is usually used to cover the substrate to be painted (e.g., brick, concrete mortar, wood, or metal). The effect of construction paint is to create a solid film that adheres firmly to the building surface for building structure protection and esthetics. Consequently, choosing an efficient construction paint supplier is crucial for construction managers. In addition to helping the construction project attain the highest quality, it also helps reduce project costs and shorten the project implementation time.

This study identifies the eight most important factors to consider when selecting the construction paint supplier in civil engineering projects based on a literature review of research papers and in-depth interviews with experts [5-22]. These criteria include (F1) the reputation of the paint supplier, (F2) the quality management system certification of the paint supplier, (F3) the quality of construction paint materials, (F4) the number of paint categories and products, (F5) delivery time, (F6) terms and conditions of payment, (F7) price of the paint product, and (F8) the warranty period.

III. RESEARCH METHODOLOGY

One approach to studying uncertainty is the grey theory, introduced by Deng in [23-25]. It excels at analyzing mathematical systems with uncertain knowledge. When working with discrete data and insufficient knowledge, grey system theory can be utilized to handle uncertainty or indeterminate problems. A grey system is defined as a system that includes grey variables and a grey number to provide ambiguous information [26]. Fig. 1 illustrates the grey system theory.

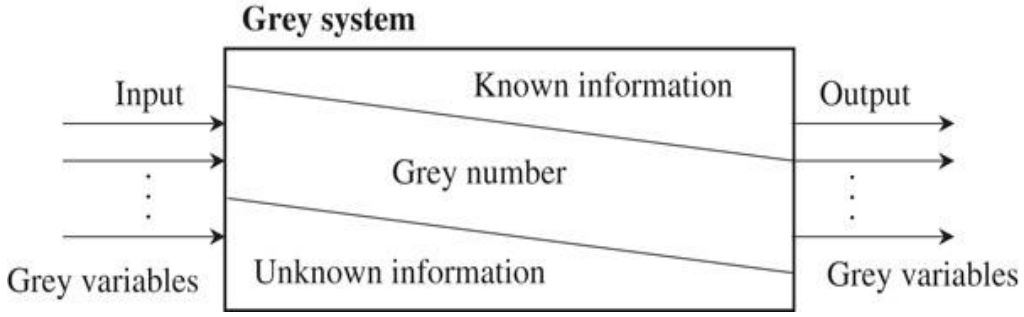

Fig. 1. Grey system theory.

The degree of information and connections between black and white systems are also explained by grey systems, in which grey numbers represent numbers with unknown precise values. Information that is partial, incomplete, or missing can take many different forms. This study uses grey numbers to reflect subjective judgments and reduce evaluation variance

among construction experts. Table I, from Liu and Forrest [27], compares black, grey, and white systems.

TABLE I. COMPARISONS OF BLACK, GREY, AND WHITE SYSTEMS

	Sytems parameter	**Black Sytem**	**Grey Sytem**	**White Sytem**
1	Information	Unknown	Incomplete	Completely known
2	Appearance	Dark	Blurred	Clear
3	Processes	New	Changing	Old
4	Properties	Chaotic	Multivariate	Order
5	Methods	Negation	Change for better	Confirmation
6	Attitude	Letting go	Tolerant	Rigorous
7	Outcomes	No solution	Multi-solutions	Unique solution

Let x denote a closed and bounded set of real numbers. A grey number, denoted as $\otimes x$, is a number with an unknown exact value but within a known range. These grey numbers represent uncertain and ambiguous data. In this study, we propose a combination of grey system theory and the analytical hierarchy process (AHP) decision-making method to reduce subjective judgments in prioritizing weights of important criteria in evaluating and selecting paint suppliers for a construction project.

In the grey AHP approach, grey numbers are used instead of crisp sets and crisp numbers. The grey AHP method uses pairwise comparisons with linguistic scales and gray scales. The main computational steps to use grey AHP in this study are as follows [28-49]:

Step 1. Define the research problem using traditional AHP. In this step, we identify the research problem, create the hierarchical structure, and construct the pairwise comparison matrix using construction experts' evaluations with linguistic scales containing grey numbers in Table II.

TABLE II. THE LINGUISTIC SCALES WITH GREY NUMBERS

Level of importance	**Linguistics Scale**	**Grey Numbers**
1	EI = Equivalent Importance	[1, 2]
3	MI = Medium Importance	[2, 4]
5	SI= Strong Importance	[4, 6]
7	VSI = Very Strong Importance	[6, 8]
9	EMI = Extreme Importance	[8, 10]

The grey comparison matrix using the geometrical mean formulation is constructed as follows:

$$D = \begin{bmatrix} \otimes x_{11} & \otimes x_{12} & \cdots & \otimes x_{1n} \\ \otimes x_{21} & \otimes x_{22} & \cdots & \otimes x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes x_{m1} & \otimes x_{m2} & \cdots & \otimes x_{mn} \end{bmatrix} \qquad (1)$$

where $\otimes x_{ij}$ is the pairwise comparison concerning the i^{th} criterion over the j^{th} criterion.

Step 2. Calculate the normalized grey comparison matrix. The normalization for the grey numbers is given in equations (2) through (4).

$$D^{*} = \begin{bmatrix} \left[\underline{x}^{*}_{11}, \overline{x}^{*}_{11}\right] & \left[\underline{x}^{*}_{12}, \overline{x}^{*}_{12}\right] & \cdots & \left[\underline{x}^{*}_{1n}, \overline{x}^{*}_{1n}\right] \\ \left[\underline{x}^{*}_{21}, \overline{x}^{*}_{21}\right] & \left[\underline{x}^{*}_{22}, \overline{x}^{*}_{22}\right] & \cdots & \left[\underline{x}^{*}_{2n}, \overline{x}^{*}_{2n}\right] \\ \vdots & \vdots & \vdots & \vdots \\ \left[\underline{x}^{*}_{m1}, \overline{x}^{*}_{m1}\right] & \left[\underline{x}^{*}_{m2}, \overline{x}^{*}_{m2}\right] & \cdots & \left[\underline{x}^{*}_{mn}, \overline{x}^{*}_{mn}\right] \end{bmatrix} \qquad (2)$$

$$\underline{x}_{ij}^{*} = \frac{\underline{x}_{ij}}{\frac{1}{2}\left(\sum_{i=1}^{m}\underline{x}_{ij} + \sum_{i=1}^{m}\overline{x}_{ij}\right)} = \frac{2\underline{x}_{ij}}{\sum_{i=1}^{m}\underline{x}_{ij} + \sum_{i=1}^{m}\overline{x}_{ij}} \tag{3}$$

$$\overline{x}_{ij}^{*} = \frac{\overline{x}_{ij}}{\frac{1}{2}\left(\sum_{i=1}^{m}\underline{x}_{ij} + \sum_{i=1}^{m}\overline{x}_{ij}\right)} = \frac{2\overline{x}_{ij}}{\sum_{i=1}^{m}\underline{x}_{ij} + \sum_{i=1}^{m}\overline{x}_{ij}} \tag{4}$$

Step 3. Calculate the grey weight of each criterion by determining the averages of the rows using Equation (5) as follows:

$$\otimes w_i = \frac{\sum_{j=1}^{n}\otimes x_{ij}^{*}}{n} = \frac{\sum_{j=1}^{n}\left[\underline{x}_{ij}^{*}, \overline{x}_{ij}^{*}\right]}{n} \tag{5}$$

where $n = \{1, 2, \ldots, N\}$ is the criterion set.

Step 4. Calculate the whitenization of the grey weight. The whited value of an interval grey weight is a crisp number with a potential value between the interval grey weight's upper and lower bounds, as follows:

$$M_i = (1-\lambda)\underline{w}_i + \lambda\overline{w}_i \tag{6}$$

where λ is the whitening coefficient and $\lambda \in [0,1]$.

Step 5. Calculate the consistency ratio (CR):

To determine whether the decision-comparison preparers were consistent, this step involves examining the consistency ratio of the pairwise comparison matrix. The calculation of the consistency ratio from construction experts is as follows [50-54]:

$$CR = \frac{CI}{RI} = \frac{\lambda_{\max} - n}{n-1} \times \frac{1}{RI} \qquad (7)$$

where

CI is the consistency index,

RI is the random index,

and $\lambda_{\max}$ is the largest eigenvalue.

IV. RESULTS AND DISCUSSION

For the calculation simplicity, TABLE III presents the integrated grey comparison matrix, developed based on the synthesis of construction expert opinions using the geometrical mean formulation for grey numbers given in TABLE II. Next, we calculated the normalized grey comparison matrix using Equations (2) to (4), shown in TABLE IV.

After obtaining the normalized grey comparison matrix, we calculate the grey weight of each criterion for evaluating and selecting the construction paint supplier by determining the row averages using Equation (5). The whitenization of the grey weights, obtained by applying Equation (6), is shown in TABLE V. We choose the value of λ to be 0.5 [55, 56]. Finally, we applied Equation (7). The consistency ratio of this pairwise comparison matrix (CR) = 2.02% < 10%, so the evaluation result is reliable because the pairwise comparison matrix is consistent.

The top five most important criteria for evaluating and selecting the paint supplier in construction projects were determined to be (F7) the price of the paint product, (F1) the reputation of the paint supplier, (F3) the quality of construction paint materials, (F2) the

quality management system certification of the paint supplier, and (F6) the terms and conditions of payment. Currently, the price of fuel, especially gasoline, is quite high due to scarcity resulting from the conflict between Russia and Ukraine. This causes most of the paint prices on the market to increase. Therefore, construction contractors are more interested in the price of paint materials than other criteria. Related to the second most important criterion, the reputation and branding of a paint supplier's products are known to many customers by advertising. Some large suppliers spend much money promoting their brands and products on all kinds of media, gaining notoriety in the business world, industry associations, and business partners. In contrast, some suppliers do not choose aggressive advertising methods but rely on their positive reputation to help them promote their branding.

Terms and conditions of payment are usually provided in the purchase contract. Contracts are documents that detail agreements between transaction objects created to achieve the needs of all parties. There are many forms of payment, including one-time payments or partial payments. The ability of the supplier to permit customers to owe money with attractive conditions will make the method of partial payment very popular because the contractor's cash flow is rarely consistent. In addition, to assist customers, the payment process needs to include whether the currency of the transaction is local (VND) or foreign (USD). The variety of options and convenience in financial transactions by the supplier will provide the contractor with more payment options. Because each contractor has its own form of currency storage and its own trading methods, some businesses pay in cash. Others pay through bank transfers, and foreign-owned companies use USD in their projects.

V. CONCLUSION

Applying a grey AHP, a new quantitative method, by integrating grey system theory with the AHP, we prioritize the critical criteria in the evaluation and selection process of building paint suppliers in construction projects. This new method has an advantage over traditional methods because it supports group decision-making. In addition, it also accounts for uncertainty in the judgments of construction professionals and data incompleteness. The top

five most important criteria for evaluating and selecting the paint supplier in construction projects are (F7) the price of the paint product, (F1) the reputation of the paint supplier, (F3) the quality of construction paint materials, (F2) the quality management system certification of the paint supplier, and (F6) the terms and conditions of payment.

TABLE III. THE INTEGRATED GREY COMPARISON MATRIX.

[1.00	1.00	[1.58	3.17	[1.25	2.51	[4.57	6.60	[3.17	5.24	[2.51	4.57	[0.63	1.25	[5.24	7.26
00,	00]	74,	48]	99,	98]	89,	39]	48,	15]	98	89]	00,	99]	15,	85]
[0.31	0.63	[1.00	1.00	[0.79	1.58	[2.00	3.63	[1.25	2.51	[1.25	2.51	[0.17	0.27	[5.24	7.26
50,	00]	00,	00]	37,	74]	00,	42]	99,	98]	99,	98]	33,	52]	15,	85]
[0.39	0.79	[0.63	1.25	[1.00	1.00	[3.17	5.24	[2.00	3.63	[1.58	3.17	[0.39	0.79	[3.63	5.76
69,	37]	00,	99]	00,	00]	48,	15]	00,	42]	74,	48]	69,	37]	42,	90]
[0.15	0.21	[0.27	0.50	[0.19	0.31	[1.00	1.00	[0.79	1.58	[0.34	0.63	[0.13	0.19	[0.79	1.58
14,	84]	52,	00]	08,	50]	00,	00]	37,	74]	67,	00]	76,	08]	37,	74]
[0.19	0.31	[0.39	0.79	[0.27	0.50	[0.63	1.25	[1.00	1.00	[0.63	1.25	[0.17	0.27	[0.79	1.58
08,	50]	69,	37]	52,	00]	00,	99]	00,	00]	00,	99]	33,	52]	37,	74]
[0.21	0.39	[0.39	0.79	[0.31	0.63	[1.58	2.88	[0.79	1.58	[1.00	1.00	[0.17	0.27	[2.00	3.63
84,	69]	69,	37]	50,	00]	74,	45]	37,	74]	00,	00]	33,	52]	00,	42]
[0.79	1.58	[3.63	5.76	[1.25	2.51	[5.24	7.26	[,3.6	5.76	[3.63	5.76	[1.00	1.00	[6.60	8.61
37,	74]	42,	90]	99,	98]	15,	85]	342	90]	42,	90]	00,	00]	39,	77]
[0.13	0.19	[0.13	0.19	[0.17	0.27	[0.63	1.25	[0.63	1.25	[0.27	0.50	[0.11	0.15	[1.00	1.00
76,	08]	76,	08]	33,	52]	00,	99]	00,	99]	52,	00]	60,	14]	00,	00]

TABLE IV. THE INTEGRATED GREY COMPARISON MATRIX.

[0.23 99,	0.23 99]	[0.14 74,	0.29 48]	[0.17 24,	0.34 48]	[0.19 08,	0.27 52]	[0.17 69,	0.29 21]	[0.16 42,	0.29 84]	[0.17 94,	0.35 89]	[0.16 90,	0.23 43]
[0.07 56,	0.15 11]	[0.09 29,	0.09 29]	[0.10 86,	0.21 72]	[0.08 33,	0.15 14]	[0.07 02,	0.14 04]	[0.08 21,	0.16 42]	[0.04 94,	0.07 84]	[0.16 90,	0.23 43]
[0.09 52,	0.19 04]	[0.05 85,	0.11 70]	[0.13 68,	0.13 68]	[0.13 23,	0.21 84]	[0.11 15,	0.20 25]	[0.10 35,	0.20 69]	[0.11 30,	0.22 61]	[0.11 72,	0.18 60]
[0.03 63,	0.05 24]	[0.02 55,	0.04 64]	[0.02 61,	0.04 31]	[0.04 17,	0.04 17]	[0.04 42,	0.08 85]	[0.02 26,	0.04 11]	[0.03 92,	0.05 43]	[0.02 56,	0.05 12]
[0.04 58,	0.07 56]	[0.03 68,	0.07 37]	[0.03 77,	0.06 84]	[0.02 60,	0.05 30]	[0.05 57,	0.05 57]	[0.04 11,	0.08 21]	[0.04 94,	0.07 84]	[0.02 56,	0.05 12]
[0.05 24,	0.09 52]	[0.03 68,	0.07 37]	[0.04 31,	0.08 62]	[0.06 60,	0.12 00]	[0.04 40,	0.08 80]	[0.06 52,	0.06 52]	[0.04 94,	0.07 84]	[0.06 45,	0.11 72]
[0.19 04,	0.38 09]	[0.33 74,	0.53 57]	[0.17 24,	0.34 48]	[0.21 84,	0.30 29]	[0.20 25,	0.32 15]	[0.23 69,	0.37 60]	[0.28 48,	0.28 48]	[0.21 29,	0.27 78]
[0.03 30,	0.04 58]	[0.01 28,	0.01 77]	[0.02 37,	0.03 77]	[0.02 63,	0.05 25]	[0.03 51,	0.07 02]	[0.01 79,	0.03 26]	[0.03 31,	0.04 31]	[0.03 22,	0.03 22]

TABLE V. THE WHITENIZATION OF THE GREY WEIGHTS.

(F1) The reputation of the paint supplier		0.2362
(F2) The quality management system certification of the paint supplier		0.1226
(F3) Quality of construction paint materials		0.1470
(F4) Number of paint categories and products		0.0425
(F5) Delivery time	=	0.0535
(F6) Terms and conditions of payment		0.0716
(F7) Price of the paint product		0.2925
(F8) Warranty period.		0.0341

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