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Application of Multi-Objective Optimization in Copper Electrical Wire Selection

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Abstract
Solving multi-objective optimization problems is a common task that plays a crucial role in various fields, ranging from economics and management to engineering. The process of solving this problem consists of two core stages: determining the criteria weights and selecting an appropriate mathematical method to rank the alternatives. This study proposes an integrated solution combining three methods—Entropy, MEREC, and TOPSIS—to solve the multi-objective optimization problem in selecting the best copper-core electrical wire from 28 existing products. Specifically, Entropy and MEREC are applied to calculate the criteria weights, while TOPSIS serves to rank the alternatives. The analysis results show that although the rankings of the wire types vary when using the two sets of weights from Entropy and MEREC, consistency is still observed for certain alternatives. Notably, the electrical wire with product code 20255114 was identified as the optimal alternative among the 28 surveyed types.
Keywords: *Multi-optimization, Entropy, MEREC, TOPSIS*

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I. Introduction

Calculating weights for objectives (also known as criteria) and selecting Multi-Criteria Decision-Making (MCDM) methods are two vital tasks in ranking alternatives to find the best one among many available options [1-3]. To calculate criteria weights, objective weighting methods, subjective weighting methods, and combined weighting methods (incorporating both subjective and objective factors) can be applied [4, 5]. Among them, numerous studies have indicated that using objective weighting methods provides users with more accurate and transparent decisions [6-8]. Various objective weighting methods have been widely applied in different fields, such as the Entropy method [9], MEREC method [10], SPC method [11], LOPCOW method [12], CRITIC method [13], ITARA method [14], etc. The Entropy and MEREC methods have been confirmed to possess high accuracy and are highly recommended [15]; for this reason, these two methods are utilized in the current study.

Currently, there are hundreds of different MCDM methods, each developed based on distinct philosophies [16]. Many prominent methods have been extensively used recently, such as TOPSIS [17], SAW [18], PIV [19], VIKOR [20], CoCoSo [21], MOORA [22], COPRAS [23], CODAS [24], EDAS [25], etc. Among them, TOPSIS is considered the most famous and widely used method [26], which explains why TOPSIS is also employed in this study.

Section 2 of this paper presents the steps for applying the Entropy and MEREC methods to calculate criteria weights, as well as the steps for applying the TOPSIS method to rank alternatives. The integration of the Entropy, MEREC, and TOPSIS methods to rank the copper-core electrical wires is presented in Section 3. The conclusion regarding the best copper-core electrical wire found is the final content of this paper.

II. Methodology

2.1. Entropy Method

To calculate criteria weights using the Entropy method, the following sequence is applied [27]:

- **Step 1:** Construct a decision matrix with *m* rows and *n* columns, where *m* is the number of alternatives to be ranked (number of experiments), and *n* is the number of criteria to evaluate each alternative.
- Let x_{ij} be the value of criterion *j* for alternative *i*, with *j* = 1 ÷*n*, *i* = 1÷*m*.

$$n_{\mathrm{ij}} = \frac{x_{\mathrm{ij}}}{m + \sum_{i=1}^{m} x_{\mathrm{ij}}^2} \tag{1}$$

- **Step 2:** Determine the normalized values for the criteria using Equation (1).

$$e_{\mathrm{j}} = \sum_{i=1}^{m} \left[n_{\mathrm{ij}} \times \ln(\mathrm{n}_{\mathrm{ij}}) \right] - \left(1 - \sum_{i=1}^{m} n_{\mathrm{ij}}\right) \times \ln\left(1 - \sum_{i=1}^{m} n_{\mathrm{ij}}\right) \tag{2}$$

Step 3: Calculate the Entropy measure for each criterion using Equation (2).

$$e_{\mathrm{j}} = \sum_{i=1}^{m}\left[n_{\mathrm{ij}} \times \ln(\mathrm{n}_{\mathrm{ij}})\right] - \left(1 - \sum_{i=1}^{m} n_{\mathrm{ij}}\right) \times \ln\left(1 - \sum_{i=1}^{m} n_{\mathrm{ij}}\right) \quad (2)$$

Step 4: Calculate the weight for each criterion using Equation (3).

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n}(1 - e_j)} \quad (3)$$

2.2. MEREC Method

To calculate criteria weights using the MEREC method, the following sequence is applied [28]:

Step 1: Same as Step 1 of the Entropy method.

Step 2: Calculate normalized values using Equations (4) and (5).

For "larger-the-better" criteria:

$$n_{ij} = \frac{minx_{ij}}{x_{ij}} \quad (4)$$

For "smaller-the-better" criteria:

$$n_{ij} = \frac{x_{ij}}{max\ x_{ij}} \quad (5)$$

Step 3: Calculate the overall performance of the alternatives using Equation (6).

$$S_i = Ln\left[1 + \left(\frac{1}{n}\sum_{j}^{n}\left|ln(n_{ij})\right|\right)\right] \quad (6)$$

Step 4: Calculate the performance of alternatives by removing each criterion using Equation (7).

$$S'_{ij} = Ln\left[1 + \left(\frac{1}{n}\sum_{k,k\neq j}^{n}\left|ln(n_{ij})\right|\right)\right] \quad (7)$$

Step 5: Calculate the absolute deviations using Equation (8).

$$E_j = \sum_{i}^{m}\left|S'_{ij} - S_i\right| \quad (8)$$

Step 6: Calculate the weight for each criterion using Equation (9).

$$w_j = \frac{E_j}{\sum_{k}^{n} E_k} \quad (9)$$

2.3. TOPSIS Method

To rank alternatives using the TOPSIS method, the following sequence is applied [29]:

Step 1: Same as Step 1 of the Entropy method.

Step 2: Determine normalized values using Equation (10).

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad (10)$$

Step 3: Calculate the weighted normalized values using Equation (11).

$$y_{ij} = w_j . n_{ij} \quad (11)$$

Step 4: Determine the best solution $A^+$and worst solution $A^-$for the criteria using Equations (12) and (13).

$$A^+ = \left\{y_1^+, y_2^+, \ldots, y_j^+, \ldots, y_n^+\right\} \quad (12)$$

$$A^- = \left\{y_1^-, y_2^-, \ldots, y_j^-, \ldots, y_n^-\right\} \quad (13)$$

Where:$y_j^+$and$y_j^-$are respectively the best and worst values of the normalized value $y_{ij}$for criterion j.

Step 5: Determine the separation measures S_i^+ and S_i^-using Equations (14) and (15).

$$\boldsymbol{S_i^+ = \sqrt{\sum_{j=1}^{n}\left(y_{ij} - y_j^+\right)^2}}\ i = 1, 2, \ldots, m \quad (14)$$

$$\boldsymbol{S_i^- = \sqrt{\sum_{j=1}^{n}\left(y_{ij} - y_j^-\right)^2}}\ i = 1, 2, \ldots, m \quad (15)$$

Step 6: Determine the relative closeness C_i^* using Equation (16).

$$C_i = \frac{s_i^-}{s_i^+ + s_i^-} \qquad i = 1, 2, \ldots, m;\ 0 \le C_i^* \le 1 \tag{16}$$

Step 7: Rank the alternatives according to the principle that the alternative with the highest S_i^+ is the best one.

3. Results and Discussion

Table 1 summarizes the data for 28 types of copper-core electrical wires provided by a supplier, denoted from A1 to A28, with corresponding product codes as shown in column 2 of Table 1 [30]. Nine criteria describing each alternative are denoted from C_1 to C_9, where C_9 is a "smaller-the-better" criterion, and the remaining eight criteria are "larger-the-better". The meanings of these criteria are respectively: Nominal cross-sectional area (mm^2); Number of strands; Copper wire strand diameter (mm); Insulation thickness between copper strands (mm); Sheath thickness (mm); Overall diameter (mm); Maximum DC resistance of conductor at20^0C (Ohm/km); Mass (kg/m); Price (VNDT/m, VNDT = Vietnamese dong thousand).

Table 1. Copper-core electrical wire types [30]

Alt.	CODE	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	20225103	1.00	20	0.18	0.6	0.8	5.4	39.00	0.0489	7.201
A2	20225106	1.50	30	0.18	0.6	0.8	6.3	26.00	0.0587	11.533
A3	20225107	2.00	40	0.18	0.6	0.8	6.6	19.50	0.0688	18.346
A4	20225108	2.00	32	0.20	0.6	0.8	6.6	19.50	0.0686	26.607
A5	20225110	3.00	48	0.20	0.7	0.8	7.6	13.20	0.0935	42.857
A6	20225111	3.00	30	0.25	0.7	0.8	7.6	13.30	0.0930	24.388
A7	20225114	5.00	50	0.25	0.8	1	9.3	7.98	0.1405	38.284
A8	20235103	1.50	20	0.18	0.6	0.8	6.2	39.00	0.0573	57.225
A9	20235106	2.25	30	0.18	0.6	0.8	6.7	26.00	0.0709	23.670
A10	20235107	3.00	40	0.18	0.6	0.8	7	19.50	0.0833	38.418
A11	20235108	3.00	32	0.20	0.6	0.8	7	19.50	0.0830	58.843
A12	20235110	4.50	48	0.20	0.7	0.9	8.3	13.30	0.1187	38.699
A13	20235111	4.50	30	0.25	0.7	0.9	8.3	13.30	0.1172	24.412
A14	20235114	7.50	50	0.25	0.8	1.1	10.1	7.98	0.1782	35.212
A15	20245103	2.00	20	0.18	0.6	0.8	6.7	39.00	0.0706	26.117
A16	20245106	3.00	30	0.18	0.6	0.8	7.2	26.00	0.0869	36.484
A17	20245107	4.00	40	0.18	0.6	0.9	7.9	19.50	0.1074	54.228
A18	20245108	4.00	32	0.20	0.6	0.9	7.9	19.50	0.1071	26.685
A19	20245110	6.00	48	0.20	0.7	1	9.3	13.30	0.1517	48.426
A20	20245111	6.00	30	0.25	0.7	1	9.3	13.30	0.1507	48.426
A21	20245114	10.00	50	0.25	0.8	1.1	10.9	7.98	0.2200	66.126
A22	20255103	2.50	20	0.18	0.6	0.9	7.7	39.00	0.0830	26.123
A23	20255106	3.75	30	0.18	0.6	0.9	8.2	26.00	0.1075	33.170
A24	20255107	5.00	40	0.18	0.6	0.9	8.9	19.50	0.1294	34.208
A25	20255108	5.00	32	0.20	0.6	0.9	8.9	19.50	0.1298	37.816
A26	20255110	7.50	48	0.20	0.7	1.1	9.7	13.30	0.1871	44.126
A27	20255111	7.50	30	0.25	0.7	1.1	9.7	13.30	0.1858	54.212
A28	20255114	12.50	50	0.25	0.8	1.2	11	13.30	0.2724	65.746

The task is to determine the best electrical wire type in Table 1. However, examining the data in this table reveals that C1 is highest at A28; C2 is highest at alternatives A14, A21, and A28; C3 is highest at A13, A14, and A28; C4 is highest at A14 and A21; C5 is highest at A28; C6 is highest at A28; C7 is highest at A22; C8 is highest at A28; while C9 is lowest at A1. This means that there is no single alternative where all parameters are the best; an alternative can only be found where all criteria are considered "best overall".

Naturally, solving this requires multi-objective optimization. In this study, the TOPSIS method is used for this task.

To apply the TOPSIS method in solving the multi-objective optimization problem, calculating the criteria weights is critical. Applying formulas (1) to (3), the weights of criteria C1 to C9 calculated by the Entropy method are 0.1089, 0.0759, 0.1183, 0.1675, 0.1739, 0.1008, 0.0804, 0.0994, and 0.0749, respectively. Applying formulas (4) to (9), the weights of criteria C1 to C9 calculated by the MEREC method are 0.2710, 0.1089, 0.0240, 0.0162, 0.0223, 0.0773, 0.1781, 0.1572, and 0.1450, respectively. It is observed that the weight values of each criterion calculated by the two different methods differ significantly. This is explained by the fact that the approaches of the Entropy and MEREC methods are very distinct. However, this also provides an opportunity to select the best electrical wire in the most objective manner.

Using the criteria weights calculated by the Entropy and MEREC methods and applying formulas (10) to (16) to calculate the Ci score for each alternative, the results are summarized in Table 2. Based on these scores, the rankings of the alternatives are established and summarized in this table.

Table 2. Scores and rankings of electrical wire types

Alt.	Entropy weight		MEREC weight	
	C_i	Rank	C_i	Rank
A1	0.3233	16	0.3267	13
A2	0.2815	20	0.2755	19
A3	0.2652	23	0.2512	24
A4	0.2333	27	0.2234	27
A5	0.2585	25	0.2240	26
A6	0.2853	19	0.2515	23
A7	0.4126	8	0.3523	10
A8	0.2595	24	0.2745	20
A9	0.2695	21	0.2685	22
A10	0.2470	26	0.2417	25
A11	0.1996	28	0.2021	28
A12	0.3459	12	0.3211	16
A13	0.3601	11	0.3345	12
A14	0.5454	3	0.5073	4
A15	0.3139	17	0.3224	14
A16	0.2691	22	0.2735	21
A17	0.2857	18	0.2793	18
A18	0.3265	15	0.3191	17
A19	0.4338	6	0.4108	6
A20	0.4240	7	0.4010	7
A21	0.6061	2	0.5962	2
A22	0.3384	13	0.3395	11
A23	0.3267	14	0.3221	15
A24	0.3804	9	0.3754	8
A25	0.3688	10	0.3658	9
A26	0.5391	4	0.5179	3
A27	0.5160	5	0.4971	5
A28	0.6969	1	0.6962	1

According to the data in Table 2, the rankings of the alternatives show considerable differences when criteria weights are calculated using the two different methods. This is entirely understandable because the weight values derived from Entropy and MEREC are relatively different, as discussed above. Nevertheless, there are still alternatives that maintain consistent rankings regardless of which weighting method is used. Specifically, A19 is always ranked 6th, A20 is always ranked 7th, A21 is always ranked 2nd, A27 is always ranked 5th, and notably, A28 is always ranked 1st. Thus, we conclude that A28 is the best alternative among all options, or in other words, the electrical wire with product code 20255114 is the best among the 28 evaluated types.

III. Conclusion

This study integrated the Entropy, MEREC, and TOPSIS methods to solve an optimization problem, specifically identifying the best electrical wire among 28 available types from a supplier. The electrical wire with product code 20255114 was identified as the best option, featuring a nominal cross-sectional area of 12.50mm2; 50 strands; a copper strand diameter of 0.25mm; an insulation thickness between copper strands of 0.8mm; a sheath thickness of 1.2mm; an overall diameter of 11mm; a maximum conductor DC resistance at 20^0C of 13.30 Ohm/km; a mass of 0.2724kg/m; and a price of 65.746VNDT/m.

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