



Integrated TOPSIS-PROMETHEE-MOORA model for material selection of crankcase cover

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Material selection is an important task for designers in all industries. To satisfy customer needs, designers have to predict the performance of all available materials and find out the best material for the product. Since the various materials are available in the market with diverse characteristics, which makes the material selection process is complex. So, there is an indispensable need for a proper material selection methodology. The designers have to identify the best approach which enhanced the product performance and also reduced the time of designing. In this study, first-time selection of materials for two-wheeler crankcase cover has done using integrated TOPSIS (Technique for order preference by similarity to ideal solution) PROMETHEE (Preference ranking organization method for enrichment evaluation), and MOORA (Multi-objective optimization by ration analysis) model. The final rankings of alternatives obtained from this integrated model have also been compared with each other for finding the best material for crankcase cover. Six aluminum alloys (Alloy 360, Alloy 380, Alloy A380, Alloy 383, Alloy B390, and Alloy 13) have been taken as alternatives, and seven attributes (Brinell hardness, yield strength, % elongation, young's modulus, ultimate tensile strength, fatigue strength, and material cost) have been taken as criteria for this study.

Keywords: Aluminum alloy, Crankcase cover, MADM, Material selection, MCDM

1 Introduction

Proper material selection has led to improve product quality, cost, and productivity. Proper material selection has not based on single criteria or dimensions. The designers have needed to consider multiple criteria for material selection¹. The goal of every designer has to select the best material for optimal design to reduce cost and enhance performance². The accuracy of the material selection has dependent on designer experiences and material data records used³. Improper selection has led to failure in customer satisfaction and incurred huge losses for the industry also. The designers must have detailed knowledge of all criteria or attributes for product development and design⁴. Initially, before the material selection, material screening has done with the help of the chart method, knowledge-based system method, or the computer-aided method⁵.

The Material selection for crankcase cover is a complex and challenging engineering problem because of the large no. of alternatives with diverse properties⁶. A two-wheeler crankcase cover has generally manufactured by the cold chamber die

casting process. Aluminum alloys have a very good performance-to-weight ratio and easy to cast. Aluminum alloys are the first choice for all the products manufactured by the die casting techniques because these alloys have provided superior performance to weight ratio and low specific gravity value. Aluminum alloys have mainly alloyed with silicon, magnesium, copper, iron, manganese, and zinc to enhance their properties. Eleven aluminum alloys are worldwide used in various die casting processes. Out of these eleven alloys, some aluminum alloys are difficult to cast e.g. Alloy A 360, Alloy 43, and Alloy 218. Alloy 390 has the least machining characteristics because of the presence of high silicon in it. Six aluminum alloys have been taken as alternatives for crankcase cover materials (Alloy 360 (A₁), Alloy 380 (A₂), Alloy A380 (A₃), Alloy 383 (A₄), Alloy B390 (A₅), and Alloy 13 (A₆)) and seven attributes (Brinell hardness (HB), yield strength (MPa), % elongation (in 2 inches), young's modulus (MPa), ultimate tensile strength (MPa), fatigue strength (MPa), and material cost (US \$ per ton) have been taken as criteria. The % elongation property represents the ductility or crash resistance of the material. This property is considered as beneficial criteria because more % elongation provides more

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safety to the passengers by dissipating some failure effects into plastic deformation. The young's modulus is a material property representing the stiffness of a material. This property remains constant for isotropic material and varies for an anisotropic material. To get a more reliable result of material selection, most of the researchers have used more than one MCDM approach^{7,8}. Many researchers have used the TOPSIS and MOORA methodology in various material selection problems as discussed in the literature part. Integrated TOPSIS MOORA methodology has been used for the new product selection⁹. For the first time, both these approaches have been applied simultaneously for the material selection of crankcase cover in the automobile industry. The first objective of the study is to find out the best material for the two-wheeler crankcase cover in the automobile industry. The second objective is to compare and validate the results by other MCDM approaches such as MOORA, reference point approach, and PROMETHEE with greater accuracy.

The material selection problem is considered an MCDM problem and it is solved by considering all multiple conflicting criteria¹⁰. Milani *et al.*¹¹ has applied the MCDM approach for material selection of plastic gear with the life cycle assessment. Gupta¹² has used the MADM approach for the material selection problem of thin-film solar cells. Bhowmik *et al.*¹³ has adopted the TOPSIS technique for energy-efficient material selection and used sensitivity analysis for validating the results. Jajimoggala *et al.*¹⁴ has utilized an MCDM approach for the material selection of impellers using the TOPSIS technique. Okokpuije *et al.*¹⁵ has utilized the AHP and TOPSIS technique for wind turbine blade material selection. Aly *et al.*¹⁶ has proposed an integrated fuzzy geometric mean method TOPSIS model for material selection and design concept. Kelemenis *et al.*¹⁷ has adopted the TOPSIS technique for personnel selection and enhanced the organization's performance. Tiwary *et al.*¹⁸ has utilized the fuzzy TOPSIS for the parameter selection of the micro-EDM process.

Mousavi-Nasab *et al.*⁸ has adopted MCDM approaches such as DEA (Data Envelopment Analysis), TOPSIS, and COPRAS for material selection problems. Zanakis¹⁹ has analyzed the performance using a simulation comparison of ELECTRE, TOPSIS Multiplicative Exponential Weighting, Simple Additive Weighting, and AHP. Dagdeviren⁵ has selected the best equipment among

many alternatives using the AHP and PROMETHEE and this proper selection has increased productivity, flexibility, precision, and product quality.

Anoj kumar *et al.*²⁰ has adopted the comparative MCDM analysis approach for material selection of pipes in the sugar industry. Shanian *et al.*³ has applied the TOPSIS technique for material selection of metallic bipolar plates. Dursun *et al.*¹⁶ has employed a fuzzy COPRAS method for material selection for the detergent manufacturers. Ashby *et al.*²¹ has described that there is a material selection option is between 40,000 to 80,000 and almost 1000 ways to process them which have shown that the material selection problems are complex and challenging. They have also shown the selection strategies for materials and processes. Chatterjee *et al.*²² has used the COPRAS and ARAS (additive ratio assessment) techniques for gear material selection. Chatterjee *et al.*²³ has also applied the four MCDM techniques together for gear material selection problems. These Four MCDM techniques are extended PROMETHEE II, COPRAS, ORESTE (Organization, Rangement Et Syn- these De Donnes Relationnelles), and operational competitiveness rating analysis (OCRA) methods. Athawale *et al.*²⁴ has solved the material selection problems using the utility additive (UTA) method. UTA method is one type of MCDM tool used for solving the various complex material selection problems. Chakraborty *et al.*²⁵ has applied the three MCDM approaches such as TOPSIS, VIKOR, and PROMETHEE for five material selection problems. They have also shown that the choices of the final selection depend on the criteria weights. Maity *et al.*²⁶ used the fuzzy TOPSIS for material selection of grinding wheel abrasive. Ilangkumaran *et al.*²⁷ has adopted the hybrid MCDM approach for material selection of automobile bumpers. They have applied the Fuzzy AHP, PROMETHEE I, and PROMETHEE II for ranking of the materials. Chakraborty²⁸ has considered the MOORA methodology for robot selection, flexible manufacturing system selection, CNC machine selection, and manufacturing process selection in the manufacturing environment.

The past studies have shown that most of the researchers have successfully applied the MCDM approach to solving the material selection problem. After reviewing the existing literature, it has been found a material selection of crankcase cover in the automobile industry is an untouched area of research. This is our motivation to find out the best material for

a two-wheeler crankcase cover in the automobile industry.

The above studies have also shown that TOPSIS and MOORA methodologies are effective in the identification and selection of the best material for a particular product. Therefore, the present study initially aims to identify the material available for the crankcase cover using experts from the automobile industry. Later on, TOPSIS methodology has applied for material selection of crankcase cover and its results are validated using the MOORA and PROMETHEE methodology.

2 Materials and Methods

Material Selection Methodology includes the MCDM (Multi-Criteria decision making) methods and optimization methods. MCDM method is stratified into two types, MADM (Multi-attribute decision making) and fuzzy MCDM methods. Multiple objective decision making, mathematical programming, computer simulation, and genetic algorithm come in the category of optimization methods²⁹. The stratification of material selection methods is shown in Fig. 1.

2.1 TOPSIS methodology

TOPSIS methodology was proposed by Tzeng and Huang in 1981. TOPSIS is an MCDM tool generally used in combination with MOORA, AHP, ELECTRE, or PROMETHEE. The advantage offered by this technique is that it allows a tradeoff between the criteria where a bad result by one criterion is compensated by a good result by another criterion. TOPSIS is a simple approach and it is superior to other MCDM techniques for the material selection

problems because it handles qualitative as well as quantitative information³⁰.

For the proper material selection of crankcase cover, we compared the attributes or properties of these crankcase cover. The seven attributes taken for this study are brinell hardness, yield strength, % elongation, ultimate tensile strength, young's modulus, fatigue strength, and material cost. The six alternatives taken in this study that is also commonly used in the industries are Alloy 360, Alloy 380, Alloy A380, Alloy 383, Alloy B390, and Alloy 13. These material selection criteria are shown in Fig. 2.

Multi-criteria decision-making methods (MCDM) helps in identifying the best alternative based on different criteria. TOPSIS is one of the best methods of MCDM in dealing with real-life problems³⁰. The steps of TOPSIS methodology are as follows:

Step 1 - The first step is to construct a Decision Matrix (DM) based on different alternatives and criteria.

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & \dots & x_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & \dots & x_{mn} \end{bmatrix} \dots(1)$$

where, i = alternative index (1, 2, 3...m) and j=criterion index (j = 1, 2, 3...n) in Eq. 1.

Step 2 - Find the normalized decision matrix x_{ij}^* using Eq. 2.

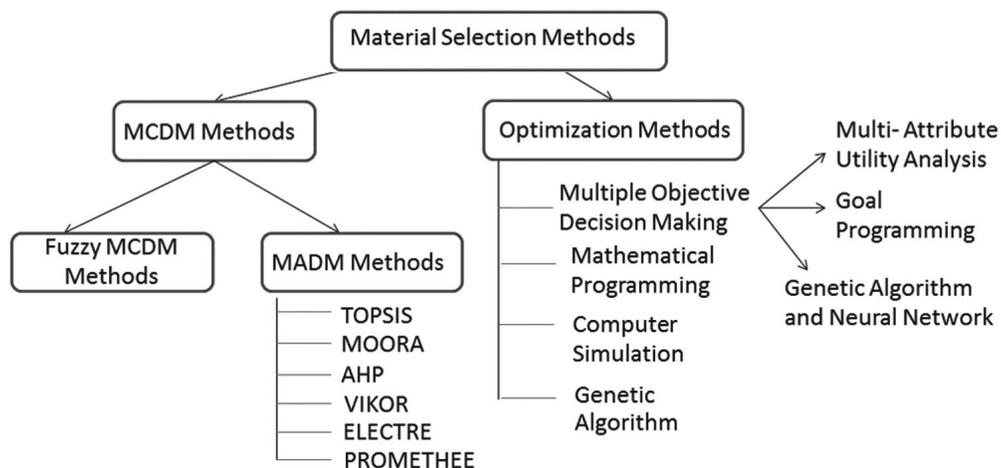


Fig. 1 — Stratification of material selection methods.

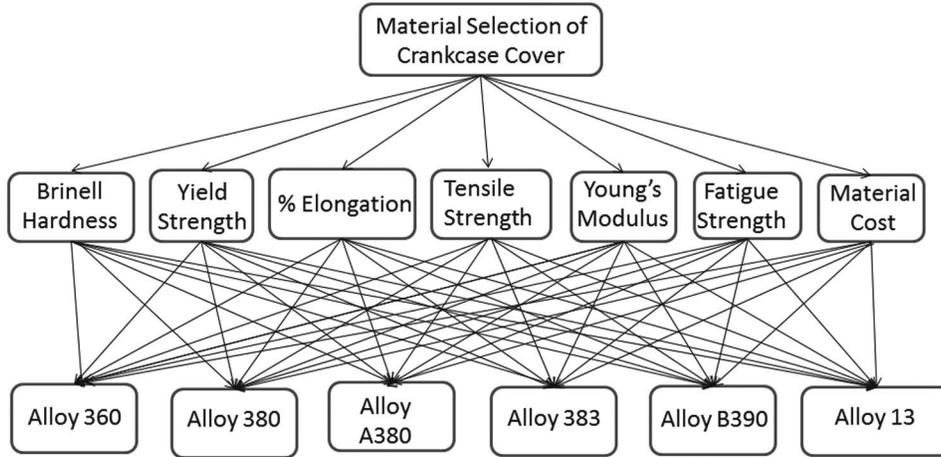


Fig. 2 — Material Selection criteria of TOPSIS.

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad \dots(2)$$

Step 3 - Calculate the weighted decision matrix d_{ij} using Eq. 3.

$$d_{ij} = w_j \times x_{ij}^* \quad \dots(3)$$

Step 4 - Find the Positive Ideal Solution A^+ and Negative Ideal Solution A^-

$$A^+ = \{d_1^+, d_2^+, \dots, d_n^+\}, \text{ where: } d_j^+ \quad \dots(4)$$

$$= \{(\max_i (d_{ij}) \text{ if } j \in K); (\min_i (d_{ij}) \text{ if } j \in K')\}$$

$$A^- = \{d_1^-, d_2^-, \dots, d_n^-\}, \text{ where: } d_j^- \quad \dots(5)$$

$$= \{(\min_i (d_{ij}) \text{ if } j \in K); (\max_i (d_{ij}) \text{ if } j \in K')\}$$

where, K and K' are beneficial and the non-beneficial based attributes in Eqs 4-5³⁵.

Step 5 - Calculate the separation distances (S^+ & S^-) of each alternative from ideal and non-ideal solutions using Eqs 6-7.

$$S^+ = \sqrt{\sum_{j=1}^n (d_j^+ - d_{ij})^2} \quad \dots(6)$$

$$S^- = \sqrt{\sum_{j=1}^n (d_j^- - d_{ij})^2} \quad \dots(7)$$

Step 6 - Measure the relative closeness C_i values using the Eq. 8.

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}, \quad 0 \leq C_i \leq 1 \quad \dots(8)$$

Step 7 - Based on the relative closeness values, a ranking of alternatives is obtained.

2.2 MOORA methodology

MOORA methodology is a multi-objective optimization technique which is preferred than other MCDM approach because of its fast computational time. MOORA methodology consists of two components. The first one is the ration system developed in 2004 by Brauers and the other reference point approach developed in 2006 by Brauers and Zavadskas. This technique is used in solving the various complex decision-making problems^{33,34}. This technique can optimize the two or more conflicting criteria at the same time e.g. minimize cost and maximize profit²⁴. The methodology of MOORA is as follows:

Step 1 - Find the decision matrix X in which x_{ij} shows performance index of i_{th} alternative w.r.t j_{th} attribute, $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$ using Eq. 1.

Step 2 - Find normalized decision matrix x_{ij}^* using Eq. 2.

Step 3 - The overall performance score of each alternative y_i^* is calculated by adding all beneficial criteria and subtracting the non-beneficial criteria as given in Eq. 9.

$$y_i^* = \sum_{j=1}^q x_{ij}^* - \sum_{j=q+1}^n x_{ij}^* \quad \dots(9)$$

Here, q and (n-q) are the number of beneficial and non-beneficial criteria respectively. Equation 10 can be used for giving weights to the different criteria^{4,28}.

$$y_i^* = \sum_{j=1}^q w_j x_{ij}^* - \sum_{j=q+1}^n w_j x_{ij}^* \quad \dots(10)$$

Step 4 - The ranking of alternatives is obtained using y_i^* values from equations 9-10.

The above four steps show the calculation of the ration system part of the MOORA method. The reference point part is shown in steps 5 and 6.

Step 5 - Determine the Tche by cheff Min–Max metric³⁴.

$$\min_i \left\{ \max_j |s_j - x_{ij}^*| \right\} \quad \dots(11)$$

s_j is the j_{th} coordinate of the reference point which shows those alternatives having the most desirable performances concerning j_{th} criterion. For determining s_j , Eq. 12 can be used. Equation 13 can be used in the case of assigning weights to alternatives.

$$s_j = \begin{cases} \max_i x_{ij}^* \\ \min_i x_{ij}^* \end{cases} \quad \dots(12)$$

$\max_i x_{ij}^*$ represents beneficial criteria & $\min_i x_{ij}^*$ represents non-beneficial criteria.

$$\min_i \left\{ \max_j |w_j s_j - w_j x_{ij}^*| \right\} \quad \dots(13)$$

Step 6 - Finally, the selection of alternatives is done using the minimum deviation value from reference point²⁴.

2.3 PROMETHEE Methodology

PROMETHEE is an MCDM method developed by Brans *et al.*^{35,36}. PROMETHEE methodology is classified into two types PROMETHEE I and PROMETHEE II. PROMETHEE I is used for obtaining the partial ranking of alternatives whereas

PROMETHEE II provides the full ranking of alternatives.

The aggregated preference index of ‘a’ over ‘b’ is represented by $\pi(a, b)$ for each alternative a, belonging to the set A of alternatives. The leaving flow $\phi^+(a)$ and the entering flow $\phi^-(a)$ show the positive and negative dominance of alternative ‘a’ on all another alternative.

The methodology of PROMETHEE II is described as follows.

Step 1 - Normalize the evaluation matrix or decision matrix (R_{ij})

$$R_{ij} = \frac{[x_{ij} - \min(x_{ij})]}{[\max(x_{ij}) - \min(x_{ij})]} \quad \dots(14)$$

$$R_{ij} = \frac{[\max(x_{ij}) - x_{ij}]}{[\max(x_{ij}) - \min(x_{ij})]} \quad \dots(15)$$

Where, $i=1, 2, \dots, m; j=1, 2, \dots, n$. Equations 14-15 are applicable for beneficial and non-beneficial criteria respectively.

Step 2 - Calculate the evaluative differences of i^{th} alternative concerning other alternatives

Step 3 - Calculate the preference function $P_j(s, t)$ using equations 16-17.

$$P_j(s, t) = 0 \text{ if } R_{sj} \leq R_{tj} \quad \dots(16)$$

$$P_j(s, t) = (R_{sj} - R_{tj}) \text{ if } R_{sj} > R_{tj} \quad \dots(17)$$

Step 4 - Determine the aggregated preference function $\pi(s, t)$

$$\pi(s, t) = \left[\frac{\sum_{j=1}^n W_j P_j(s, t)}{\sum_{j=1}^n W_j} \right] \quad \dots(18)$$

Step 5 - Calculate the leaving and the entering outranking flows

Leaving flow for s^{th} alternative

$$\phi^+ = \frac{1}{m-1} \sum_{t=1}^m \pi(s, t) \quad (s \neq t) \quad \dots(19)$$

Entering flow for s^{th} alternative

$$\varphi^- = \frac{1}{m-1} \sum_{t=1}^m \pi(t,s) \quad (s \neq t) \quad \dots (20)$$

where, m is the number of alternatives in equations 19-20.

Step 6 - Calculate the net outranking flow $\varphi(s)$ for each alternative

$$\varphi(s) = \varphi^+(s) - \varphi^-(s) \quad \dots (21)$$

Step 7 - Determine the ranking of alternatives based on the net outranking flow value $\varphi(a)$.

2.4 Application of TOPSIS-PROMETHEE-MOORA model

In this study, seven attributes are considered and these attributes are of different types, among these six attributes belong to the category of beneficial criteria and there is only one non-beneficial criterion. The beneficial criteria are Brinell hardness (C_1), yield strength (C_2), % elongation (C_3), tensile strength (C_4), young’s modulus (C_5), and fatigue strength (C_6) whereas the material cost (C_7) is the non-beneficial criteria. This study aims to maximize the beneficial criteria and minimize the non-beneficial criteria. The conflicting criteria are optimized using the Integrated TOPSIS MOORA approach. The Specification parameter values of various Aluminum Alloys as collected from the literature review are shown in Table 1. This entire numerical value used in Table 1 is converted to an approximate score out of 10 as shown in Table 2.

3 Results and Discussion

Steps 1 and 2 are common in TOPSIS and MOORA methodology which give the same value of decision matrix and normalized decision matrix as given in Tables 1 and 2 respectively. In this study, equal weightage is given to all the criteria. Thus, the weighted normalized decision matrix for crankcase cover material selection is the same as the normalized decision matrix. For the calculation of ranking of the alternatives using the TOPSIS technique, separation distances of alternatives (S^+ & S^-) from the positive ideal and negative ideal solution is calculated using equations 6-7. Based on these separation distance values, the relative closeness of each alternative to the

ideal solution C_i is determined using Eq. 8. The final ranking using the TOPSIS methodology ($A_3 > A_2 > A_4 > A_1 > A_5 > A_6$) is obtained using the decreasing order of these C_i values. For the calculation of ranking of alternatives using the MOORA methodology, the first $\sum x_{ij}^*$ value is obtained by adding weighted normalized values of six beneficial criteria which are brinell hardness, yield strength, % elongation, ultimate tensile strength, young’s modulus, and fatigue strength.

Similarly, $\sum_{j=q+1}^n x_{ij}^*$ represents the material cost which is a non-beneficial criterion in this study. The final ranking of the crankcase cover ($A_3 > A_5 > A_2 > A_4 > A_1 > A_6$) is decided by the overall performance score which is represented by Y_i^* . Since the number of

Table 1 — Specification parameter of various aluminum alloys

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A ₁	75	172	2.5	303	71	138	1490.52
A ₂	80	159	3.5	317	71	138	1478.20
A ₃	80	159	3.5	324	71	138	1355.02
A ₄	75	152	3.5	310	71	145	1478.20
A ₅	120	248	<1	317	81	138	1724.57
A ₆	80	145	2.5	296	71	131	1847.75

Table 2 — Decision and weighted normalized decision matrix using TOPSIS-MOORA

	C1	C2	C3	C4	C5	C6	C7
A1	6.00	6.88	6.25	9.18	8.66	9.20	7.84
A2	6.40	6.36	8.75	9.61	8.66	9.20	7.78
A3	6.40	6.36	8.75	9.82	8.66	9.20	7.13
A4	6.00	6.08	8.75	9.39	8.66	9.67	7.78
A5	9.60	9.92	2.00	9.61	9.88	9.20	9.08
A6	6.40	5.80	6.25	8.97	8.66	8.73	9.73
A ₁	0.35	0.40	0.35	0.40	0.40	0.41	0.39
A ₂	0.38	0.37	0.49	0.42	0.40	0.41	0.38
A ₃	0.38	0.37	0.49	0.42	0.40	0.41	0.35
A ₄	0.35	0.35	0.49	0.41	0.40	0.43	0.38
A ₅	0.57	0.57	0.11	0.42	0.45	0.41	0.45
A ₆	0.38	0.34	0.35	0.39	0.40	0.39	0.48

Table 3 — Normalized decision matrix using PROMETHEE

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A ₁	0.000	0.262	0.615	0.250	0.000	0.500	0.725
A ₂	0.111	0.136	1.000	0.750	0.000	0.500	0.750
A ₃	0.111	0.136	1.000	1.000	0.000	0.500	1.000
A ₄	0.000	0.068	1.000	0.500	0.000	1.000	0.750
A ₅	1.000	1.000	0.000	0.750	1.000	0.500	0.250
A ₆	0.111	0.000	0.615	0.000	0.000	0.000	0.000

Table 4 — Ranking of alternatives using reference point approach

	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	P _i	Rank
A ₁	0.213	0.176	0.141	0.028	0.056	0.021	0.035	0.213	2
A ₂	0.189	0.206	0.000	0.009	0.056	0.021	0.032	0.206	1
A ₃	0.189	0.206	0.000	0.000	0.056	0.021	0.000	0.206	1
A ₄	0.213	0.222	0.000	0.019	0.056	0.000	0.032	0.222	3
A ₅	0.000	0.000	0.382	0.009	0.000	0.021	0.096	0.382	5
A ₆	0.189	0.239	0.141	0.037	0.056	0.042	0.128	0.239	4

Table 5 — Ranking of the alternatives using TOPSIS-MOORA-PROMETHEE method

S ⁺	S ⁻	C _i	TOPSIS Ranking	$\sum_{j=1}^q x_{ij}^*$	$\sum_{j=q+1}^n x_{ij}^*$	y_i^*	MOORA Ranking	$\phi^+(s)$	$\phi^-(s)$	$\phi(s)$	PROMETHEE Ranking	
A ₁	0.319	0.267	0.455	4	2.311	0.387	1.924	5	0.615	1.410	0.795	5
A ₂	0.288	0.398	0.580	2	2.464	0.384	2.080	3	1.094	0.776	0.318	4
A ₃	0.286	0.408	0.588	1	2.473	0.352	2.121	1	1.594	0.676	0.918	2
A ₄	0.315	0.397	0.558	3	2.436	0.384	2.052	4	1.372	0.969	0.403	3
A ₅	0.394	0.329	0.455	5	2.534	0.448	2.086	2	3.263	1.441	1.822	1
A ₆	0.368	0.242	0.397	6	2.242	0.480	1.762	6	0.167	2.834	2.666	6

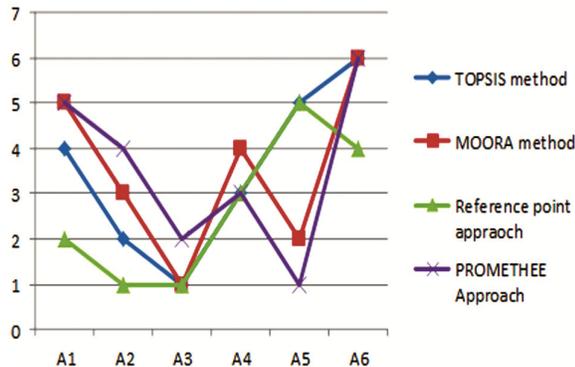


Fig. 3 — Rankings of the alternatives for material selection.

beneficial criteria is more than the number of non-beneficial criteria, so the overall performance score becomes positive. The final ranking of crankcase cover using the reference point method is (A₃ = A₂ > A₁ > A₄ > A₆ > A₅).

PROMETHEE approach shows the final ranking A₅ > A₃ > A₄ > A₂ > A₁ > A₆. All the above approaches except PROMETHEE represents the aluminum alloy A380 (A₃) is the best material for crankcase cover. Figure 3 shows the final ranking of alternatives using the TOPSIS, MOORA, reference point approach, and PROMETHEE. The final ranking of alternatives obtained using these approaches are shown in Tables 4 and 5.

4 Conclusion

In this study, a comparative analysis of MCDM approaches such as TOPSIS-PROMETHEE-MOORA methods has done for material selection of a two-

wheeler crankcase cover in the automobile industry. Results of TOPSIS methodology have concluded that the aluminum alloy A380 (A₃) is the best material for the two-wheeler crankcase cover in the automobile industry. This result has compared and validated by the multi-objective optimization by ration analysis (MOORA) and reference point approach with greater accuracy. MOORA approach is very simple and easy to implement as compared to the other MCDM approaches. MOORA approach has not given accurate results when large numbers of qualitative attributes are present. Limitations of this type of study are uncertainty in the decision-making process arises due to uncertainties in the input data and it is also difficult to show the performance of most alternatives by single numerical data. TOPSIS technique has not considered the correlation of the attributes. The proposed integrated model is a simple, easy to implement, and efficient tool for decision-makers. This novel TOPSIS-PROMETHEE-MOORA method can also be utilized for other material selection problems in the automobile industry. The results obtained in this study are valuable for all automobile industries and research organizations. This study can be further extended by applying other remaining MCDM approaches.

References

- 1 Aly M F, Attia H A, & Mohammed A M, *Int J Innov Res Sci Eng Technol*, 2 (2013) 6464.
- 2 Anojkumar L, Ilangkumaran M, & Sasirekha V, *Expert Syst Appl*, 41 (2014) 2964.
- 3 Ashby M F, Cebon D, & Salvo L, *Mater Des*, 25 (2004) 51.

- 4 Athawale V M, Kumar R, & Chakraborty S, *Int J Adv Manuf Technol*, 57 (2011) 11.
- 5 Bhowmik C, Gangwar S, & Bhowmik S, *Stud Comput Intell*, 761 (2018) 59-79.
- 6 Brans J P, & Vincke P, *Manage Sci*, 31 (1985) 647.
- 7 Brans J P, Vincke P, & Mareschal B, *Eur J Oper Res*, 24 (1986) 228.
- 8 Brauers W K, Optimization Methods for a Stakeholder Society (Kluwer Academic, Boston) 2004th Edn, ISBN-13: 978-1402076817
- 9 Brauers W K M, & Zavadskas E K, *Control Cybern*, 35 (2006) 445.
- 10 Chakraborty S, *Int J Adv Manuf Technol*, 54 (2011) 1155.
- 11 Chakraborty S, & Chatterjee P, *Decis Sci Lett*, 2 (2013) 135.
- 12 Chatterjee P, *Int J Mater Sci Eng*, 1 (2013) 104.
- 13 Chatterjee P, & Chakraborty S, *Mater Des*, 35 (2012) 384.
- 14 Chawla S, Agrawal S, & Singari R M, *Lecture Notes in Mechanical Engineering*, (Springer, Singapore), ISBN: 978-981-13-6468-6, 2019, p.755-765.
- 15 Dagdeviren M, *J Intell Manuf*, 19 (2008) 397.
- 16 Dursun M, & Arslan O, *Symmetry (Basel)*, 10 (2018) 1.
- 17 Edwards K L, *Mater Des*, 26 (2005) 469.
- 18 Gupta N, *Mater Des*, 32 (2011)1667.
- 19 Ilangkumaran M, Avenash A, Balakrishnan V, Kumar B, & Raja M B, *Int J Ind Syst Eng*, 14 (2013) 20.
- 20 Ipek M, Selvi I H, Findik F, & Torkul O, *Mater Des*, 47 (2013) 331.
- 21 Jahan A, Bahraminasab M, & Edwards K L, *Mater Des*, 35 (2012) 647.
- 22 Jahan A, Ismail M Y, Sapuan S M, & Mustapha F, *Mater Des*, 31 (2010) 696.
- 23 Jajimoggala S, & Karri R R, *Int J Appl Decis Sci*, 6 (2013) 144.
- 24 Karande P, & Chakraborty S, *Mater Des*, 37 (2012) 317.
- 25 Kelemenis A, & Askounis D, *Expert Syst Appl*, 37 (2010) 4999.
- 26 Liu H, Liu L, & Wu J, *Mater Des*, 52 (2013) 158.
- 27 Maity S R, & Chakraborty S, *Mater Manuf Process*, 28 (2013) 408.
- 28 Milani A S, Eskicioglu C, Robles K, & Bujun K, *eXPRESS Polym Lett*, 5 (2011) 1062.
- 29 Mousavi-nasab S H, & Sotoudeh-anvai A, *Mater Des*, 121 (2017) 237.
- 30 Okokpujie I P, Okonkwo U C, Bolu C A, Ohunakin O S, Agboola M G, & Atayero A A, *Heliyon*. 6 (2020) 1.
- 31 Rai D, Jha G K, Chatterjee P, & Chakraborty S, *Univers J Mater Sci*, 1 (2013) 69.
- 32 Rao R V, & Patel B K, *Mater Des*, 31 (2010) 4738.
- 33 Shanian A, & Savadogo O, *J Power Sources*, 159 (2006) 1095.
- 34 Tiwary A P, Pradhan B B, & Bhattacharyya B, *Adv Manuf*, 2 (2014) 251.
- 35 Wang L, Chu J, & Wu J, *Int J Prod Econ*, 107 (2007) 151.
- 36 Yurdakul M, & Tansel Y, *J Mater Process Technol*, 209 (2009) 310.
- 37 Zanakis S H, Solomon A, Wishart N, & Dublisch S, *Eur J Oper Res*, 107 (1998) 507.