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MATERIAL SELECTION BASED ON PROMETHEE II METHOD

Santosh Kumar Tamang[1*], V. Praveenkumar[2]

[1]Mechanical Engineering, NERIST (DU) Nirjuli, Itanagar, Arunachal Pradesh, India

[2]University West, Trollhatan, Sweden

ABSTRACT

Material selection is an important aspect of engineering design because it directly influences component performance, durability, reliability, and manufacturing cost. Selecting a suitable material becomes challenging when several conflicting criteria must be considered simultaneously. In this study, a multi-criteria decision-making (MCDM) method, the Priority Ranking Organization Method for Reinforcement Evaluation (PROMETHEE II), is applied to determine the optimal engineering material from seven alternatives. Six evaluation criteria are considered: cost (C), surface hardness (SH), bending endurance limit (BFL), ultimate tensile strength (UTS), surface fatigue limit (SFL), and center hardness (CH). Cost is treated as a minimization criterion, while the remaining five mechanical properties are considered maximization criteria. The analysis employs equal criterion weights and the usual preference function (Type I) to calculate positive, negative, and net preference flows for each alternative. The results indicate that carburized steel (M5) achieves the highest net preference flow of 0.6944, followed by nitride steel (M1) and surface-hardened alloy steel (M3), with net flows of 0.4167 and 0.1111, respectively. In contrast, cast iron (M7) records the lowest net preference flow of −0.7222, indicating the weakest overall performance under the adopted evaluation framework. Final ranking: M5 > M1 > M3 > M6 > M2 > M4 > M7. The results obtained identify carburized steel as the most preferable alternative for the material selection problem under consideration. The study demonstrates the applicability of PROMETHEE II as a systematic decision-support technique for evaluating engineering materials with conflicting performance requirements.

Keywords: Engineering material selection, Multicriteria decision-making, PROMETHEE II, Material optimization, Mechanical properties, Preference ranking.

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*Corresponding author: Santosh Kumar Tamang
Email: santoshtamang05@yahoo.com

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1. INTRODUCTION

Choosing the right materials is essential for both conception and manufacturing, and it has a big impact on how well products function for a variety of engineering problems. Materials have a significant impact on consumer-user interactions and are crucial to the entire product design and production process. To meet the demands of cost reduction and performance enhancement, the material selection technique is also essential. There are many ways to select materials, but the principles are always the same. Material selection for products seems to be either 'design oriented,' motivated by development and modification, necessitating thoughtful analysis of chemical, mechanical, and physical properties, 'product oriented,' driven by industry or democratic mandate, or 'expenses oriented,' aiming to achieve a sustainable competitive advantage. Cleaner manufacturing has been integrated into supply chain management as a countermeasure to climate change. On the other hand, in the manufacturing industry, the concept of ``environmentally conscious design'' centred on ``environmentally friendly design'' has gradually emerged. Careful selection of raw materials can improve life-cycle innovations such as recyclability and reuse, improve product quality, minimize toxicity, and reduce the negative impact of products on the environment and human health (Cui et al., 2021; Ehsan et al., 2022; Esangbedo et al., 2021; Tchobanoglous & Kreith, 2002; Williams, 2005). Preference ranking organisation Method for enrichment evaluations (PROMETHEE) method is adapted by Gul et al. (2018) for selection of automotive instrument panel. The use of PROMETHEE method in analysing material selection problem have been reported in the literature. The authors selected the best material from a list of alternative materials, including polycarbonate and polypropylene, considering eight criteria including toxicity level, recyclability, thermal

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conductivity, elongation, weight, and more. They argued that most material selection problems involve the use of classical MCDM techniques, in contrast to fuzzy MCDM, which has very limited application to materials analysis, and combined fuzzy set theory and PROMETHEE techniques to fill this gap (Gul et al., 2018). Sharma and Maan (2026) highlights the critical need to evaluate the application of multi-criteria decision-making (MCDM) methods to maximize material selection based on the increasing demand for efficiency and sustainability. The application and development of MCDM techniques such as TOPSIS, AHP and VIKOR in sectors such as automotive and energy storage are explored using a bibliometric and thematic analysis of 341 research articles from the Scopus database. This analysis reveals a movement from standard metrics (e.g., cost and mechanical properties) to more detailed elements, including energy efficiency and sustainability, as India ranks highest in publication frequency. The findings of this investigation are significant because they provide a detailed examination of MCDM techniques in material selection and underline critical trends and promising future research. Selecting the best material for a particular application can be considered a multi-criteria decision-making (MCDM) problem with diverse and conflicting objectives. New MCDM methods have been developed and existing methods have been improved, demonstrating the importance and continued value of decision-making research. This article describes the use of recently developed MCDM techniques, namely Combined Proportional Assessment (COPRAS) and Aggregate Weighted Total Product Assessment (WASPAS), to select the optimal pavement material (Petković et al., 2015). Bhaskar and Khan (2022) aim to demonstrate the capabilities of five different hybrid multi-criteria decision-making (HMCDM) methods to identify the best polymer-based biomaterial used in dentistry. In total, seven materials were evaluated according to ten criteria. First, an analytical hierarchy process (AHP) was used to determine the weighting of the perceived criteria. The materials were then classified using the AHP-VIKOR, AHP-TOPSIS, AHP-MOORA, AHP-ELECTRE, and AHP-PROMTHEE procedures. The methodologies have demonstrated their effectiveness by assigning equivalent grades to materials. Finally, Spearman's rank correlation was determined to compare the HMCDM methods. Comparative analysis revealed that AHP-VIKOR, AHP-TOPSIS, and AHP-PROMETHEE have higher correlations than AHP-MOORA and AHP-ELECTRE.

2. MATERIALS AND METHODS

According to the above-mentioned literature, MCDM are only used jointly in a few research papers for decision-making reasons. As a result, in this study piece, an effort is made to integrate both Multicriteria decision approaches and embed them to resolving material selection difficulties. The major contribution of this study is to suggest a priority and to choose the leading engineering material based on six important criteria, including Cost (C), Surface hardness (SH), bending fatigue limit (BFL), Ultimate tensile strength (UTS), Surface fatigue limit (SFL), and Core hardness (CH), to relative ranking of the seven selected alternatives. Entropy is utilized to find the criterion weight, whereas PROMETHEE II is used to rank the alternatives and choose the best option. The current problem was adopted from (Chatterjee and Chakraborty, 2012), which was solved using TOPSIS, and subsequently by (Hussain and Mandal, 2016), which was solved using COPRAS. Next, Pankaj Prasad Dwivedi and Dilip Kumar Sharma (2022). We are currently using the PROMETHEE II approach to study the optimal material and compare it to other materials that pose the same problem. Table 1 presents the initial decision matrix of materials.

Table 1: Presents the initial decision matrix of materials.

Material	C	SH	BFL	UTS	SFL	CH
Nitride steels (M1)	4.732	750	760	1250	1250	315
Cast alloy steel (M2)	0.119	270	435	590	630	270
Surface hardened alloy steel (M3)	3.128	585	680	1580	1160	240
Ductile iron (M4)	0.342	220	360	880	460	220
Carburized steels (M5)	2.315	700	920	2300	1500	315
Hardened alloy steel (M6)	1.283	270	540	1190	670	270
Cast iron (M7)	0.171	200	100	380	330	200

3. PREFERENCE RANKING ORGANISATION METHOD OF ENRICHMENT EVALUATION (PROMETHEE II) METHOD ANALYSIS

Table 1 shows two types of objective functions. Although component Aα (the highest level of apathy) shows the largest difference, this is not significant when measuring both options against this criterion. The PROMETHEE II method determines the priority of material M1 over material M2 through an aggregated priority index.

$$\pi(a,b) = \sum_{j=1}^{m} w_j \, P_j(a,b) \quad (1)$$

where (wj) indicates the normalized importance weight of criterion (j) and (Pj(a,b)) indicates the priority of material M1 compared to material M2. Victory flow on the leaderboard:

$$\phi^{+}(a) = \frac{1}{n-1}\sum_{b\neq a}\pi(a,b) \quad (2)$$

The flow of negative wins in the rankings is as follows:

$$\phi^{-}(a) = \frac{1}{n-1}\sum_{b\neq a}\pi(b,a) \quad (3)$$

The net revenue flow is as follows:

$$\boxed{\phi(a) = \phi^{+}(a) - \phi^{-}(a)} \quad (4)$$

Materials are listed in descending order of net income. The alternative with the highest net flow takes first place.

Criterion	Optimization direction
C	Minimize (MIN)
SH	Maximize (MAX)
BFL	Maximize (MAX)
UTS	Maximize (MAX)
SFL	Maximize (MAX)
CH	Maximize (MAX)

Using equal criterion weights (1/6 each) and the usual preference function (Type I), the verified ranking is:

Rank	Alternative	Positive flow (Φ+)	Negative flow (Φ−)	Net flow (Φ)
1	A5	0.8333	0.1389	0.6944
2	A1	0.6944	0.2778	0.4167
3	A3	0.5556	0.4444	0.1111
4	A6	0.4722	0.4722	0.0000
5	A2	0.4444	0.5000	−0.0556
6	A4	0.2778	0.7222	−0.4444
7	A7	0.1389	0.8611	−0.7222

Final ranking order

{A5>A1>A3>A6>A2>A4>A7}

A5 is the best alternative according to PROMETHEE II, followed by A1 and A3.

The PROMETHEE II analysis was employed to evaluate and rank the seven alternatives (A1–A7) based on their overall performance across the selected criteria. The ranking was determined using the net preference flow (Φ), calculated as the difference between the positive preference flow (Φ^{+}) and negative preference flow (Φ^{-}). A higher positive net flow indicates better overall performance, whereas a negative net flow reflects comparatively weaker performance.

The results reveal that alternative A5 achieved the highest rank, with a positive flow of 0.8333, a negative flow of 0.1389, and a net flow of 0.6944. The high positive flow and low negative flow indicate that A5 exhibits a strong overall preference over the other alternatives, making it the most favourable option under the selected criteria and preference assumptions. Alternative A1 secured the second position with a net flow of 0.4167, followed by A3 in third place with a net flow of 0.1111. Although A1 and A3 demonstrated positive net flows, their overall preference strengths were lower than that of A5.

Alternative A6 occupied the fourth position, with equal positive and negative flows of 0.4722, resulting in a net flow of zero. This indicates a balanced preference relationship with the other alternatives, where its overall strengths and weaknesses offset each other. Alternative A2 ranked fifth, with a slightly negative net flow of −0.0556, suggesting that its disadvantages marginally exceeded its advantages in the pairwise comparisons.

In contrast, alternatives A4 and A7 exhibited considerably lower performances, with net flows of −0.4444 and −0.7222, respectively. A7 recorded the lowest positive flow (0.1389) and the highest negative flow (0.8611), indicating that it was the least preferred alternative among those evaluated.

The overall ranking obtained through the PROMETHEE II method is (Annamalai & Dhavamani, 2023; Jagannathan et al., 2025; Viswanathan et al., 2025) is: A5 > A1 > A3 > A6 > A2 > A4 > A7.

These findings demonstrate that A5 provides the most favourable overall compromise among the considered criteria, whereas A7 shows the weakest comparative performance. The results also highlight the capability of PROMETHEE II to distinguish between alternatives through positive, negative, and net preference flows. However, the ranking depends on the assigned criterion weights, preference functions, and evaluation data. Therefore, sensitivity analysis would be useful to assess the robustness of the ranking under different weighting scenarios.

4. CONCLUSION

This study investigated the application of the PROMETHEE II method for selecting the most suitable engineering material from seven alternatives based on six evaluation criteria: cost, surface hardness, bending fatigue limit, ultimate tensile strength, surface fatigue limit, and core hardness. The method provided a systematic framework for evaluating the alternatives by considering both beneficial and non-beneficial criteria. Positive, negative, and net preference flows were calculated using equal criterion weights and the usual preference function to establish the final ranking. The results identified carburized steel (M5) as the most preferred material, with the highest net preference flow of 0.6944. Its

leading position can be attributed to its favourable combination of mechanical properties, particularly bending fatigue limit, ultimate tensile strength, and surface fatigue limit, despite not having the lowest cost. Nitride steel (M1) ranked second with a net flow of 0.4167, followed by surface-hardened alloy steel (M3) with a net flow of 0.1111. Hardened alloy steel (M6) occupied the fourth position with a zero net preference flow, while cast alloy steel (M2) and ductile iron (M4) ranked fifth and sixth, respectively. Cast iron (M7) exhibited the lowest net flow of −0.7222 and was consequently identified as the least preferred alternative under the specified evaluation conditions. The PROMETHEE II approach effectively captures these trade-offs through pairwise comparisons and net preference flow calculations.

The study concludes that carburized steel (M5) is the most suitable alternative among the seven materials evaluated under the adopted criteria, equal weighting scheme, and usual preference function.

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CONFLICT OF INTEREST

None.

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