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Determination of the best materials for development and designing product using a multi-criteria decision-making

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Abstract

Purpose – Material selection, driven by wide and often conflicting objectives, is an important, sometimes difficult problem in material engineering. In this context, multi-criteria decision-making (MCDM) methodologies are effective. An approach of MCDM is needed to cater to criteria of material assortment simultaneously. More firms are now concerned about increasing their productivity using mathematical tools. To occupy a gap in the previous literature this research recommends an integrated MCDM and mathematical Bi-objective model for the selection of material. In addition, by using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the inherent ambiguities of decision-makers in paired evaluations are

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considered in this research. It goes on to construct a mathematical bi-objective model for determining the best item to purchase.
Design/methodology/approach – The entropy perspective is implemented in this paper to evaluate the weight parameters, while the TOPSIS technique is used to determine the best and worst intermediate pipe materials for automotive exhaust system. The intermediate pipes are used to join the components of the exhaust systems. The materials usually used to manufacture intermediate pipe are SUS 436LM, SUS 430, SUS 304, SUS 436L, SUH 409 L, SUS 441 L and SUS 439L. These seven materials are evaluated based on tensile strength (TS), hardness (H), elongation (E), yield strength (YS) and cost (C). A hybrid methodology combining entropy-based criteria weighting, with the TOPSIS for alternative ranking, is pursued to identify the optimal design material for an engineered application in this paper. This study aims to help while filling the information gap in selecting the most suitable material for use in the exhaust intermediate pipes. After that, the authors searched for and considered eight materials and evaluated them on the following five criteria: (1) TS, (2) YS, (3) H, (4) E and (5) C. The first two criteria have been chosen because they can have a lot of influence on the behavior of the exhaust intermediate pipes, on their performance and on the cost. In this structure, the weights of the criteria are calculated objectively through the entropy method in order to have an unbiased assessment. This essentially measures the quantity of information each criterion contribution, indicating the relative importance of these criteria better. Subsequently, the materials were ranked using the TOPSIS method in terms of their relative performance by measuring each material from an ideal solution to determine the best alternative. The results show that SUS 309, SUS 432L and SUS 436 LM are the first three materials that the exhaust intermediate pipe optimal design should consider.
Findings – The material matrix of the decision presented in Table 3 was normalized through Equation 5, as shown in Table 5, and the matrix was multiplied with weighting criteria ß_j. The obtained weighted normalized matrix V_ij is presented in Table 6. However, the ideal, worst and best value was ascertained by employing Equation 7. This study is based on the selection of material for the development of intermediate pipe using MCDM, and it involves four basic stages, i.e. method of translation criteria, screening process, method of ranking and search for methods. The selection was done through the TOPSIS method, and the criteria weight was obtained by the entropy method. The result showed that the top three materials are SUS 309, SUS 432L and SUS 436 LM, respectively. For the future work, it is suggested to select more alternatives and criteria. The comparison can also be done by using different MCDM techniques like and Choice Expressing Reality (ELECTRE), Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE).
Originality/value – The results provide important conclusions for material selection in this targeted application, verifying the employment of mutual entropy-TOPSIS methodology for a series of difficult engineering decisions in material engineering concepts that combine superior capacity with better performance as well as cost-efficiency in various engineering design.

Keywords TOPSIS, Multi-criteria decision-making, Entropy method, Material selection

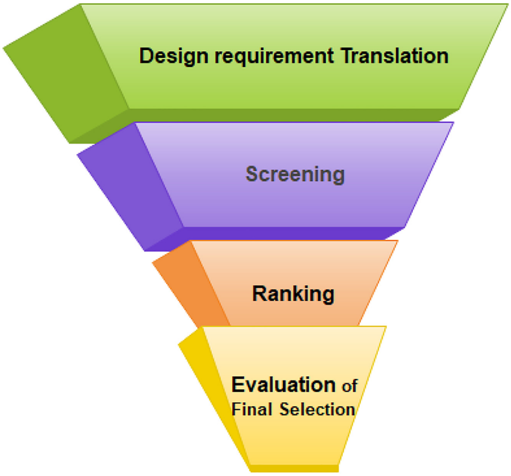
Paper type Research paper

1. Introduction

This is a significant aspect used in the development and design of a product. Choice of materials in the same years has received significant importance due to encouraging new material developments (Balakrishna, Chandra, Gogulamudi, & Someswararao, 2011). Inappropriate material selection can lead to failure to meet manufacturer and customer requirements (Chen *et al.*, 2019). Another research was done by Yashpalsinh, Molvi, and Student (2019), and the authors found out that the AISI 409 stainless steel pipe failed after 50,000 km with high-temperature exposure, corrosion and mechanical stress. The microstructural analysis detected large grain growth, carbide precipitation and oxidation and the chemical analysis found chromium depletion and significant carbon increase. The authors recommend using better quality materials, improving design and maintenance, etc. to avoid these failures. The failure of the de Havilland Comet in the 1950s is a notable example of improper material selection that has led to assembly failure. The de Havilland Comet Material choice hence plays an important role in enabling products to be competitive and successful in the market, combined with meeting efficiency and consumer requirements. It is estimated that there are more than 100,000 selections available for engineering materials (Rahim, Musa, Ramesh, & Lim, 2020). However, improper material selection may cause assembly failure or dissatisfaction and tremendously reduce the performance and efficiency of products, thereby adversely affecting the organization's productivity, profitability and credibility (Ganesh Kumar, Meikandan, Sakthivadivel, & Vigneswaran, 2021). This involves four main categories of engineering materials: ceramics, metals, composites and polymers (Liu *et al.*, 2021). Ceramics are known for their high hardness and temperature resistance, making them suitable for extreme environments. Metals are valued for their strength, ductility and conductivity, essential for structural and mechanical parts. Composites, which combine different materials for enhanced properties, are ideal for aerospace and automotive uses due to their excellent strength-to-weight ratio. Polymers are versatile, lightweight and cost-effective and are used widely for their corrosion resistance. The wide range of choices, combined with complex interactions, made the process selection challenging for the design of industries, as these usually involve stakeholders across various fields to check along with their requirements to find the correct choice for the application (Jahan, Ismail, Sapuan, & Mustapha, 2010). As engaging stakeholders in material selection involves effective communication and collaboration across various disciplines, it would be ideal to direct the process through a framework consisting of screening, comparison and best material selection (Emovon & Oghenenyerovwho, 2020). This may be done in four basic stages, i.e. method of translation of criteria, a screening process, a method of ranking and a search for an appropriate approach (Ashby, Bréchet, Cebon, & Salvo, 2004). During screening, materials are filtered based on fundamental criteria like mechanical properties and cost. The comparison stage employs multi-criteria decision-making (MCDM) methods such as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Choice Expressing Reality (ELECTRE), Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) to assess and rank materials using weighted criteria. The final selection involves in-depth analysis, prototyping and testing to determine the best material. This framework should be integrated into the design process, involve cross-functional team collaboration, utilize software tools, maintain thorough documentation and include a feedback loop for continuous improvement in material selection.

However, Kesteren *et al.* also concur with the similar basic method, which includes selecting criteria, setting up a range of candidates, comparison and selecting an appropriate candidate (Van Kesteren, De Bruijn, & Stappers, 2008). The approach expresses resemblances among steps like screening and rating, regardless if they are implemented in the phases of design or selection criteria (Kokaraki, Hopfe, Robinson, & Nikolaidou, 2019). On the other hand, Gharibi, Babazadeh, and Hasanzadeh (2024) used the TOPSIS method to rank various tests for identifying the best and worst trials for the developed multi-layer perceptron (MLP) neural networks and regression models to accurately predict the performance of polyethylene gasification. Mojaver, Jafarmadar, Khalilarya, and Chitsaz (2019) combine analytic hierarchy process (AHP) and the TOPSIS technique for the identification of best alternatives for the synthesis gas composition. Similarly, Hasanzadeh, Mojaver, Khalilarya, and Azdast (2023) conducted research addressed how gasification parameters interact to influence outcomes. It involved an MCDM study with eleven alternatives and five criteria focusing on energy, environmental and economic aspects of gasification performance. Criteria weights were determined using the AHP, the Shannon entropy technique and a composite weighting approach. The TOPSIS and VIKOR techniques were employed alongside these weighting methods to rank the alternatives effectively. Hasanzadeh, Azdast, Mojaver, and Park (2022) conducted a study using the MCDM technique to determine optimal conditions for gasifying waste polystyrene (PS). This paper presents the identification of the optimal design material for engineering applications, utilizing a hybrid approach that combines entropy-based criteria weighting with the TOPSIS for alternative ranking. The study addresses the knowledge gap in optimal material selection for exhaust intermediate pipes. Figure 1 presents a standard process stage in material selection.

Figure 2 illustrates the categories for the selection criteria of material for pipe products including six important criteria for selecting materials in engineering: cost, reliability, ease of



Source(s): Rahim *et al*. (2020)

Figure 1.
Process of selecting material

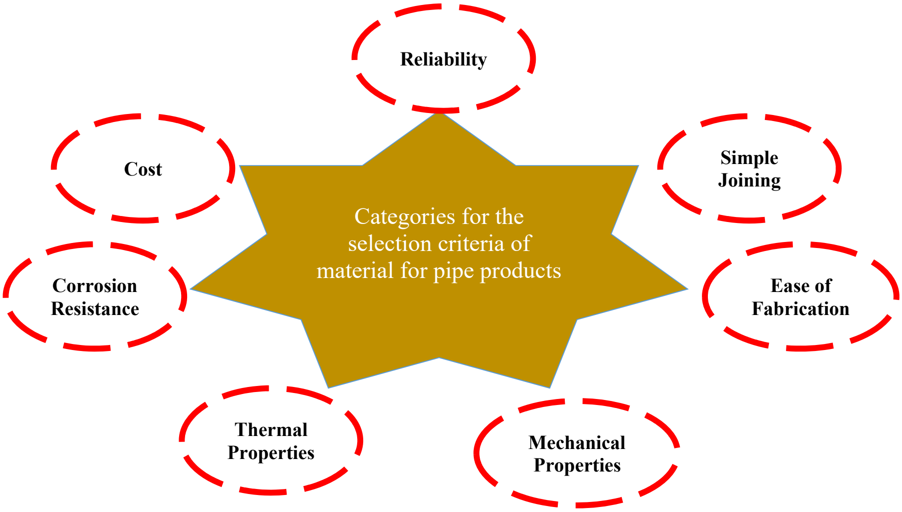


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Figure 2.
Selection criteria for the mechanical products

joining, ease of fabrication, mechanical properties and electrical properties. These factors are crucial for assessing materials based on their economic viability, consistent performance, ease of assembly, workability, strength and electrical characteristics (Cornish, 1987). Considering these criteria helps engineers choose the most appropriate materials, ensuring a balance of performance, cost-effectiveness and manufacturability for specific engineering applications, ultimately leading to optimal design and functionality.

Table 1 summarizes the specifications required for the intermediate pipe. It describes that the pipe should be sustainable to high temperatures, durable and cost-effective.

The structure of the article is methodically organized, beginning with an introduction that sets the stage for the research. This is followed by a detailed discussion of the methodology, incorporating aspects of MCDM and entropy. The paper then presents the results of the application of this methodology, engages in a thorough discussion to interpret these results and concludes with a summary of findings and implications of the study.

2. Literature review

MCDM aims to focus on providing a finite number of alternatives to decision-makers with fair recommendations when assessing against various requirements or goals (Kumar *et al.*, 2017). With the dynamic properties of the process's selection of product materials, the consideration of MCDM is significant. Although the optimal material also depends on the experience of designers and previously known information, for a designer, it is quite challenging to decide if there are so many parameters from which some might not be well known (Morente-Molinera, Wu, Morfeq, Al-Hmouz, & Herrera-Viedma, 2020). The utilization of MCDM is significant for material selection where differentiation of product, different materials, complex applications and market opportunities are included (Hamzeh & Xu, 2019). Hence, a method that helps the designers to find the optimal solution is highly preferred. Researchers have similar thoughts in diminishing problems towards selection of material, and it is recommended that evaluation and selection of the process take into consideration several criteria/attributes in recommending an optimal choice (Mousavi-Nasab & Sotoudeh-Anvari, 2018). In addition, the essence of problems in material selection fits best with the domain of MCDM (Dotoli, Epicoco, & Falagario, 2020).

Various methods have been suggested in the literary works to tackle the challenge for the material selection and to enhance the effectiveness in the design procedure, like AHP, Entropy criterion, Fuzzy logic, Ashby Method, Gray relational analysis (GRA), Elimination Et Choice Translating Reality (ELECTRE), Complex Proportional Assessment (COPRAS), VIekriterijumsko KOmpromisno Rangiranje (VIKOR), Graph theory matrix approach (GTMA) and TOPSIS.

Ali, Lalji, and Ali *et al.* (2024) and Ali, Lalji, and Haider *et al.* (2024) present a unique risk prioritizing strategy that blends the Fuzzy VIKOR with the Shannon entropy. This integrated strategy enhances the handling of ambiguity and complexity in risk assessment for core preparation experiments. The case study proves the model's usefulness, providing engineers with a reliable tool for improving safety and decision-making.

Several scholars used different decision-making attributes to solve problems related to the selection of the material. However, under several circumstances, because of the difficulty of material selection issue, precise data are insufficient to model actual life situation. In order to cope with the vagueness and process uncertainty of decision-making,

Table 1. Properties required for intermediate pipe

Sr. #	Property	Utility
1	Thermal expansion	Endures constant exposure to heat from exhaust normally from 500°C to 1000°C
2	Fatigue strength	Could manages vibrations and exhaust pressure
3	Rust resistance	Withstands damage from road salt, moisture and exhaust fumes
4	Weldability	Should permits simple shaping to occur during production
5	Weight	Should have enhanced fuel efficiency (best if lightweight)
6	Cost	Acquire a cost-effective balance between necessary attributes

Source(s): Authors' own work

fuzzy set theory was implemented. Elevli *et al.* imposed the MCDM method to determine and assess the contamination of heavy metals in the Dilovasi region Turkey. Elevli and Ozturk, (2019) and Lederer, Kotas, and Khatibi (2020) describe a new method for assessing and predicting the lifetime of large area solder connections in microelectronics. This approach overcomes the constraints of standard models by including thorough experimental data and failure analysis. The suggested model effectively forecasts the lifetime of solder junctions, which significantly improves the reliability of electronic assemblies. Ali, Lalji, and Ali *et al.* (2024) and Ali, Lalji, and Haider *et al.* (2024) expound an upgraded risk ranking model for rigging up operational tasks using fuzzy MCDM methodologies. This technique addresses the complexities and uncertainties inherent in such operations, providing a more effective and accurate risk management tool. The case study demonstrates the model's applicability and benefits, emphasizing its ability to improve safety and operational efficiency in the oil and gas industry. Deshmukh *et al.* used three methodologies for selection of material that best suitable for switching components of shunt capacitive switches. The methodologies that are utilized for the best selection of material are VIKOR, Ashby and TOPSIS (Deshmukh & Angira, 2019). Srinivasan *et al.* utilized TOPSIS, GRA and Taguchi method to improve the welding parameters of steel 15CDV6 (Srinivasan, Khan, Kannan, Sathiya, & Biju, 2019). To obtain a suitable workability and strength combination in sic/al composite, Khorshidi *et al.* used the MCDM technique for comparison analysis among Preference Selection Index (PSI) and TOPSIS methods for material selection (Khorshidi & Hassani, 2013). Pankaj *et al.* focused on TOPSIS methodology for the material selection of cutting tools (Shelar & Lekurwale, 2016). Prasenjit *et al.* used to tackle the problem of selecting material through the method of preferential ranking (Chatterjee & Chakraborty, 2012). A multi-criteria assessment framework was proposed by Bai *et al.* that permits decision-makers to estimate the systematic efficiency of the cutting fluid application in their lines of production granite (Bai, Hua, Elwert, & Wang, 2018).

2.1 Entropy method

The entropy method is being used in different areas of research as it is relatively simpler and gives good results. The alternatives are allotted weights, which are based upon their entropy calculated using the indicator values (Saad, Darras, & Nazzal, 2021). Each indicator is defined by the amount of information provided, which is a statistical parameter (Azadfallah, 2020). The importance of the indicator is directly proportional to the amount of information provided for the indicator. In this research, the entropy approach is used to derive the indicator values for the TOPSIS input weights, making weight assessment less arbitrary and allowing a more efficient procedure of safety assessment.

2.2 Research gap

The literature review revealed that, as of previous literature, no efficient method is developed for the material selection. There are not many studies on material selection, as this is mainly addressed in material properties and is a part of mechanical engineering. Since TOPSIS is a statistical tool and there aren't many mechanical engineers who relate material properties to statistics, an approach of MCDM is needed to cater criteria of material assortment simultaneously. More firms are now concerned about increasing their productivity using mathematical tools. To occupy a gap in the previous literature, this research recommends an integrated MCDM and mathematical Bi-objective model for the selection of material. In addition, by using TOPSIS, the inherent ambiguities of decision-makers in paired evaluations are considered in this research. It goes on to construct a mathematical bi-objective model for determining the best item to purchase.

3. Methodology

The entropy perspective is implemented in this paper to evaluate the weight parameters, while the TOPSIS technique is used to determine the best and worst intermediate pipe materials for automotive exhaust systems. The intermediate pipes are used to join the components of the exhaust system. The materials usually used to manufacture intermediate pipe are SUS 436LM, SUS 430, SUS 304, SUS 436L, SUH 409 L, SUS 441 L and SUS 439L. These seven materials are evaluated based on Tensile Strength (TS), Hardness (H), Elongation (E), Yield Strength (YS) and cost (C).

Figure 3 illustrates the phases of suitable material selection for product design or development. In the first phase, the study was conducted to get an exploration idea after getting the idea. The literature review was done to identify how the MCDM approach is used to tackle such problems. The second phase involves the selection of material alternatives and the determination of the important criteria for the material. The third phase is based on the calculation of weight criteria by using the entropy method, and these weighted criteria are the most important to implement the TOPSIS technique, which helps to determine the Euclidean distance from the ideal worst and best values. The performance score is calculated to identify the highest and lowest ranking of the material. This ranking helps in the most suitable selection of material for product development.

3.1 Entropy method to determine criteria weighting

The knowledge is formulated through the theory of probability and uncertainty measures by entropy (Deng, 2020). It shows that a large distribution is often more unpredictable than a sharply peaked one (Ding, Chong, Bao, Xue, & Zhang, 2017). Following are the four steps of finding the weight by using the method of entropy.

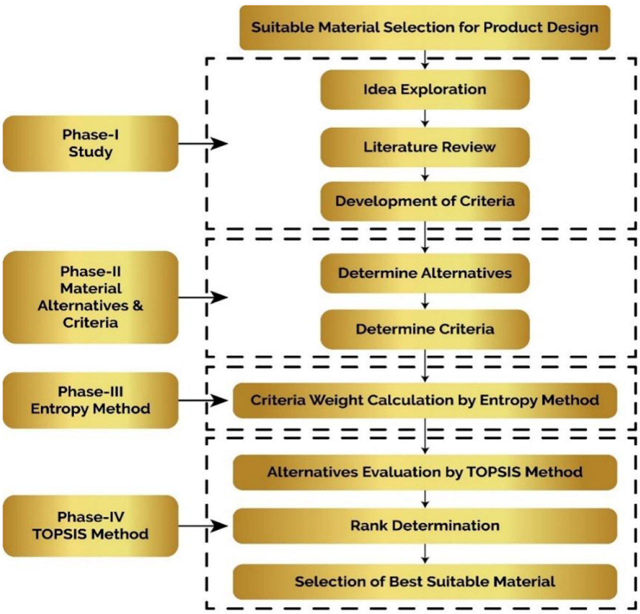

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Figure 3.
Suitable material selection for product design phases

Step 1: Determine the decision matrix

Equation (1) indicates the matrix of decision M of the dilemma of multi-criteria with alternatives “m” and criteria “n” (Lotfi & Fallahnejad, 2010).

$$M = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \cdots & C_n \end{array} \\ \begin{bmatrix} X_{11} & X_{12} & X_{13} & \ldots & X_{n1} \\ X_{21} & X_{22} & X_{23} & \ldots & X_{n2} \\ X_{31} & X_{32} & X_{33} & \ldots & X_{n3} \\ X_{41} & X_{42} & X_{43} & \ldots & X_{n4} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ X_{m1} & X_{m2} & X_{m3} & \cdots & X_{nm} \end{bmatrix} \end{array} \tag{1}$$

where,

$A_1, A_2, A_3, \cdots A_m$ are the available alternatives
$C_1, C_2, C_3, \cdots C_m$ are the criterions and
$X_{ij}\ (i = 1, 2, 3, 4 \cdots m\,;\ j = 1, 2, 3, 4 \cdots n)$ is the value of performance of the i^{th} alternative to the j^{th} criteria.

Step 2: Normalization of the decision matrix

P_{ij} is calculated through Equation (2). It is the normalized decision matrix and measured to evaluate weights by using the method of entropy (Hussain, Mandal, & Mondal, 2017). The normalization objective is to attain dimensionless values to equate them with different parameters.

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \tag{2}$$

Step 3: Determine the entropy value

The computation of entropy measure by using the underneath equation (Hashemi, 2020)

$$e_j = -h \sum_{i=1}^{m} P_{ij} \ln P_{ij} \tag{3}$$

where,

$h = \frac{1}{\ln m}$ is constant $0 \le e_j \le 1$

$$m = number\ of\ alternative\ materials$$

Step 4: Determine the entropy weight

Thus, the entropy weight computed by using equation (4)

$$\beta_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)} \tag{4}$$

where,

$1-e_j$ is the degree of divergence.

3.2 TOPSIS method

Hwang established the TOPSIS method (Balioti, Tzimopoulos, & Evangelides, 2018) for selecting a spillway for a dam. This technique is considered when a simpler weighting solution is preferred by the user. The TOPSIS approach is implemented in this research to attain the solution that is near mostly idealist solution and most far away from the negative ideal solution (Ramdania, Manaf, Junaedi, & Hadiana, 2020). The procedure includes details on the comparative value of the characteristics that are included in the procedure of selection. The TOPSIS approach includes the following steps.

Step 1: Determine the normalized matrix

Decision matrix normalization is carried out by using Equation (5) (Saqlain, Jafar, Hamid, & Shahzad, 2019).

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \tag{5}$$

where,

$$i = 1, 2, 3, 4 \cdots m\,;\, j = 1, 2, 3, 4 \cdots n$$

Step 2: Determine the weighted normalized matrix

The normalized columns of the decision matrix are multiplied by corresponding the weights in Equation (4), and the normalized matrix of weight is attained via Equation (6) (Saqlain *et al.*, 2019).

$$V_{ij} = \overline{X}_{ij}\beta_j \tag{6}$$

Step 3 Determine the ideal, best and worst value

The value of ideal, worst and best value is determine by Equations (7) and (8), respectively (Çalişkan, Kurşuncu, Kurbanoĝlu, & Güven, 2013).

$$V_1^+, V_2^+, V_3^+, V_4^+, \cdots V_i^+ = \{(Max\ V_{ij}|j \in k), (Min V_{ij}|j \in k')|\, i = 1, 2, 3, 4 \ldots m \tag{7}$$

$$V_1^-, V_2^-, V_3^-, V_4^-, \cdots V_i^- = \{(Min\ V_{ij}|j \in k), (Max V_{ij}|j \in k')|\, i = 1, 2, 3, 4 \ldots m \tag{8}$$

where.

k = benefit criteria index;

k' = criteria of cost index and

Step 4: Determine the Euclidean distance.

The Euclidean distance from the ideal, worst and best is determined by Equations (9) and (10) (Kumar, Sreebalaji, & Ganesan, 2015).

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2} \tag{9}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2} \tag{10}$$

j = 1, 2, 3, 4. . .. n; i = 1, 2, 3, 4. . ..m

Step 5: Determine the performance score

The performance score is calculated by Equation (11) (Athawale & Chakraborty, 2011).

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{11}$$

The result of Equation (11) shows the best rank is the higher value, and the lowest value has the worst ranking, meaning that the rank is in decreasing order.

3.3 Implementation of proposed methodology

The intermediate pipe of automotive exhaust system material selection is done through alternative material and alternative criteria. Table 2 represents the eight alternative materials, which used for the manufacturing of intermediate pipe, whereas Table 3 illustrates the material criteria, and the matrix of decision is represented in Table 4.

4. Results and discussion

The selection of material problems was assumed to depict the pertinence of the TOPSIS technique in combination with the entropy weighting method. The various steps included in the method were discussed above. The MCDM approach was implemented to the problem after evaluating the weights of various parameters using the entropy method.

4.1 Weighting criteria

The β_j weights were calculated by the entropy method, and the result is displayed in Table 5. The outcome showed that the most significant criterion is cost ($ 0.469).

Table 2.
Alternative materials

S. No.	Material
1	SUS 441L
2	SUS 439L
3	SUS 430
4	SUS 432L
5	SUS 436 LM
6	SUS 304
7	SUS 309
8	SUS310

Source(s): Authors ’ own work

4.2 TOPSIS method

The material matrix of the decision presented in Table 6 which was normalized through Equation (5) shown in Table 6 and the matrix was multiplied with weighting criteria β_j. The obtained weighted normalized matrix V_{ij} is presented in Table 7. However, the ideal, worst and best value was ascertained by employing Equations (7) and (8), and the result is shown in Table 8.

The Euclidean distance from the ideal, worst and best value is determined by Equations (9) and (10). The performance score is calculated by Equation (11). The best rank is the higher

Criteria	Unit
Yield strength (YS)	(N/mm^2)
Tensile strength (TS)	(N/mm^2)
Elongation (E)	(%)
Hardness (H)	(HV)
Cost (C)	\$/Kg

Source(s): Authors' own work

Table 3. Material criteria

Material	*YS*	*TS*	*E*	*H*	*C*
SUS 441L	270	470	38	166	3.2
SUS 439L	260	490	36	165	4.5
SUS 430	205	450	31	200	3.2
SUS 432L	260	456	32	152	2.4
SUS 436 LM	281	479	33	152	2.9
SUS 304	345	605	55	164	5.6
SUS 309	310	621	45	225	2.7
SUS310	212	532	43	210	5

Source(s): Authors' own work

Table 4. Material decision matrix

YS	TS	E	H	C	
β_j	0.142	0.078	0.197	0.114	0.469

Source(s): Authors' own work

Table 5. Criteria weighting by entropy method

Material	YS	TS	E	H	C
SUS 441L	0.35176	0.32162	0.33702	0.32393	0.29390
SUS 439L	0.33873	0.33530	0.31928	0.32198	0.41330
SUS 430	0.26708	0.30793	0.27494	0.39028	0.29390
SUS 432L	0.33873	0.31204	0.28381	0.29661	0.22042
SUS 436 LM	0.36609	0.32778	0.29268	0.29661	0.26635
SUS 304	0.44947	0.41400	0.48780	0.32003	0.51432
SUS 309	0.40387	0.42495	0.39911	0.43906	0.24798
SUS310	0.27620	0.36404	0.38137	0.40979	0.45922

Source(s): Authors' own work

Table 6. Normalized matrix decision

value, and the lowest value has the worst ranking, meaning that the ranking is in decreasing order, as presented in Table 9.

Table 10 presents the results of a MCDM analysis for selecting the best material for an intermediate exhaust pipe. The analysis utilizes both the COPRAS and the TOPSIS methods. A ranking of materials based on the both the COPRAS and the TOPSIS approaches, with a lower rank number indicating a superior material.

Table 7. Weighted and normalized decision matrix, $\mathbf{V}_{ij}$

Material	*YS*	*TS*	*E*	*H*	*C*
SUS 441L	0.04994	0.02508	0.06640	0.03699	0.13779
SUS 439L	0.04809	0.02614	0.06291	0.03677	0.19377
SUS 430	0.03792	0.02401	0.05417	0.04456	0.13779
SUS 432L	0.04809	0.02433	0.05592	0.03387	0.10335
SUS 436 LM	0.05197	0.02556	0.05767	0.03387	0.12488
SUS 304	0.06381	0.03228	0.09611	0.03654	0.24114
SUS 309	0.05734	0.03313	0.07864	0.05014	0.11626
SUS310	0.03921	0.02839	0.07514	0.04679	0.21530

Source(s): Authors' own work

Table 8. Ideal, best and worst value

V+	0.063810	0.033134	0.096110	0.050135	0.103346
V−	0.037916	0.024010	0.054171	0.033869	0.241140

Source(s): Authors' own work

Table 9. Distance from ideal and nonideal solution and $\mathrm{P_i}$

Material	Si+	Si−	P_i	Rank
SUS 441L	0.049994	0.104811	0.677054	4
SUS 439L	0.098764	0.049360	0.333234	6
SUS 430	0.061076	0.103898	0.629782	5
SUS 432L	0.046953	0.138181	0.746383	2
SUS 436 LM	0.049027	0.117173	0.705014	3
SUS 304	0.138466	0.050049	0.265491	7
SUS 309	0.022675	0.130067	0.851549	1
SUS310	0.116675	0.035987	0.235731	8

Source(s): Authors' own work

Table 10. Comparison of materials using COPRAS and TOPSIS methods

Materials	S+	F-Ci	Min (FCi)/F-Ci	Qi	Udi (%)	COPRAS rank	TOPSIS rank
SUS 441L	0.17841	0.138	0.750	0.347	82.803	4	4
SUS 439L	0.17391	0.194	0.533	0.294	70.114	8	6
SUS 430	0.16066	0.138	0.750	0.329	78.565	5	5
SUS 432L	0.16221	0.103	1.000	0.387	92.332	2	2
SUS 436 LM	0.16907	0.125	0.828	0.355	84.729	3	3
SUS 304	0.22874	0.241	0.429	0.325	77.590	6	7
SUS 309	0.21925	0.116	0.889	0.419	100.000	1	1
SUS310	0.18953	0.215	0.480	0.297	70.985	7	8

Source(s): Authors' own work

Where Qi is a composite score generated using the COPRAS approach that represents the overall performance of each substance and Udi is the utility degree, given as a percentage, demonstrating each material's relative utility in comparison to the best-performing material (SUS 309 at 100%).

The evaluation findings of several stainless-steel alloys utilizing the VIKOR method are shown in Table 11, along with the TOPSIS method rankings. The lower rank indicates a higher quality of each material according to the VIKOR technique.

Qi (0.5) is the overall VIKOR index, which includes both the group utility (Si) and individual regret (Ri) values. The value of Qi is determined using a weight (v) of 0.5, signifying equal relevance for both Si and Ri.

According to the results depicted in Table 11, it can be seen that SUS309, SUS441L and SUS432L occupy the first three rank positions, respectively, whereas SUS304 comes last.

The graphical illustration of results, and the TOPSIS ranking is portrayed in Figure 4.

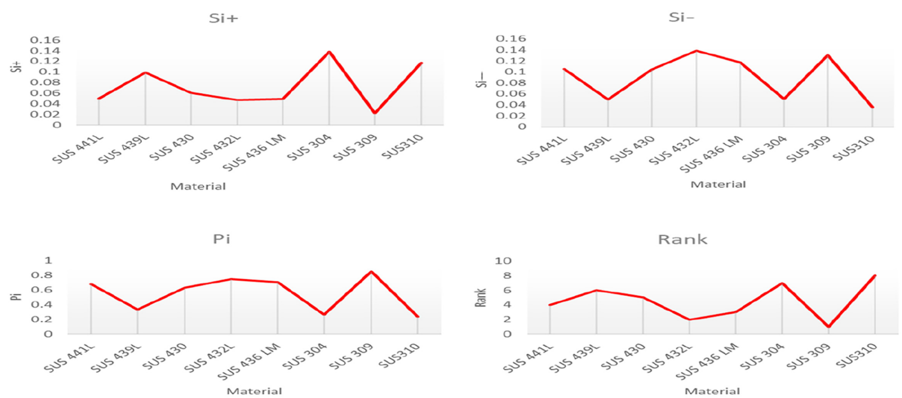
Figure 5 effectively compares the performance of various stainless steel alloys using three separate MCDM methodologies.

The optimal choice for designing exhaust intermediate pipes includes SUS 309, SUS 432L and SUS 436LM due to their distinctive attributes. These materials provide a well-rounded blend of high-temperature endurance, resistance to corrosion, flexibility and cost-efficiency. They can effectively function within a broad temperature spectrum, spanning from 500°C to 1000°C, rendering them suitable for various exhaust system uses. Moreover, they exhibit

Materials	Si	Ri	Qi (0.5)	VIKOR rank	TOPSIS rank
SUS 441L	0.49383227	0.13955674	0.40013176	2	4
SUS 439L	0.7033864	0.30776998	0.86700069	6	6
SUS 430	0.57328974	0.1970047	0.56685705	5	5
SUS 432L	0.46426223	0.18878442	0.45289164	3	2
SUS 436 LM	0.49752951	0.18056415	0.47022109	4	3
SUS 304	0.57158108	0.469	1.00754388	8	7
SUS 309	0.16149626	0.0820618	0	1	1
SUS310	0.67845562	0.38105016	0.96315049	7	8

Source(s): Authors' own work

Table 11. Comparative analysis of different materials using VIKOR and TOPSIS techniques



Source(s): Authors' own work

Figure 4. Graphical representation of ideal and nadir solution P_i and ranking

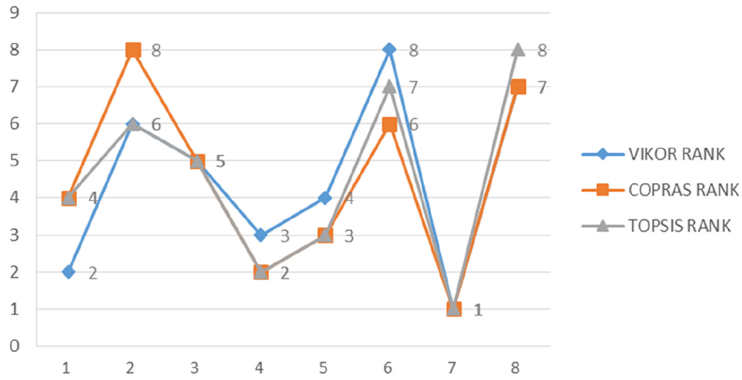


Figure 5. Comparison of materials using VIKOR, COPRAS and TOPSIS methods

Source(s): Authors' own work

resilience against corrosive elements found in exhaust emissions, such as sulfuric acid, water and nitrogen oxides. Furthermore, their widespread acceptance and availability in the industry streamline the sourcing and fabrication of components.

5. Conclusion

This study is based on the selection of material for the development of intermediate pipe using MCDM, and it involves four basic stages, i.e. method of translation criteria, screening process, method of ranking and search for methods. The selection was done through the TOPSIS method, and the criteria weight was obtained by the entropy method. The result showed that the top three materials are SUS 309, SUS 432L and SUS 436 LM, respectively, due to their balanced properties of high-temperature resistance, corrosion resistance, formability and cost-effectiveness. For future research, it is recommended to broaden the selection scope by incorporating more alternatives and criteria. Additionally, the comparison process can benefit from employing various MCDM techniques such as ELECTRE, DEMATEL and PROMETHEE. Diversifying material options may involve exploring alternatives like titanium or ceramics and considering factors like environmental impact. MCDM methods provide better analysis: ELECTRE for uncertain data, DEMATEL for identifying critical factors and PROMETHEE for systematic ranking. By combining these strategies, you can give facets importance, handle interdependencies and help decision-making as necessary. As a result, the overall evaluation of materials to be used for the exhaust system's performance, cost and sustainability is achieved.

The study underscores the need to extend material considerations and employ MCDM methods in exhaust system design. This approach enables managers to prioritize decision-making on multiple options and drivers and, in so doing, achieve savings, performance enhancements and more sustainable development. Among others, organizations can benefit from competitive advantages and increased material choice security by considering environmental matters and utilizing advanced decision-making approaches. Ultimately, the research contains critical information for managers interested in refining the design of an actual system to enhance its operational performance and meet rigorous regulatory and industrial standards.

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