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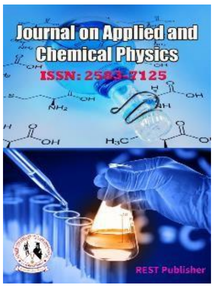

Optimizing Metallic Bipolar Plates for Polymer Electrolyte Fuel Cells in Electric Vehicles

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Abstract: *Polymer Electrolyte Fuel Cells (PEFCs) are increasingly recognized as a promising power source for electric vehicles (EVs) due to their high energy conversion efficiency and environmental benefits. Among the critical components of PEFCs, bipolar plates play a vital role in gas distribution, current collection, thermal management, and overall system durability. Conventional graphite bipolar plates suffer from limitations such as high cost, poor mechanical strength, corrosion issues, and difficulties in large-scale manufacturing. To overcome these challenges, this study investigates the suitability of metallic bipolar plates as alternatives for PEFC applications in EVs. A systematic evaluation of selected metallic materials—including 316, 310, 317L, and 316L austenitic stainless steels, along with gold-plated aluminium—was carried out using the Weighted Aggregated Sum Product Assessment (WASPAS) method. Key performance criteria such as specific stiffness ($E^{1/3}/\rho$), thermal stress resistance ($\sigma f/E\alpha$), thermal diffusion (α/k), and electrical resistivity ($\mu\Omega\cdot cm$) were considered. Equal weights were assigned to all criteria to ensure unbiased comparison. Experimental characterization and normalization of data were performed, followed by weighted decision matrix construction and preference score calculation using both Weighted Sum Model (WSM) and Weighted Product Model (WPM). The results reveal that gold-plated aluminium achieved the highest overall rank, indicating superior performance under the selected criteria, while 310 austenitic stainless steel ranked lowest. The findings demonstrate the effectiveness of the WASPAS method in material selection and highlight the potential of metallic bipolar plates—particularly aluminium with protective coatings—for improving the performance, efficiency, and longevity of PEFC systems in electric vehicles.*

Keywords: *Metallic Bipolar Plates, PEFC, Electric Vehicles, electrical conduction*

1. INTRODUCTION

The rapid expansion of electric vehicles (EVs) has intensified the demand for advanced, efficient, and environmentally sustainable energy conversion and storage systems. Among the emerging technologies, Polymer Electrolyte Fuel Cells (PEFCs) have gained significant attention as a promising power source for EVs due to their high energy conversion efficiency, low operating temperature, and minimal environmental impact. A critical component influencing the performance, durability, and cost of PEFC systems is the bipolar plate. Bipolar plates perform multiple essential functions within a PEFC stack, including reactant gas distribution, current collection, thermal regulation, and water management. They also act as structural supports and coolant channels, ensuring uniform electrochemical reactions by delivering hydrogen and oxygen efficiently to the electrode surfaces. Consequently, the material selection and structural configuration of bipolar plates have a direct impact on the efficiency, reliability, and lifespan of PEFC systems. Conventional graphite bipolar plates, although widely used, present several drawbacks that limit their large-scale commercial application. These include high material and manufacturing costs, low mechanical strength, limited corrosion resistance, and complex fabrication processes that hinder mass production. Additionally, graphite plates often require surface treatments to improve sealing and durability, further increasing cost and complexity. To overcome these limitations, research has increasingly focused on metallic bipolar plates made from materials such as stainless steel, titanium, aluminium, and nickel alloys. Compared to graphite, metallic bipolar plates offer superior electrical conductivity, enhanced mechanical robustness, improved corrosion resistance, and better suitability for high-volume manufacturing. These advantages make metallic bipolar plates attractive alternatives for next-generation PEFC systems in electric vehicles.The development of reliable and efficient metallic bipolar plates is therefore crucial for improving the overall performance, economic feasibility, and long-term sustainability of PEFC-powered electric vehicles.

2. MATERIALS AND METHODS

Different metallic bipolar plate materials considered for Polymer Electrolyte Fuel Cells (PEFCs) in electric vehicles. The materials analyzed include four grades of austenitic stainless steel—316, 310, 317L, and 316L—and gold-plated aluminium. Their performance is assessed using four key material indices that are important for fuel cell operation.

E1/3/: E stands for the Young's modulus, a parameter used to assess the stiffness or deformation resistance of a material. E's value is divided by three, and the resulting number is then divided by, the material's density. This formula is frequently used to determine a material's particular stiffness, demonstrating just how thin or dense it is in relation to its stiffness.
f/E: f is a material's ultimate tensile strength or the highest stress it can bear before failing. E stands for Young's modulus, as was previously indicated. The coefficient of expansion due to heat, or, quantifies how a substance swells or shrinks as a function of temperature. This formula is used to determine how much thermal stress a material will experience when it is heated [14].
As was already explained, /k: denotes a coefficient of thermal expansion. A material's thermal conductivity, or k, is a measure of how well it can conduct heat. The thermal diffusion of a material is represented by the ratio /k, which describes how rapidly it can transfer heat in comparison to how much it will expand or contract as the temperature changes.
Resistivity (cm): A resistivity is a unit of measurement for how well a material can thwart the flow of an electric current. It is represented by the symbol and expressed in microohm-centimeters (cm) units. Electrical resistance in a substance is described by its resistivity, which is the opposite of electrical conductivity (). While materials with low resistivity enable effective electrical conduction, those with high resistivity obstruct the passage of electric current.

WASPAS method: Research Design: The use of metallic bipolar plates for polymer electrolyte fuel cells (PEFCs) used in electric automobiles (EVs) is thoroughly examined in this research article. The Weighted Aggregate Product Assessment (WASPAS) approach is used in the study methodology to rank and assess the performance of various metallic bipolar plate materials for PEFCs [15]. The study includes the selection of materials, experimental characterization, and performance assessment based on a number of factors. Materials: For this investigation, a variety of metallic materials, including stainless steel, titanium, a metal and alloys of nickel, that are frequently used for bipolar plates, were taken into consideration. The electrical conductivity, toughness, and corrosion resistance of these materials are taken into consideration while choosing them [17]. Reputable sources are used to get commercial samples of the chosen materials, which are then processed to facilitate the subsequent experimental characterization. Experimental Characterization: To evaluate physical, electrical work, and mechanical characteristics of the metallic bipolar plate samples, a number of experimental characterizations are performed. The following steps are included in the characterization process a Surface Roughness Analysis: A profilometer is used to analyse the surface smoothness of each bipolar plate sample. This research sheds light on the appropriateness of the plate for efficient distribution of coolant and gas within the fuel tank stack [18]. Selection of Criteria and Weighting: Based on the significance of each criterion to fuel cell operation, the performance of metallic bipolar plates. Electrical conductivity, durability, corrosion resistance, roughness of the surfaces, and expenditure were among the factors considered. According to the WASPAS evaluation. WASPAS approach: The metallic bipolar plates are ranked using the Stochastic Sum Product Assessment (WASPAS) approach based on the specified criteria and their accompanying weights [19]. This approach offers a thorough assessment of the performance of the materials by combining the benefits of the weighed total and output methods. The weighted ratings for each criterion are determined using the WASPAS method's mathematical calculations, and a final Utilising statistical methods and data visualization tools, the data obtained through the actual characterizations and WASPAS evaluation are examined. Based on the defined criteria and their corresponding weights, the findings are evaluated to determine the best metallic substance for bipolar plates in PEFCs. The results offer insightful guidance for the selection and enhancement of metallic bipolar plates in applications for electric vehicles [20]. Research Restrictions: It's vital to recognize that this study has certain restrictions. The resources and experimental setting that are used determine the materials and procedures that are used. The efficacy of the titanium bipolar plates may be influenced by additional parameters, including as manufacturing procedures, particular operating environments, and long-term durability, however they are outside the purview of this study [21].

3. RESULTS AND DISCUSSIONS

TABLE 1. Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles

	E1/3/ρ	σf/Eα	α/k	resistivity (μΩ cm)
316 austenitic stainless steel	0.729	0.147	19.02	71
310 austenitic stainless steel	0.84	0.094	29.31	80
317L austenitic stainless steel	0.867	0.133	24.1	74
S316L austenitic stainless steel	0.768	0.111	24.43	69
aluminium (gold plated)	2.474	0.036	158.8	3.9

Table 1 compares different metallic bipolar plate materials for Polymer Electrolyte Fuel Cells (PEFCs) used in electric vehicles, including austenitic stainless steels (316, 310, 317L, and 316L) and gold-plated aluminium. The parameters $E^{1/3}/\rho$ indicate specific stiffness, σf/Eα represents resistance to thermal stress, α/k reflects thermal management behavior, and electrical resistivity shows current-carrying ability. Gold-plated aluminium exhibits the highest specific stiffness and lowest resistivity, indicating excellent lightweight and electrical performance. Stainless steels demonstrate moderate stiffness and conductivity with better thermal stability, offering a balanced combination of mechanical strength, durability, and corrosion resistance for PEFC bipolar plate applications.

TABLE 2. Performance Value

316 austenitic stainless steel	0.29466	1.00000	1.00000	0.05493
310 austenitic stainless steel	0.33953	0.63946	0.64893	0.04875
317L austenitic stainless steel	0.35044	0.90476	0.78921	0.05270
316L austenitic stainless steel	0.31043	0.75510	0.77855	0.05652
aluminums (gold plated)	1.00000	0.24490	0.11977	1.00000

Table 2 presents the normalized performance values of different metallic bipolar plate materials used in Polymer Electrolyte Fuel Cells (PEFCs). The values are obtained by dividing each criterion value by the maximum value in the dataset, resulting in dimensionless numbers between 0 and 1. This normalization enables fair comparison among materials with different units and magnitudes. A value of 1.000 indicates the best performance for that specific criterion, while lower values represent relatively weaker performance. Gold-plated aluminium achieves the highest performance in specific stiffness and electrical conductivity, whereas austenitic stainless steels show stronger performance in thermal and mechanical-related parameters. These normalized performance values form the basis for subsequent weighting, aggregation, and ranking using the WASPAS method.

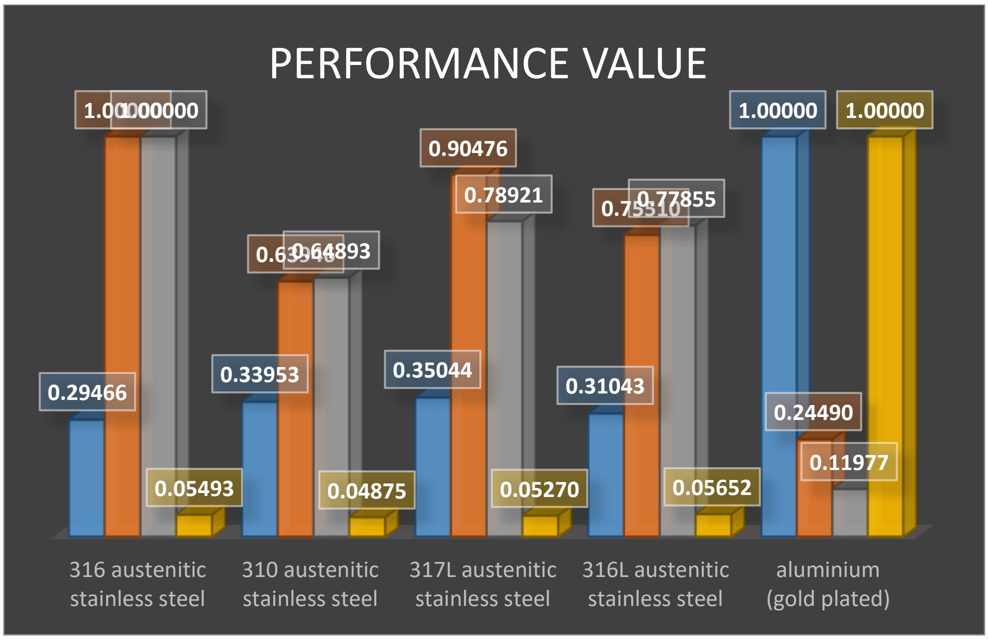

FIGURE 1. Performance Value

The figure 1 illustrates the normalized performance values of various metallic bipolar plate materials used in Polymer Electrolyte Fuel Cells (PEFCs) for electric vehicles. The materials compared include 316, 310, 317L, and 316L austenitic stainless steels, along with gold-plated aluminium. Each group of bars represents the performance of a material across the selected evaluation criteria after normalization. Gold-plated aluminium exhibits the highest performance in specific stiffness and electrical conductivity, reaching a normalized value of 1.000 in both cases, highlighting its lightweight nature and excellent current-carrying capability. In contrast, austenitic stainless steels show moderate but balanced performance across mechanical and thermal criteria, with 317L stainless steel demonstrating relatively stronger thermal performance among the steel grades..

TABLE 3. Weightages

316 austenitic stainless steel	0.25	0.25	0.25	0.25
310 austenitic stainless steel	0.25	0.25	0.25	0.25
317L austenitic stainless steel	0.25	0.25	0.25	0.25
316L austenitic stainless steel	0.25	0.25	0.25	0.25
aluminium (gold plated)	0.25	0.25	0.25	0.25

Table 3 shows Weightages used for the analysis. We take same weights for all the parameters for the analysis.

TABLE 4. Weighted Normal Decision Matrix

316 austenitic stainless steel	0.07367	0.25000	0.25000	0.01373
310 austenitic stainless steel	0.08488	0.15986	0.16223	0.01219
317L austenitic stainless steel	0.08761	0.22619	0.19730	0.01318
316L austenitic stainless steel	0.07761	0.18878	0.19464	0.01413
aluminium (gold plated)	0.25000	0.06122	0.02994	0.25000

Table 4 shows the weighted normalization decision matrix it is calculated by multiplying the weight and performance value in table 2 and table 3 E1/3/ρ, σf/Eα, α/k, resistivity (µΩ cm), 316 austenitic stainless steel, 310 austenitic stainless steel, 317L austenitic stainless steel, 316L austenitic stainless steel and aluminium (gold plated) weighted normalization decision matrix value.

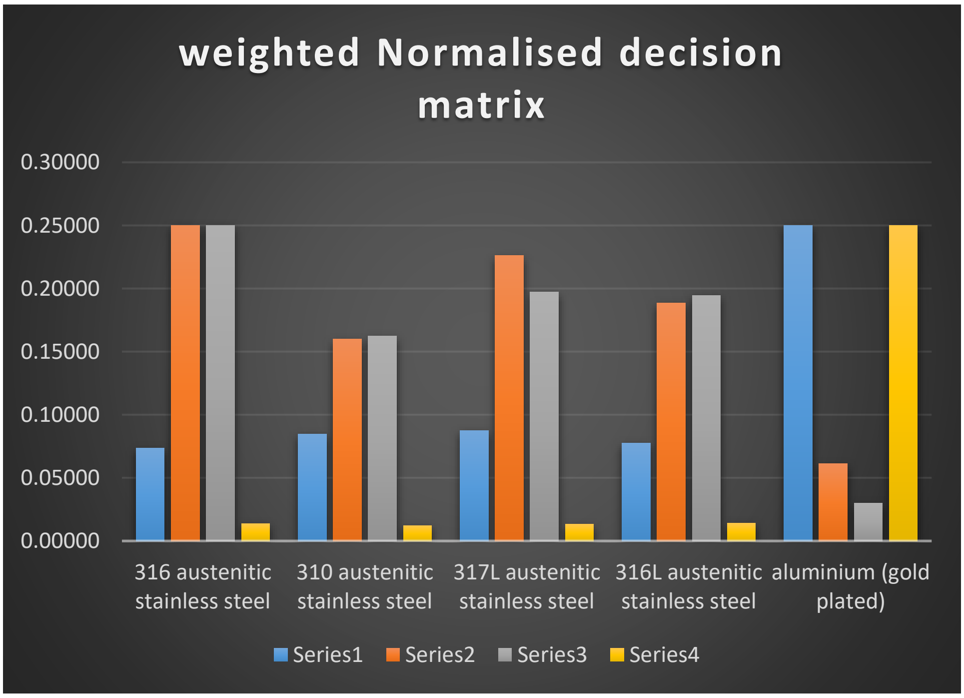

FIGURE 2. Weighted Normal Decision Matrix

Figure 2 shows the weighted normalization decision matrix it is calculated by multiplying the weight and performance value in table 2 and table 3 E1/3/ρ, σf/Eα, α/k, resistivity (μΩ cm), 316 austenitic stainless steel, 310 austenitic stainless steel, 317L austenitic stainless steel, 316L austenitic stainless steel and aluminium (gold plated) weighted normalization decision matrix value.

TABLE 6. Preference Score, WASPAS Coefficient

Preference Score	WSM Weighted Sum Model	Preference Score	WPM Weighted Product Model	lambda	WASPAS Coefficient
				0.5	
0.58740		0.35668			0.47204
0.41917		0.28788			0.35352
0.52428		0.33888			0.43158
0.47515		0.31869			0.39692
0.59117		0.41384			0.50251

Table 6 presents the preference scores of metallic bipolar plate materials obtained using the WASPAS method, which combines the Weighted Sum Model (WSM) and the Weighted Product Model (WPM). The WSM preference score is calculated by summing the weighted normalized values, while the WPM score is obtained by multiplying them. A weighting factor ($\lambda = 0.5$) is used to give equal importance to both models. The final WASPAS coefficient represents the overall performance of each material. Higher WASPAS coefficient values indicate better suitability of the material for PEFC bipolar plate applications.

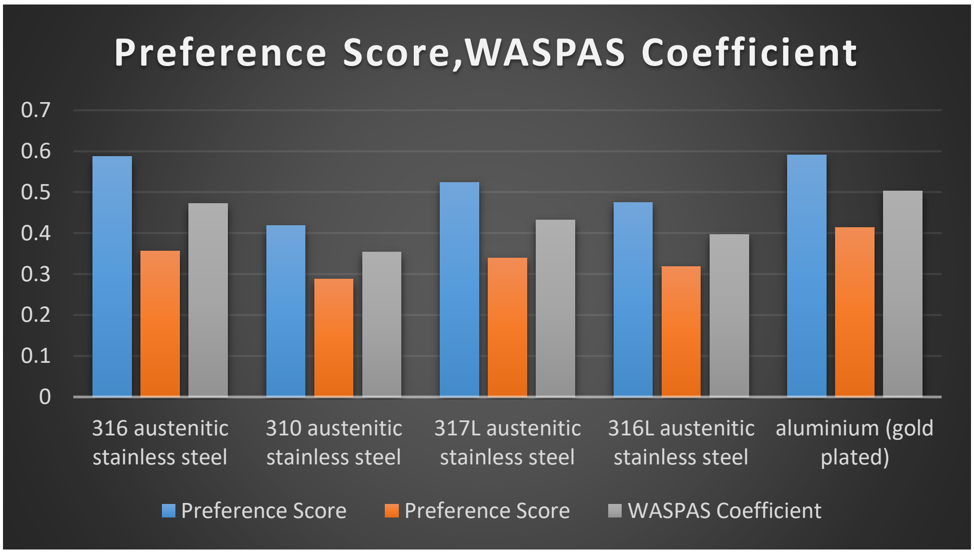

FIGURE 4. Preference Score, WASPAS Coefficient

Figure 5 Shows the preference score of WSM Weighted Sum Model it is calculated by the sum of the value on the row of weighted normalized decision matrix. the preference score of WPM Weighted Product Model it is calculated by the product of the value on the row on weighted normalized decision matrix.

TABLE 7. Final Result of Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles

	RANK
316 austenitic stainless steel	2
310 austenitic stainless steel	5
317L austenitic stainless steel	3
316L austenitic stainless steel	4
aluminium (gold plated)	1

Table 7 shows the Final Result of Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles using the analysis Method in WASPAS. aluminium (gold plated) is got the first rank whereas is the 310 austenitic stainless steel is having the Lowest rank.

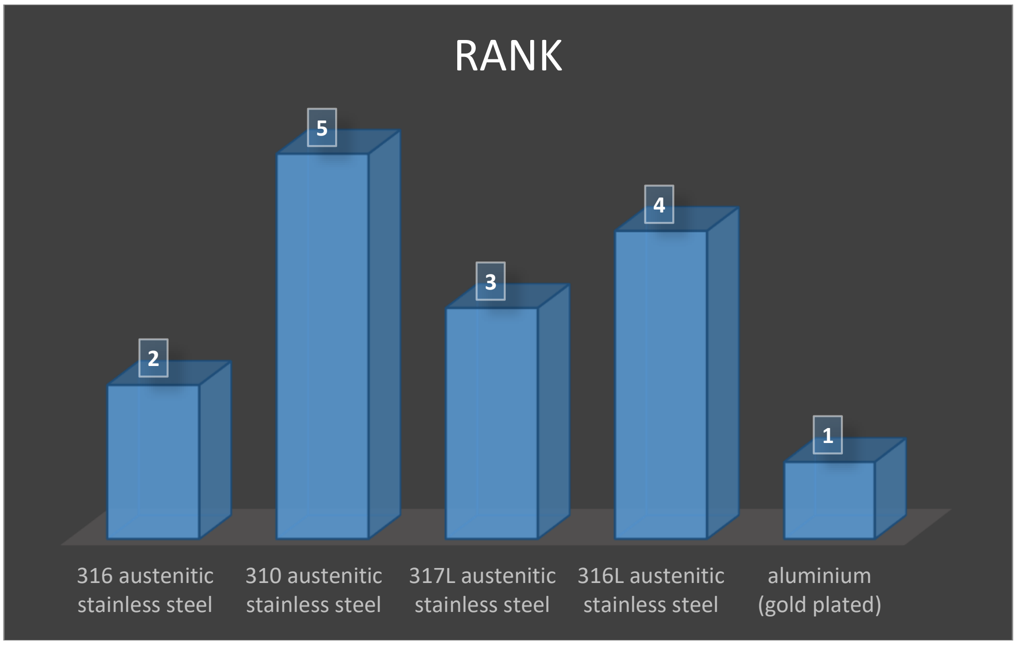

FIGURE 7. Rank

Figure 7 shows the Final Result of Metallic Bipolar Plates for Polymer Electrolyte Fuel Cell (PEFC) used In Electric Vehicles using the analysis Method in WASPAS. aluminium (gold plated) is got the first rank whereas is the 310 austenitic stainless steel is having the Lowest rank.

4. CONCLUSION

In conclusion, the successful implementation of effective customer retention strategies is essential for the long-term growth and sustainability of the telecommunications sector. Rapid technological advancements and intense market competition have significantly increased customer churn, making retention a strategic priority for telecom service providers. The findings clearly indicate that a comprehensive and customer-centric retention approach is necessary to address this challenge. Understanding customer needs and expectations, delivering high-quality service, and building long-term relationships are fundamental to retaining customers. Telecom companies must leverage advanced data analytics and statistical tools to identify customers at risk of switching, personalize interactions, and proactively resolve issues. Competitive pricing, flexible and customizable service plans, and attractive value-added services also play a crucial role in influencing customer retention. Continuous investment in network infrastructure is equally important to ensure reliable connectivity and consistent service quality, which directly enhances customer satisfaction and loyalty. Moreover, proactive communication and responsive customer support help build trust, reduce dissatisfaction, and strengthen long-term customer relationships. The adoption of digital platforms and self-service options further empowers customers by enabling easy access to information, efficient issue resolution, and convenient account management, while simultaneously reducing operational costs for service providers. Employee training and development are also critical, as skilled and motivated employees contribute significantly to positive customer experiences. Well-trained personnel can address customer concerns effectively, resolve problems promptly, and foster loyalty through professional service delivery.

REFERENCES

[1]. Saaty, T. L. (2008). Decision making with the analytic hierarchy process. International journal of services sciences, 1(1), 83-98 (1)
[2]. Chatterjee, P., & Hadi, A. S. (2012). Regression analysis by example. John Wiley & Sons(2)
[3]. Aka, Venkata Pavan Kumar, and Kiran Kumar Mandula Samuel. "Adoption of SAP FSCM–Enhancing Collections and Dispute Processes in Spain, Portugal, and UK Operations." *International Journal of Information Technology and Management Information Systems (IJITMIS)* 15, no. 2 (2024): 148-161.

[4]. Gurubasannavar, S. D. "A Predictive and Scalable Framework for B2b Commerce Platforms Using Micro Services, Micro Frontends." *And Machine Learning Models. International Journal of Artificial intelligence and Machine Learning* 1, no. 3 (2023): 1-9.

[5]. Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2014). Multivariate data analysis (7th ed.). Pearson Education Limited(1)

[6]. Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1988). SERVQUAL: A multiple-item scale for measuring consumer perceptions of service quality. Journal of Retailing, 64(1), 12-40.(2)

[7]. Zeithaml, V. A., Berry, L. L., & Parasuraman, A. (1996). The behavioral consequences of service quality. Journal of Marketing, 60(2), 31-46.(5)

[8]. Keeney, R. L., & Raiffa, H. (1976). Decisions with multiple objectives: Preferences and value tradeoffs. John Wiley & Sons.(4)

[9]. Brans, J. P., & Vincke, P. (1985). A preference ranking organization method. Management Science, 31(6), 647-656.(6)

[10]. Edwards, W., & Barron, F. H. (1994). SMARTS and SMARTER: Improved simple methods for multiattribute utility measurement. Organizational Behavior and Human Decision Processes, 60(3), 306-325(7)

[11]. Bouyssou, D., Marchant, T., & Pirlot, M. (2006). Evaluation and decision models with multiple criteria: Stepping stones for the analyst. Springer Science & Business Media.(15).

[12]. Gurubasannavar, S. D. "Evaluating Enterprise Data Accuracy Using Batch Migration Algorithm Analysis." *International Journal of Computer Science and Data Engineering* 1, no. 2 (2024): 1-6.

[13]. Sunku, Raghavendra. "Enterprise Sales Compensation Optimization: A Machine Learning Framework for Accurate Payout Forecasting." *International International Journal of Robotics and Machine Learning Technologies* 1, no. 2 (2025): 240.

[14]. Thota, Sandeep Kumar, Kumari Gubbala, Ashok Polavarapu, Vikram Narayandas, Hari Suresh Babu Gummadi, Narendra Chennupati, Sreedhar Babu Seshagani, Shivakrishna Deepak Veeravalli, and Manisha Guduri. "Adversarial Training with Attention-Guided DCGAN for Robust Lung Segmentation in Medical Imaging." In *2025 IEEE Region 10 Symposium (TENSYMP)*, pp. 1-6. IEEE, 2025.

[15]. Nayeemuddin, . and Salma, Umme, Analysis of a Drilling Hybrid Aluminum Metal Matrix Composites by Using SPSS (May 7, 2023). Int. J. Adv. Res. 11(01), 82-91, 2023, Available at SSRN: https://ssrn.com/abstract=4440349

[16]. Ali, Jawad, Zia Bashir, and Tabasam Rashid. "WASPAS-based decision making methodology with unknown weight information under uncertain evaluations." Expert Systems with Applications 168 (2021): 114143.

[17]. Keshavarz Ghorabaee, Mehdi, Maghsoud Amiri, Edmundas Kazimieras Zavadskas, and Jurgita Antuchevičienė. "Assessment of third-party logistics providers using a CRITIC–WASPAS approach with interval type-2 fuzzy sets." Transport 32, no. 1 (2017): 66-78.

[18]. Mardani, Abbas, Mehrbakhsh Nilashi, Norhayati Zakuan, Nanthakumar Loganathan, Somayeh Soheilirad, Muhamad Zameri Mat Saman, and Othman Ibrahim. "A systematic review and meta-Analysis of SWARA and WASPAS methods: Theory and applications with recent fuzzy developments." Applied Soft Computing 57 (2017): 265-292.

[19]. Zavadskas, E. K., D. Kalibatas, and D. Kalibatiene. "A multi-attribute assessment using WASPAS for choosing an optimal indoor environment." Archives of Civil and Mechanical Engineering 16, no. 1 (2016): 76-85.

[20]. Turskis, Zenonas, Nikolaj Goranin, Assel Nurusheva, and Seilkhan Boranbayev. "A fuzzy WASPAS-based approach to determine critical information infrastructures of EU sustainable development." Sustainability 11, no. 2 (2019): 424.

[21]. Diana George, R. Navya, Vinitha V, “Next-Gen Air Quality Index Forecasting with Hybrid Machine Learning Models and Cloud Synergy”, International Journal of Engineering Trends and Technology, 73(8), 2025, 129-136.

[22]. Rudnik, Katarzyna, Grzegorz Bocewicz, Aneta Kucińska-Landwójtowicz, and Izabela D. Czabak-Górska. "Ordered fuzzy WASPAS method for selection of improvement projects." Expert Systems with Applications 169 (2021): 114471.

[23]. Hwang, C. L., & Yoon, K. (1981). Multiple attribute decision making: Methods and applications. Springer Science & Business Media.(7)

[24]. Gurubasannavar, S. D. "Predictive Analysis of User Satisfaction in Omni-Channel Retailing a Comparative Analysis of Linear Regression and Random Forest Models." *J Comp Sci Appl Inform Technol* 8, no. 2 (2023): 1-8.

[25]. Kathad, S. K., and D. J. Pandya. "Virtual Inertia Evaluation for Frequency Instability in Renewable Energy Integration." *Indonesian Journal of Electrical Engineering and Computer Science* 37, no. 1 (2024): 380.

[26]. Nayeemuddina Umme Salma, Green Fabrication of Nio Nano Particles Doped PS-PVDF Nanocomposite Films: Structural, Morphology and Electrical Studies, Journal of Information Systems Engineering and Management, 10(23), 2025, 794-800.

[27]. Lahdelma, R., & Salminen, P. (2001). SMAA: Stochastic multicriteria acceptability analysis. European Journal of Operational Research, 129(2), 386-396.(7)

[28]. Belton, V., & Stewart, T. J. (2002). Multiple criteria decision analysis: An integrated approach. Springer Science & Business Media.(6)

[29]. Munda, G. (2008). Social multi-criteria evaluation for a sustainable economy. Springer Science & Business Media.(5)

[30]. Goumas, M., & Lygerou, V. (2000). An extension of the PROMETHEE method for decision making in fuzzy environment: Ranking of alternative energy exploitation projects. European Journal of Operational Research, 123(3), 606-613.(6)

[31]. Zanakis, S. H., Solomon, A., & Wishart, N. (1998). Multi-attribute decision making: A simulation comparison of select methods. European Journal of Operational Research, 107(3), 507-529(8).

[32]. Abhinav, E. Meher, Sai Naveen Kavuri, Thota Sandeep Kumar, Maragani Thirupathi, M. Chandra Mohan, and A. Suresh Reddy. "Analysis of molecular single-electron transistors using silicene, graphene and germanene." In *Proceedings of the Second International Conference on Computer and Communication Technologies: IC3T 2015, Volume 1*, pp. 77-84. New Delhi: Springer India, 2015.

[33]. Kathad, Shilpa K., and Pandya Dharmesh. "A review on Virtual Inertia emulation during Integration of Renewable Energy Sources." (2023).

[34]. Sunku, Raghavendra. "AI-Powered Data Warehouse: Revolutionizing Cloud Storage Performance through Machine Learning Optimization." *International Journal of Artificial intelligence and Machine Learning* 1, no. 3 (2023): 278.