EVALUATING MOTOR CHOICES FOR A SMART WHEELCHAIR PROTOTYPE USING AN INTEGRATED TODIM-COCOSO APPROACH WITH MEREC WEIGHTING

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Abstract:

This study aims to advance the decision-making process for assessing the optimal motor for a smart wheelchair prototype through the application of a hybrid Multi-Criteria Decision-Making (MCDM) method. By integrating the TODIM (Tomada de Decisao Interativa Multicriterio), CoCoSo (Combined Compromise Solution), and MEREC (Method based on the Removal Effects of Criteria) methodologies, the research aims to enhance the precision and reliability of evaluations. These methods are designed to manage complex decision-making, considering 10 critical parameters such as MRP, Weight, Noise level, Power, Torque, Speed, Energy efficient, Size and Integration, control and responsiveness, Durability and Reliability, and 9 potential motors for their suitability in smart wheelchair design. While the TODIM and CoCoSo approaches independently compute the performance rating to generate ranking of selected motors, the MEREC weighting methodology assesses the influence of criteria as sourced from online B2B market data and expert recommendations. The M-9 version is the greatest choice for developing smart wheelchairs. The purpose of the sensitivity evaluation was to collect pertinent data for the purpose of streamlining the decision-making process related to motor purchases. It also provides practical insights into motor selection for smart wheelchair prototypes, with potential applications in healthcare and assistive technology design.

1 Introduction

People with impairments now live much better thanks to smart wheelchairs, which provide more mobility, safety, and independence. With the use of sophisticated features like sensors, cameras, and self-navigating systems, users may navigate a variety of surroundings with ease thanks to these devices. Smart wheelchairs offer a wider range of users various control options, such as joysticks, voice commands, and even eye-tracking devices, for people who might find it difficult to operate standard wheelchairs [1].

Conventional wheelchairs are powered by the user's strength or the assistance of another person and are manually driven. They are frequently less expensive, lighter, and simpler to move and maintain. For people who have frequent help or have the upper body strength to propel themselves, traditional wheelchairs are a good choice. They are especially useful in settings like flat terrain and close quarters where accessibility is simple. However, individuals who lack the power or stamina to move themselves over long distances or difficult terrains may find using regular wheelchairs to be physically taxing.

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This may restrict the user's freedom of movement, particularly in unsteady or outdoor settings [2]. Even while classic wheelchairs are straightforward, it is still possible to add different seating arrangements and assistance functions to improve the user's comfort and use. On the other hand, motorized wheelchairs are driven by electric motors and managed by a joystick or additional interfaces like head controls or sip-and-puff devices. For people who find it difficult to operate a manual wheelchair due to significant mobility limitations or inadequate upper body strength, these wheelchairs are perfect. With less physical strain, users of motorized wheelchairs can travel farther and negotiate a broader variety of terrain, including hills and rough spots, giving them more independence [3]. The motor is one of the most important parts of a smart wheelchair; it determines the wheelchair's functionality, maneuverability, and energy economy. Carefully weighing several aspects, such as the wheelchair's intended use, terrain adaptability, weight capacity, and power requirements, is necessary when choosing the right motor.

The decision between various motor types, such as brushed DC motors, brushless DC motors, and stepper motors, can have a big impact on how well a smart wheelchair works. Brushless DC motors, for example, are well-known for their affordability and ease of use, but because of brush wear, they may need additional upkeep [4]. Brushless DC motors, on the other hand, have a greater efficiency, a longer lifespan, and a quieter operation, which makes them perfect for applications where responsive and smooth control is essential.

1.1 Role of motor selection in smart wheelchair

The choice of motors in a smart wheelchair is crucial in defining its overall functionality, effectiveness, and comfort for the user. The selection of motors should be based on their capacity to deliver sufficient power and torque to travel smoothly and controllably across a variety of terrains, including uphill and uneven ground. Energy-efficient motors help prolong battery life, which enables the wheelchair to be used for longer periods of time between charges. This makes the motor efficiency even more important. To provide user comfort, the motors should also run softly, particularly in calm or interior spaces. Another crucial element is compatibility with the wheelchair's control systems, since the motors must be able to precisely and consistently respond to commands for both manual and autonomous navigation [5]. Minimizing the size and weight of the motors will help keep the wheelchair lightweight and manageable without sacrificing functionality. Ultimately, the long-term safety and functionality of the smart wheelchair depend on the motors' robustness and dependability to survive regular use and a range of climatic circumstances.

It is essential to pick motor-related aspects that influence the design and development of the smart wheelchair prototype to carry out further research. First, the 10 most important factors influencing motor selection have been determined. These factors include motor specs that are readily available on websites, customer inquiries that are regularly asked on an online page, and literature data on motors. According to a panel discussion with smart wheelchair designers, these are the most crucial elements that they consider when selecting a motor. It is challenging to test every model available in the market because there are so many of them. According to product ratings and reviews on e-commerce websites like Amazon.in, Robu.in, Flyrobo.in, and Electronicscomp.com, all nine of these designs are currently quite popular. It's fascinating to notice that people choose these solutions above others for design prototyping, based on the extremely favorable feedback and ratings they've received from customers.

This study evaluates the best motors available using the TODIM and CoCoSo methodologies in conjunction with the MEREC approach. The primary goal of this study is to use ten parameters to choose the best model from these nine possibilities. The parameter's weight is calculated using the MEREC approach, and the top design is then chosen by combining it with the ranking tools as previously discussed. The methodology section covers both the TODIM and CoCoSo techniques and ranks them. To validate the robustness of the model, a sensitivity analysis is conducted, which results in a comprehensive alternative evaluation of an alternative model. This research will help smart wheelchair designers since they will have a solid understanding of the best models on the market and be able to legitimately choose the best one.

The sections of the research that follow are organized as follows. An overview of prior research based on MEREC, TODIM, CoCoSo, and various MCDM models is given in Section 2. Section 3 offers suggested motor selection methodologies. Furthermore, the results and discussions are presented in Section 4, and the validation of the planned study is explained in Section 5. A conclusion of the study's findings, limitations, and potential future paths is presented in Section 6.

2 Literature Review

The creation of intelligent wheelchairs entails the use of cutting-edge technology like robotics, sensors, and artificial intelligence to augment the mobility and autonomy of those with physical limitations. Consideration must be given to a number of factors during this process, such as cost, user comfort, safety, and functionality. Multi-Criteria Decision-Making (MCDM) approaches provide useful frameworks for assessing and optimizing design possibilities, especially given the difficulty of developing smart wheelchairs. Using MCDM techniques, decision-makers can ensure that the final prototype satisfies a variety of needs by balancing several, frequently opposing objectives. This review examines the use of MCDM techniques in the creation of smart wheelchair prototypes, emphasizing their benefits, drawbacks, and potential areas for further study.

Determining the essential characteristics and functions of the prototype smart wheelchair requires careful thought throughout the conceptual design stage. MCDM techniques, such as the Analytic Hierarchy Process (AHP), have been widely employed at this stage to rank design needs and assess alternative ideas. By dividing the decision problem into a hierarchy of criteria and sub-criteria, AHP offers an organized method that enables methodical pairwise comparisons and weighting. AHP has been used in the context of smart wheelchairs to assess different design options according to standards like maneuverability, safety features, user comfort, and cost-effectiveness [6].

Additionally useful in design optimization is CoCoSo, based on thirteen sustainability criteria, a hybridized CoCoSo approach that combines Dombi operators and similarity measures with interval-valued Fermatean fuzzy sets (IVFFSs) assesses and ranks manufacturers of autonomous smart wheelchairs [7]. The best configuration that satisfies functional and user comfort requirements is chosen with the aid of the method's capacity to rank solutions according to how near an ideal solution they are.

A prototype's durability, weight, and cost can all be affected by the material choice made throughout the design process. Materials that satisfy the unique needs of smart wheelchairs have been assessed and selected using MCDM techniques. This research evaluates 12 materials using 7 criteria, using the CRITIC, EDAS, and COPRAS frameworks for low-cost robotic wheelchair chassis material selection. It is determined that gray cast iron is ideal because it balances weight, cost, and mechanical qualities, improving wheelchair design and user experience [8].

The quality, cost, and viability of production of prototypes are all greatly impacted by the manufacturing procedures selected. In order to examine additive manufacturing (AM) processes, this study employs a hybrid MCDM approach that combines complex proportional evaluation with stepwise weight assessment ratio analysis. Based on economic, social, and environmental factors, fused deposition modeling (FDM), which promotes waste minimization and energy efficiency, is found to be the most sustainable solution [9].

The application of MCDM has also been used to training environment of smart wheelchair application. In order to assess Smart Training Environments (STEs) for Brain-Computer Interfaces (BCIs) based on Motor Imagery, this study creates a two-phase MCDM methodology. It benchmarks 27 STE applications using the Analytic Hierarchy Process (AHP) and the Fuzzy Decision by Opinion Score Method (FDOSM), determining important parameters and setting priorities to enable successful MI-BCI rehabilitation [10].

Examples of different MCDM methodologies successfully applied to the MCDM domain are provided in the next section. Since its inception, the three acknowledged tools—MEREC, TODIM, and CoCoSo—have functioned as viable tools for decision-making across various industries. Still, the researchers tried to provide in Table 1 a handful of the desired outcomes attained with those three approaches.

Table 1. Previous research based on MEREC, TODIM, CoCoSo, and Different MCDM models.

References	Weight Calculation Method	Priority Ranking Method	Observation
Kumar et al. (2024) [11]	MEREC	TOPSIS	Selecting coating materials for large-scale metal forming dies.
Mohamed et al. (2024) [12]	MEREC	Root Assessment Method	Identification of Unmanned Aerial Vehicless for Forest Fire Management and Detection.

References	Weight Calculation Method	Priority Ranking Method	Observation
Sönmez and Toktaş et al. (2024) [13]	MEREC	CoCoSo	Optimal supplier selection in a medical device firm.
Karbassi Yazdi et al. (2024) [14]	Delphi method, Fermatean fuzzy weighted aggregated sum product assessment technique, MEREC	WASPAS	Long-term fixes select the ideal site for renewable energy initiatives.
Taşcı (2024) [15]	ENTROPY and MEREC	MACONT	Multifaceted Assessment of Performance in the Turkish Non-Life Insurance Industry.
Ashofteh and Dougaheh (2024) [16]	ENTROPY	TODIM	Sorting the best low-impact urban development systems in light of climate change.
Chawala et al. (2024) [17]	Fuzzy Pythagorean	TODIM	Assigning a sustainable ABC analysis for inventory control.
Liu et al. (2024) [18]	Hesitant fuzzy linguistic	TODIM	Supplier evaluation for emergency material.
Yang et al. (2024) [19]	Fuzzy Linguistic Terms	TODIM	Sustainable third-party reverse logistics provider selection in electronic manufacturing industry.
Thilagavathy and Mohanaselvi et al. (2024) [20]	T-spherical fuzzy, SMART	TODIM	Encourages and cultivates in order to improve the general quality of education.
Vijayananth et al. (2024) [21]	CRITIC	TODIM	Evaluation of the mechanical and thermal properties of a polymer composite reinforced with eggshell particles and cigarette filter fibers utilizing integrated.
Okursoy and Coşansu (2024) [22]	MEREC	CoCoSo	Selection of Electric Vehicles with No Emissions.
Soumith et al. (2024) [23]	Entropy-CRITIC	TOPSIS, COPRAS and CoCoSo	The Best Option for Enhancing Passive Heat Transfer Sustainability in a Circular Pipe Heat Exchanger.
Parsa et al. (2024) [24]	Fuzzy Set Theory And Gray Numbers	CoCoSo	Sustainability standards and uncertainty into account when choosing suppliers for downstream oil and gas and petrochemical industries.
Saputro et al. (2024) [25]	Fuzzy AHP	CoCoSo	Green supplier selection under supply risks.
Hussain and Ullah (2024) [26]	Spherical fuzzy System	Sugeno-Weber aggregation operators	This system effectively handles uncertainty using spherical fuzzy environments for aggregation.

References	Weight Calculation Method	Priority Ranking Method	Observation
Kawecka et al. (2024) [27]	MEREC	SAW	To determines control parameters for optimizing efficiency and quality in Abrasive Water Jet Machining.
Kousar et al. (2024) [28]	MEREC	Best Worst Method, TOPSIS	Optimisation of smog-related challenges in Pakistan.
Biswas et al. (2024) [29]	AHP	TOPSIS	To optimise restaurant site selection by highway.
Biswas et al. (2023) [30]	Spherical fuzzy System	Einstein aggregation	To develops a hybrid spherical fuzzy MAGDM framework to assess SMEs' readiness for Quality 4.0.
Wang et al. (2023) [31]	Intuitionistic Fuzzy	Dombi Prioritized Aggregation Operators	Supplier selection in resilient supply chain management
Kannan et al. (2025) [32]	Linear Diophantine Fuzzy Set	CODAS	To enhance decision-making under uncertainty Logistic Specialist Selection.
Elraaid et al. (2024) [33]	AHP	-	To analyzes challenges in establishing a PMO in Libya's Misrata Free Zone.
Deivanayagampillai et al. (2023) [34]	Single-valued Neutrosophic sets	TODIM	To identify and ranks obstacles to Industry 5.0 for decision-making.
Biswas et al. (2024) [35]	DEMATEL	CoCoSo	To analyze the efficiency of the related criterion for adopting the circular economy concepts.
Tripathi et al. (2023) [36]	Intuitionistic fuzzy	CoCoSo	To evaluate medical therapies.
Keshavarz-Ghorabaee et al. (2021) [37]	MEREC	-	A new method to calculate weight of different criteria in MCDM method.
Gomes and Lima et al. (1991) [38]	-	TODIM	A MCDM method to rank alternatives.
Yazdani et al. (2019) [39]	-	CoCoSo	A MCDM method to rank alternatives.

2.1 Research Gap and Novelty of the presented work

Few research studies have presented the methodologies for the optimal selection of motors for design and development problems, even though, according to prior research, the use of the MCDM idea for making successful judgments in the design and development of new prototype is extremely unusual [40]. The following is a description of the research's uniqueness and list of research gaps:

- The motors, which help the smart wheelchair move, are a crucial part of the wheelchair's design, even though little scientific study was done to determine the best course of action.
- The ranks of two different integrated motor selection systems, MEREC-TODIM and MEREC-CoCoSo, are evaluated in this study.

- Sensitivity analysis on cost criteria is carried out to show the robustness and stability of the established processes, helping stakeholders cut the cost of wheelchairs.

2.2 Identification of Criteria for the proposed Study

The central emphasis of MCDM investigation is on a restricted set of potential criteria and alternative options. For this investigation, nine alternate motors and ten conflicting factors are being addressed. Identifying essential criteria is critical prior researchers use MCDM to acquire the best possible motor for implementing on a prototype. A focus group of five members, including one Professors, two Ph.D. students, and two research associates, who are working on a prototype development of smart wheelchair, was organized to discuss the important criteria and get their views on a 7 point likert scale that will help in decision making on the purchase of motor that are currently available on the market. The outcome of the discussion collected through facts and information gathered from a variety of resources, including websites, literature from various publications, different YouTube channels, comments, and focus group discussions. The ten crucial and contradictory parameters are as follows, as mentioned in detail.

- Maximum retail price (MRP): This is a non-beneficial feature because the goal of the study is to keep mrp as low as possible to lower the overall cost of prototype's final design [41].
- Weight (W): The wheelchair's total weight is directly impacted by the weight of the motor. A lighter engine is better since it makes the wheelchair easier to transport and handle. Furthermore, a lighter motor can need less energy to move, prolonging the life of the battery [42].
- Noise Level (NL): For the sake of user comfort, the motor's noise level is crucial, particularly in peaceful spaces like homes, businesses, or libraries. To guarantee that the wheelchair functions silently and causes the least amount of disturbance to the user and anyone around them, low-noise motors are usually preferred.
- Power (P): The motor's power output controls how well the wheelchair can be driven, particularly on uneven and sloping surfaces. Although a motor with more power can run more smoothly and support bigger loads, it may also use more energy.
- Torque (T): Torque, a measurement of the motor's rotational force, influences the wheelchair's capacity to move from a stationary position, ascend hills, and pull larger weights.
- Speed (S): To suit the user's mobility needs, the wheelchair's motor speed is a critical factor. The wheelchair should be comfortable for the user to operate by having a motor that strikes a balance between safety concerns and enough speed for rapid movement.
- Energy Efficient (EE): The motor's ability to convert electrical energy into mechanical energy is referred to as its energy efficiency. The wheelchair's battery life is increased with an energy-efficient motor, enabling longer usage between charges. For users who depend on their wheelchair for prolonged periods of time without access to charging, this is especially crucial.
- Size and Integration (SI): The wheelchair's overall functionality and aesthetics are influenced by the size of the motor and how well it blends in with the design. In order to provide a sleek design and simple maintenance, the motor should blend in smoothly with the wheelchair's construction without adding extra mass or complexity.
- Control and Responsiveness (CR): This criterion gauges the motor's precision and speed in responding to user commands. To ensure that the wheelchair can be handled precisely, especially in small places or in response to abrupt changes in the environment, high control and responsiveness are essential. This improves user safety and confidence.
- Durability and Reliability (DR): For the wheelchair to continue to perform with little maintenance, the motor's longevity and dependability are essential. Long-term value and fewer repairs or replacements are required with a durable motor since it is resistant to weather variables, wear and tear, and regular use.

This study represents 9 different models with expenditures varying from cheap to high be picked from a variety of manufacturers and have variable qualities that can be obtained on different online stores, as indicated in Table 2.

The following section includes material and methods, results and discussion, conclusion, and future work of the current study, fulfilling the purpose of the study that aim to get the following objective:

- To employ the MEREC tool to determine each criterion's weight.

- To demonstrate the TODIM and CoCoSo MCDM algorithms for ranking nine different motors.
- Sensitivity analysis of the MRP criteria to determine how changes in the objective parameter choice weight affect the motors' rankings.

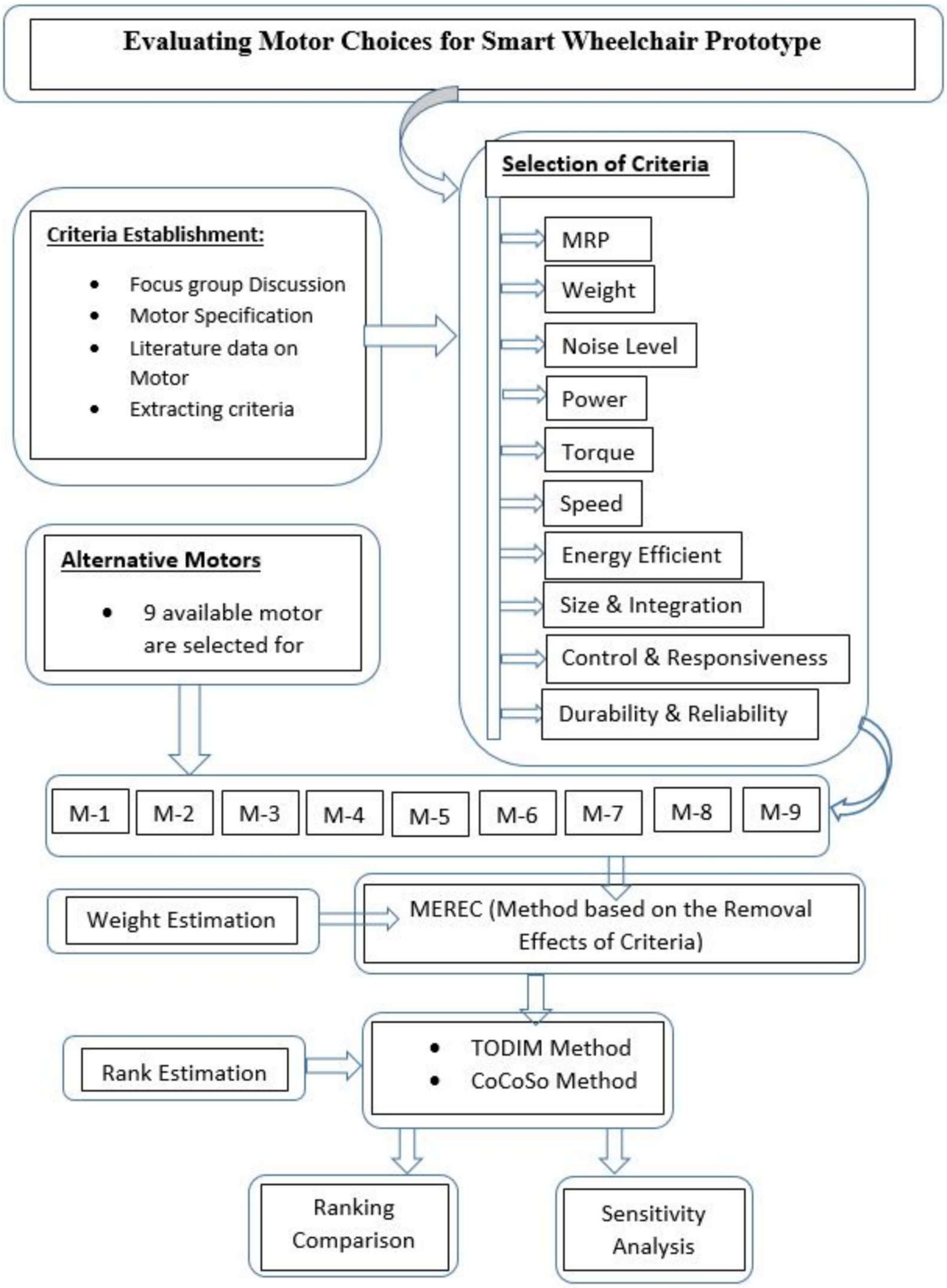

Figure 1. Flow Chart of presented research study.

Table 2. Selected motors with their specifications.

Criteria	MRP	W	NL	P	T	S	EE	SI	CR	DR
M-1(DC Motors)	2832	2.1	2.2	350	11	300	3.8	5.2	4.2	3.6
M-2(PMDC Motor)	5404	5.6	3.4	450	7.5	480	4	4	5.4	4

Criteria	MRP	W	NL	P	T	S	EE	SI	CR	DR
M-3(PMDC Motor)	3912	2.77	4	250	15	120	4	4	3.2	5.4
M-4(PMDC Motor)	6293	3.12	4	250	15	120	5.8	4.2	4.2	4.2
M-5(PMDC Motor)	6395	5.5	3.4	600	18	480	4.8	4	4	3.2
M-6(PMDC Motor)	9999	7	3	200	16.95	190	5.6	5.8	3.8	4.4
M-7(PMDC Motor)	10999	7	2.2	200	16	135	5	4.8	5	6
M-8(BLDC HUB Motor)	6499	3.5	2.6	350	12	300	5.4	6.8	6.2	4.4
M-9(BLDC HUB Motor)	7500	4.5	1.2	350	15	450	6.6	6.4	6.4	6.2

3 Material and Methods

This section includes all of the study's numerical computations and methods, as seen in Figure 1. The evaluation criteria were developed by consulting a wide range of sources, such as motor specifications, literature reviews, and focus group discussions. Table 2 displays a decision matrix that is the outcome of evaluating nine different motor options based on ten different criteria. The MEREC tool was used to determine the relative importance of each criterion, making it easier to estimate weights based on quantitative data and expert opinions.

The TODIM and CoCoSo methodologies were used to rank the possibilities, offering a methodical and structured way to compare the different motor options. These techniques enable a thorough examination of the options, considering the weighted criteria to ensure a thorough assessment of the performance and suitability of each motor.

After the results from the TODIM and CoCoSo techniques were compared, the Copeland voting criteria was applied to help aggregate the data and identify the best motor alternative. This resulted in the final ranking. Furthermore, a sensitivity analysis was performed to evaluate the stability of the results with respect to the cost parameters. This research ensures that the conclusions are sound and applicable in a range of scenarios by providing insights into how variations in prices could affect the overall rankings. All things considered; the methodology offered offers a comprehensive framework for wise choice-making when choosing a motor option.

3.1 MEREC Technique for evaluating criterion weight

A weight-determination technique in regard to effect of deleting criterion was presented by Ghorabaee et al. [37]. In contrast to conventional techniques such as ENTROPY and CRITIC, which assess variance in alternative performance, MEREC affects weights by inspecting the outcome by eliminating each criterion. The following are the plan of action provided by the original author to estimate MEREC weight:

Step 1: A decision matrix $(\overline{D})$ is developed, forming a $n \times m$ matrix, where m represents criteria, and n represents alternatives using equation 1. Each row and column contain performance values for corresponding alternatives and criteria. Elements in the matrix are denoted as d_{ij} in i^{th} row and j^{th} column.

$$\overline{D} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & \cdots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix} \tag{1}$$

Step 2: In this stage, Matrix $(\overline{D})$ is normalized using equation 2, in which all the members of the normalized matrix is shown by DN_{ij}^{d} as follows for both beneficial criteria (B) and cost criteria (C).

$$DN_{ij}^{d} = \begin{Bmatrix} \dfrac{\min_k d_{kj}}{d_{ij}} if\ j \in B \\ \dfrac{d_{ij}}{\max_k d_{kj}} if\ j \in C \end{Bmatrix} \tag{2}$$

Step 3: In this stage, the total performances are obtained by introducing a logarithmic function with comparable criteria weights to estimate the overall performance of the alternatives OP_i using equation 3 as follows:

$$OP_i = \ln\left(1 + \left(\frac{1}{m}\sum_j \left|\ln\left(DN_{ij}^{d}\right)\right|\right)\right) \tag{3}$$

Step 4: In this stage, performance of alternatives is estimated by eliminating each criterion using equation 4 as follows:

$$OP_{ij}' = \ln\left(1 + \left(\frac{1}{m}\sum_{k,k\neq j} \left|\ln\left(DN_{ij}^{d}\right)\right|\right)\right) \tag{4}$$

Step 5: In this stage, sum of absolute deviation is estimated using equation 5 as follows:

$$SAD_j = \sum_i \left|OP_{ij}' - OP_i\right| \tag{5}$$

Step 6: In this stage, weight of criteria (w_j) is estimated using equation 6 which will be used for all MCDM method in this paper as follows:

$$w_j = \frac{SAD_j}{\sum_k SAD_j} \tag{6}$$

3.2 TODIM Technique for ranking alternatives

Gomes and Lima constructed the TODIM technique in 1991, which used a multi-criteria approach to rank alternatives [38]. This approach incorporates the concepts of prospect theory into the multi-criteria decision-making procedure. Making a multi-criteria decision matrix with m criteria and n choices is the initial step in applying the TODIM approach as follows:

Step 1: This stage is same as step-1 of MEREC technique as shown in section 3.1.

Step 2: In this stage, the decision matrix need to be standardize. Equation 7 is used to normalize the performances of the alternatives for beneficial criteria, and equation 8 is used for cost criteria as follows:

$$ND_{ij} = \frac{d_{im}}{\sum_{i=1}^{n} d_{im}}, for\ beneficial\ criteria \tag{7}$$

$$ND_{ij} = \frac{\frac{1}{d_{im}}}{\sum_{i=1}^{n} \frac{1}{d_{im}}}, for\ \cos t\ criteria \tag{8}$$

Step 3: In this stage, relative weight is estimated using equation 9, where weight of each criterion (w_c) is taken from MEREC technique and w_r is maximum weight of all criteria.

$$w_{cr} = \frac{w_c}{w_r} \tag{9}$$

Step 4: In this stage, dominance of one alternative is estimated over other alternative using equation 10 and 11 as follows:

$$\delta\left(A_i, A_j\right) = \sum_{j=1}^{n} \phi_j\left(A_i, A_j\right) \tag{10}$$

Where, the dominance function is as follows:

$$\phi_j = \begin{cases} \sqrt{\dfrac{w_{cr}\left(ND_{ic} - ND_{jc}\right)}{\sum_{c=1}^{m} w_{cr}}}, & if\left(ND_{ic} - ND_{jc}\right) > 0 \\ 0, & if\left(ND_{ic} - ND_{jc}\right) = 0 \\ \dfrac{-1}{\theta}\sqrt{\dfrac{\left(\sum_{c=1}^{m} w_{cr}\right)\left(ND_{ic} - ND_{jc}\right)}{w_{cr}}}, & if\left(ND_{ic} - ND_{jc}\right) < 0 \end{cases} \tag{11}$$

And θ is the loss aversion parameter; $ND_{ic} > ND_{jc}$ shows a gain for one alternative over other alternative; $ND_{ic} = ND_{jc}$ means no gain no loss condition; $ND_{ic} < ND_{jc}$ means a loss.

Step 5: Global dominance $\varphi(A_i)$ is estimated using equation 12 for obtaining a ranking order as follows:

$$\varphi\left(A_i\right) = \frac{\sum_{j=1}^{n} \delta\left(A_i, A_j\right) - \min \sum_{j=1}^{n} \delta\left(A_i, A_j\right)}{\max \sum_{j=1}^{n} \delta\left(A_i, A_j\right) - \min \sum_{j=1}^{n} \delta\left(A_i, A_j\right)} \tag{12}$$

Step 6: Ranking of alternative is estimated, where a larger score of $\varphi(A_i)$ shows a best alternative.

3.3 CoCoSo Technique for ranking alternatives

The Combined Compromise Solution (CoCoSo) method is a decision-making strategy that provide a compromised remedy for tackle MCDM problems [29]. To produce a reliable and well-rounded answer, it combines two well-liked decision-making models: simple additive weighting (SAW) and exponentially weighted product (EWP). Through the amalgamation of these models' abilities, CoCoSo seeks to surmount the constraints of singular approaches and furnish a thorough assessment of substitutes grounded in a multitude of criteria. Upon defining pertinent and alternative criteria, the CoCoSo model's steps indicates as follows:

Step 1: This stage is same as step-1 of MEREC technique as shown in section 3.1.

Step-2: Compromise normalization equations 13 and 14 are used to determine the normalizing of the selection matrix for the benefit and cost factors, respectively.

$$r_{ij} = \frac{c_{ij} - \min_i c_{ij}}{\max_i c_{ij} - \min_i c_{ij}}; \textit{for benefit criterion} \tag{13}$$

$$r_{ij} = \frac{\max_i c_{ij} - c_{ij}}{\max_i c_{ij} - \min_i c_{ij}}; for\ cost\ criterion \tag{14}$$

Step-3: For every alternative, the sum of the weighted comparability sequence Si and the total of the power weighted comparability sequence Pi are determined using equations 15 and 16, respectively.

$$S_i = \sum_{j=1}^{n} \left(w_j r_{ij} \right) \tag{15}$$

$$P_i = \sum_{j=1}^{n} \left(r_{ij} \right)^{w_j} \tag{16}$$

Step-4: In this stage, three equations connected to performance scores are used to determine the relative weights of the other options. Equation 17 gives the arithmetic means of the WPM and WSM grading sums. The relative ratings of WSM and WPM in relation to the most advantageous are added in Equation 18. A reasonable trade-off between the WSM and WPM model scores is produced by Equation 19.

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} \left(P_i + S_i \right)} \tag{17}$$

$$k_{ib} = \frac{P_i}{\min_i P_i} + \frac{S_i}{\min_i S_i} \tag{18}$$

$$k_{ic} = \frac{\beta \left(S_i \right) + \left(1 - \beta \right) \left(P_i \right)}{\beta \max_i S_i + \left(1 - \beta \right) \max_i P_i}, 0 \le \beta \le 1 \tag{19}$$

For the sake of the initial study in this work, the value β of is taken to be 0.5 (β = 0.5).

Step-5: As Equation 20 shows that the assessment rating, or $k_i$value, is the only factor that determines the final ranking of the options—the higher the score, the larger the benefit.

$$k_i = \left(k_{ia} k_{ib} k_{ic} \right)^{\frac{1}{3}} + \frac{1}{3} \left(k_{ia} + k_{ib} + k_{ic} \right) \tag{20}$$

The CoCoSo method's highest evaluation rating indicates which selection is the best.

3 Result and discussion

In this section, the representative cases are studied to demonstrate the applicability and validity of the proposed methodology in addressing the motor selection process for the electric wheelchair.

4.1 Implementation of MEREC technique on proposed study

The MEREC approach is used to establish the weights of the criterion after a thorough overview of the criteria is provided in the literature review and methodology sections. Equations 2 is used to calculate the normalized decision matrix, which is the first step in the process as shown in table 3. Equations 3 to 6 are used to build matrix that represents performance of alternatives by removing attributes and the final weight of each parameters as shown in table 4.

Table 3. Normalized decision matrix.

Criteria	MRP	W	NL	P	T	S	EE	SI	CR	DR
M-1	0.2575	0.3000	0.5500	0.5714	0.6818	0.4000	1.0000	0.7692	0.7619	0.8889
M-2	0.4913	0.8000	0.8500	0.4444	1.0000	0.2500	0.9500	1.0000	0.5926	0.8000
M-3	0.3557	0.3957	1.0000	0.8000	0.5000	1.0000	0.9500	1.0000	1.0000	0.5926
M-4	0.5721	0.4457	1.0000	0.8000	0.5000	1.0000	0.6552	0.9524	0.7619	0.7619
M-5	0.5814	0.7857	0.8500	0.3333	0.4167	0.2500	0.7917	1.0000	0.8000	1.0000
M-6	0.9091	1.0000	0.7500	1.0000	0.4425	0.6316	0.6786	0.6897	0.8421	0.7273
M-7	1.0000	1.0000	0.5500	1.0000	0.4688	0.8889	0.7600	0.8333	0.6400	0.5333
M-8	0.5909	0.5000	0.6500	0.5714	0.6250	0.4000	0.7037	0.5882	0.5161	0.7273
M-9	0.6819	0.6429	0.3000	0.5714	0.5000	0.2667	0.5758	0.6250	0.5000	0.5161

Table 4. Performance of alternatives by removing each attribute and weight of each parameter.

Criteria	MRP	W	NL	P	T	S	EE	SI	CR	DR
M-1	0.0906	0.0799	0.0389	0.0364	0.0247	0.0603	0.0000	0.0169	0.0175	0.0075
M-2	0.0517	0.0160	0.0116	0.0593	0.0000	0.1036	0.0036	0.0000	0.0378	0.0160
M-3	0.0800	0.0714	0.0000	0.0167	0.0529	0.0000	0.0038	0.0000	0.0000	0.0397
M-4	0.0429	0.0627	0.0000	0.0169	0.0535	0.0000	0.0323	0.0037	0.0207	0.0207
M-5	0.0374	0.0165	0.0111	0.0773	0.0611	0.0986	0.0160	0.0000	0.0152	0.0000
M-6	0.0074	0.0000	0.0225	0.0000	0.0653	0.0363	0.0305	0.0292	0.0134	0.0250
M-7	0.0000	0.0000	0.0471	0.0000	0.0600	0.0091	0.0213	0.0141	0.0349	0.0495
M-8	0.0346	0.0459	0.0283	0.0369	0.0309	0.0611	0.0230	0.0349	0.0437	0.0208
M-9	0.0228	0.0264	0.0735	0.0335	0.0417	0.0810	0.0331	0.0281	0.0417	0.0397
Weight	0.1326	0.1150	0.0841	0.1000	0.1408	0.1624	0.0591	0.0458	0.0812	0.0790

This method ensures a systematic and quantitative approach to weighting, enhancing the accuracy and reliability of the analysis. Based on MEREC MCDM method, the most important factors in wheelchair development selection are speed (0.1624) and torque (0.1408), which highlight performance. The important metrics of cost (MRP, 0.1326) emphasize cost effectiveness of the final product. Moderately significant factors are Power (0.1000) and Control and Responsiveness (0.0812). Durability (0.0790) and Noise Level (0.0841) are not as important. The decision was made with secondary thought, as seen by the lowest levels of effect for Size and Integration (0.0458) and Energy Efficiency (0.0591).

4.2 Implementation of TODIM technique on proposed study

The TODIM approach is implemented in accordance with the process provided in section 3.2 of this article, using the performance of the alternatives across the researched criteria, as defined in table 2, and the associated criterion weights outlined in Table 4. All criteria are viewed as maximizing criteria for the sake of this study, which means that the best option should maximize net equity across all ranking investment fund categories. To maintain uniformity, the attenuation factor θ is assigned a value of 1 to every criterion. The normalized decision matrix and relative weight (Wcr) is developed using equation 7, 8, and 9 as shown in table 5. Using equation from 10 to 12, the global dominance and rank of alternative is estimated as shown in table 5.

Table 5. Normalized decision matrix.

Criteria	MRP	W	NL	P	T	S	EE	SI	CR	DR
M-1	0.2225	0.2060	0.1281	0.1167	0.0870	0.1165	0.0844	0.1150	0.0991	0.0870
M-2	0.1166	0.0772	0.0829	0.1500	0.0593	0.1864	0.0889	0.0885	0.1274	0.0966
M-3	0.1611	0.1562	0.0705	0.0833	0.1186	0.0466	0.0889	0.0885	0.0755	0.1304
M-4	0.1001	0.1386	0.0705	0.0833	0.1186	0.0466	0.1289	0.0929	0.0991	0.1014
M-5	0.0985	0.0786	0.0829	0.2000	0.1423	0.1864	0.1067	0.0885	0.0943	0.0773
M-6	0.0630	0.0618	0.0939	0.0667	0.1340	0.0738	0.1244	0.1283	0.0896	0.1063

M-7	0.0573	0.0618	0.1281	0.0667	0.1265	0.0524	0.1111	0.1062	0.1179	0.1449
M-8	0.0969	0.1236	0.1084	0.1167	0.0949	0.1165	0.1200	0.1504	0.1462	0.1063
M-9	0.0840	0.0961	0.2348	0.1167	0.1186	0.1748	0.1467	0.1416	0.1509	0.1498
Wcr	0.8167	0.7083	0.5178	0.6156	0.867	1	0.3636	0.2820	0.5000	0.4865

Based on global dominance, the TODIM method analysis is used to choose an electric motor alternative for wheelchair development. The results show that M-9, with a dominance score of -4.27879, is the best option that offers the best overall performance across parameters. M-8 comes in second place with a score of -10.4798, not far behind. M-1, with a score of -17.8423, comes in third. With lower ranks and scores, the options M-3, M-6, and M-7 perform worse and are therefore less desirable as shown in table 6.

Table 6. Results of global dominance and Ranking.

Alternatives	Global Dominance	Rank
M-1	-17.8423	3
M-2	-24.8139	5
M-3	-28.162	9
M-4	-26.0746	7
M-5	-21.7818	4
M-6	-26.4993	8
M-7	-25.0124	6
M-8	-10.4798	2
M-9	-4.27879	1

4.3 Implementation of CoCoSo Technique on proposed study

The CoCoSo technique was used to rank and evaluate motors intended for wheelchair applications, in accordance with procedures described in Section 3.3. Equation 13 and 14 was used to carry out the compromise normalization of the choice matrix, which was the first stage, and the corresponding value is shown in Table 7. The data was scaled suitably because of this normalizing process, enabling fair comparisons across many parameters.

Table 7. Normalization Decision Matrix.

Criteria	MRP	W	NL	P	T	S	EE	SI	CR	DR
M-1	1.0000	1.0000	0.6429	0.3750	0.3333	0.5000	0.0000	0.4286	0.3125	0.1333
M-2	0.6851	0.2857	0.2143	0.6250	0.0000	1.0000	0.0714	0.0000	0.6875	0.2667
M-3	0.8678	0.8633	0.0000	0.1250	0.7143	0.0000	0.0714	0.0000	0.0000	0.7333
M-4	0.5762	0.7918	0.0000	0.1250	0.7143	0.0000	0.7143	0.0714	0.3125	0.3333
M-5	0.5637	0.3061	0.2143	1.0000	1.0000	1.0000	0.3571	0.0000	0.2500	0.0000
M-6	0.1224	0.0000	0.3571	0.0000	0.9000	0.1944	0.6429	0.6429	0.1875	0.4000
M-7	0.0000	0.0000	0.6429	0.0000	0.8095	0.0417	0.4286	0.2857	0.5625	0.9333
M-8	0.5510	0.7143	0.5000	0.3750	0.4286	0.5000	0.5714	1.0000	0.9375	0.4000
M-9	0.4284	0.5102	1.0000	0.3750	0.7143	0.9167	1.0000	0.8571	1.0000	1.0000

Then, using the weighted normalized matrix and the exponentially weighted normalized matrix, respectively, the performance indices, designated as Si and Pi, were calculated. Equations 15 and 16 were utilized in the computation of these figures as shown in table 9 and 8.

Table 8. Si Calculation.

Criteria	MRP	W	NL	P	T	S	EE	SI	CR	DR	Si
M-1	0.1326	0.1150	0.0541	0.0375	0.0469	0.0812	0.0000	0.0196	0.0254	0.0105	0.5229
M-2	0.0909	0.0329	0.0180	0.0625	0.0000	0.1624	0.0042	0.0000	0.0558	0.0211	0.4477

M-3	0.1151	0.0993	0.0000	0.0125	0.1006	0.0000	0.0042	0.0000	0.0000	0.0579	0.3896
M-4	0.0764	0.0911	0.0000	0.0125	0.1006	0.0000	0.0422	0.0033	0.0254	0.0263	0.3778
M-5	0.0748	0.0352	0.0180	0.1000	0.1408	0.1624	0.0211	0.0000	0.0203	0.0000	0.5726
M-6	0.0162	0.0000	0.0300	0.0000	0.1267	0.0316	0.0380	0.0294	0.0152	0.0316	0.3188
M-7	0.0000	0.0000	0.0541	0.0000	0.1140	0.0068	0.0253	0.0131	0.0457	0.0737	0.3326
M-8	0.0731	0.0822	0.0420	0.0375	0.0604	0.0812	0.0337	0.0458	0.0761	0.0316	0.5636
M-9	0.0568	0.0587	0.0841	0.0375	0.1006	0.1489	0.0591	0.0393	0.0812	0.0790	0.7451

Table 9. Pi Calculation.

Criteria	MRP	W	NL	P	T	S	EE	SI	CR	DR	Pi
M-1	1.0000	1.0000	0.9635	0.9066	0.8567	0.8935	0.0000	0.9619	0.9099	0.8528	8.3450
M-2	0.9511	0.8658	0.8785	0.9541	0.0000	1.0000	0.8557	0.0000	0.9700	0.9008	7.3760
M-3	0.9814	0.9832	0.0000	0.8123	0.9537	0.0000	0.8557	0.0000	0.0000	0.9758	5.5621
M-4	0.9295	0.9735	0.0000	0.8123	0.9537	0.0000	0.9803	0.8862	0.9099	0.9169	7.3622
M-5	0.9268	0.8727	0.8785	1.0000	1.0000	1.0000	0.9410	0.0000	0.8935	0.0000	7.5125
M-6	0.7569	0.0000	0.9171	0.0000	0.9853	0.7665	0.9742	0.9800	0.8729	0.9302	7.1830
M-7	0.0000	0.0000	0.9635	0.0000	0.9707	0.5969	0.9512	0.9442	0.9544	0.9946	6.3754
M-8	0.9240	0.9620	0.9434	0.9066	0.8875	0.8935	0.9675	1.0000	0.9948	0.9302	9.4095
M-9	0.8937	0.9255	1.0000	0.9066	0.9537	0.9860	1.0000	0.9930	1.0000	1.0000	9.6584

From the previously computed performance indicators, three separate appraisal scores were obtained in the following phase. Equations 17 to 19, when applied, yielded these scores. Equation 20 was then used to aggregate these appraisal ratings and get the ranking index k for each choice. As a composite metric, the ranking index represents each motor's total performance. Table 10 displays the performance indices' final determined values along with the associated ranks. Higher values of the ranking index k indicated better overall performance, and the options were arranged in decreasing order of value.

Table 10. Ranking of alternatives.

Alternatives	Ka	Kb	Kc	K	Rank
M-1	0.1214	3.1404	0.8524	2.0589	3
M-2	0.1071	2.7305	0.7520	1.8001	5
M-3	0.0815	2.2221	0.5721	1.4282	9
M-4	0.1059	2.5085	0.7440	1.7021	6
M-5	0.1107	3.1466	0.7772	1.9917	4
M-6	0.1027	2.2914	0.7211	1.5920	7
M-7	0.0918	2.1896	0.6448	1.4815	8
M-8	0.1365	3.4595	0.9586	2.2861	2
M-9	0.1424	4.0734	1.0000	2.5726	1

To choose the best motor for wheelchair, this rating offers a clear hierarchy of the options. The ranking suggests that motor M-9 is the best choice for a smart wheelchair, as it holds the top rank (1st). M-8 and M-1 follow, making them viable alternatives. Lower-ranked motors, such as M-3 and M-7, may be less suitable.

4 Validation of Results

The validation of the results is done in three stages in this section. In the first, the outcomes of a chosen MCDM approach are compared with other MCDM methods, and the Copeland voting concept is used to provide a final ranking of the alternatives. To determine the correlation between the various rankings provided by the chosen MCDM approach, the second section computes Spearman's rank correlation coefficient. In contrast, sensitivity analysis on the cost component is done in the third section to ensure that the ranking of alternatives is stable.

4.1 Comparative result of different MCDM methods and Overall Ranking

The results of two approaches, MEREC-CoCoSo and MEREC-TODIM, are compared with other selected MCDM methods such as TOPSIS, CODAS, WSM, and WPM to determine the rank of motors for a smart wheelchair prototype. The Borda count method, which considers both the number of wins and losses an alternative obtains, is extended by the Copeland technique [43; 44]. Each alternative's WIN score in this case is determined by adding up all its ranks from different MCDM approaches. On the other hand, the loss score is obtained by deducting the ranks of the other alternative from the alternative's WIN score. The final ranking is obtained from FINAL score which is calculated by subtracting the score of WIN and LOSS.

By incorporating all six ranks and using the Copeland voting principle to identify the specific best option from the list, the article proposes an ultimate priority ranking for the possible choices in table 11 and figure 2 depicts the ranking analogy. This will help wheelchair stakeholders to label the nine motors in the order, from best to worst effectiveness, based on remarkable properties.

Table 11. Alternative's ranking.

Alternatives	TODIM	CoCoSo	TOPSIS	CODAS	WSM	WPM	WIN	LOSS	FINAL	RANK
M-1	3	3	3	3	2	2	16	80	-64	2
M-2	5	5	4	4	5	5	28	140	-112	5
M-3	9	9	6	5	6	6	41	205	-164	6
M-4	7	6	7	9	8	7	44	220	-176	7
M-5	4	4	2	1	4	3	18	90	-72	3
M-6	8	7	8	8	9	8	48	240	-192	9
M-7	6	8	9	7	7	9	46	230	-184	8
M-8	2	2	5	6	3	4	22	110	-88	4
M-9	1	1	1	2	1	1	7	35	-28	1

The table 11 and figure 2 presented provides a MCDM analysis for motor selection of a wheelchair, utilizing various methods such as TODIM, COCOSO, TOPSIS, CODAS, WSM, and WPM. These methods help rank the motors (M-1 to M-9) based on different criteria as follows:

i. M-9 consistently ranks the highest across all methods, achieving the best scores (rank 1) in TODIM, COCOSO, TOPSIS, and CODAS. It also scores 1 in WSM and WPM, leading to the lowest loss score (35) and the highest final score (-28). This motor emerges as the top candidate for selection with the best performance across the majority of MCDM methods.

ii. M-1 shows moderate performance, with rank 3 across TODIM, COCOSO, and TOPSIS, and rank 2 in CODAS, WSM, and WPM. It has a relatively low loss score (80), placing it second in the final ranking (-64). This motor could be considered a viable option as it maintains consistency across all criteria.

iii. M-5 ranks well in TOPSIS (rank 2) and CODAS (rank 1), making it another strong contender. However, it shows a slight drop in other methods but still manages to have a relatively low loss score (90) and a respectable final score (-72), placing it third overall.

iv. M-8 has mixed performance, doing well in TOPSIS (rank 5) and CODAS (rank 6) but faltering in TODIM and COCOSO (rank 2). Its final score of -88 places it in the fourth position, which shows it might be considered but is less optimal compared to M-9 and M-1.

v. M-2 ranks around the middle in most methods, with consistent scores of 4 or 5 in TODIM, COCOSO, TOPSIS, CODAS, WSM, and WPM. However, it suffers from a relatively high loss score (140) and a lower final score (-112), placing it fifth.

vi. M-3, M-4, and M-6 perform worse, particularly M-3 and M-6, which rank poorly across most methods, with M-6 having the highest loss score (240) and final score (-192). These motors show less potential for wheelchair motor selection.

vii. M-7 performs better than M-6 but still ranks low in most methods, with a high final score of -184, placing it in eighth position.

So, M-9 is the most suitable motor for wheelchair selection based on the MCDM analysis, followed by M-1, M-5, and M-8. M-3, M-4, M-6, and M-7 are less favorable options due to their lower rankings and higher loss scores.

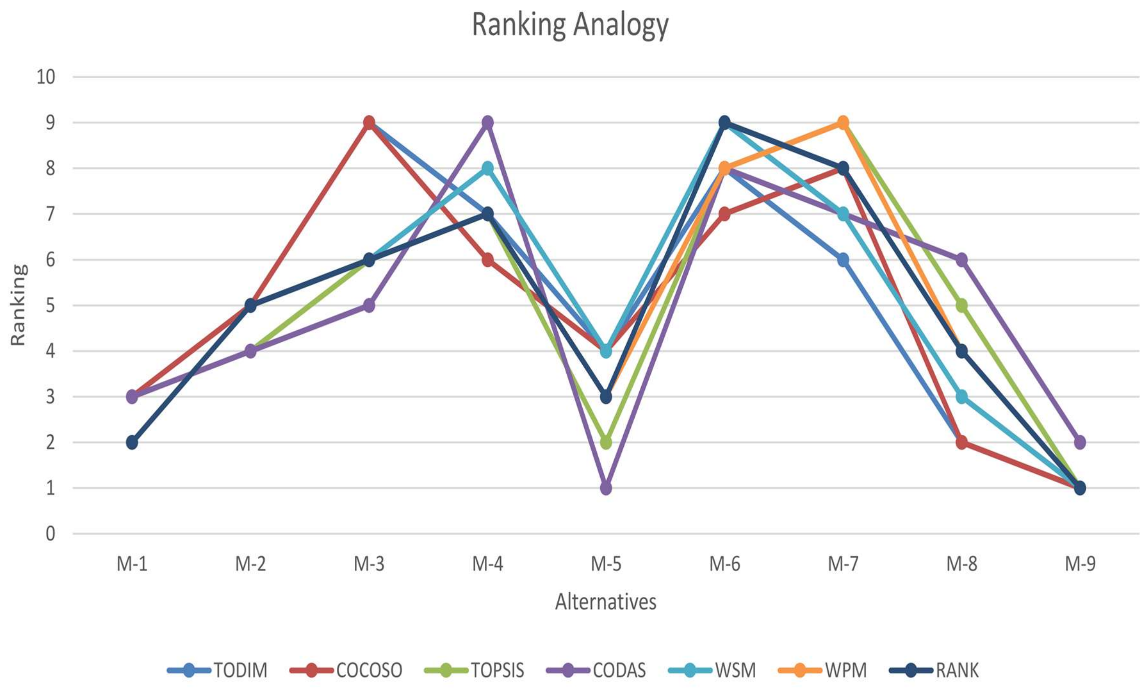

Figure 2. Ranking Analogy of alternatives with different MCDM method.

4.2 Spearman's rank correlation

This study examines the results to assess the consistency of the performance rankings of the various options [45; 46]. The Spearman rank correlation coefficient is used to quantify the degree of correlation between the rankings generated by different combination procedures. Equation 21 is used to calculate the Spearman's correlation coefficient, which shows the degree of concordance between the ranks obtained from various methodologies.

$$C_r = 1 - \frac{6 \times \sum D_r^2}{N \times \left(N^2 - 1\right)} \tag{21}$$

Equation 21 computes the Spearman coefficient (C_r), which assesses the variance in ranking, with C_r scores falling between 1 and -1. Whereas D_r represent the difference between the selected MCDM method rank and N represents number of alternatives.

Equation 21 is used in Table 12 to display the findings. Since the anticipated value of Cr for the suggested MCDM approach is usually in the range of 0.8 to 1.0, it is close to or equal to 1. This high Cr score indicates strong consistency in the performance ratings between the techniques. As a result, it is shown that this study's technique is similarly successful at determining the best course of action for selecting motors.

Table 12. Spearman Correlation values by selected MCDM methods.

	TODIM	COCOSO	TOPSIS	CODAS	WSM	WPM
TODIM	1.000	0.950	0.733	0.600	0.883	0.800
COCOSO	0.950	1.000	0.783	0.550	0.833	0.850

	TODIM	COCOSO	TOPSIS	CODAS	WSM	WPM
TOPSIS	0.733	0.783	1.000	0.900	0.867	0.967
CODAS	0.600	0.550	0.900	1.000	0.800	0.833
WSM	0.833	0.833	0.867	0.800	1.000	0.933
WPM	0.800	0.850	0.967	0.833	0.933	1.000

The Spearman correlation matrix provides valuable insights into the relationships between different Multi-Criteria Decision-Making (MCDM) methods used for motor selection in wheelchairs. The correlation values range from 0.6 to 1.0, indicating varying levels of agreement between the methods.

There is a strong correlation between most of the methods, with several pairs showing values close to or above 0.8. For instance, the correlation between TOPSIS and WPM is 0.967, suggesting that these methods produce very similar rankings of the motors. Other high correlations, such as between COCOSO and TODIM (0.950) or WSM and WPM (0.933), further reinforce the consistency across the methods in ranking motor alternatives. This high level of agreement is useful for decision-makers, as it indicates that the results generated by these methods are in alignment and can be trusted for robust decision-making.

However, there are some cases where the correlation values are moderately low, such as between TODIM and CODAS (0.600) or COCOSO and CODAS (0.550). These lower correlations indicate that these methods may diverge more significantly in how they prioritize or rank motors. This could be due to differences in the algorithms or sensitivity to criteria used in each method, leading to variations in motor rankings.

Overall, the strong correlations, typically ranging from 0.8 to 1.0, suggest a high level of reliability in using these MCDM methods for selecting motors. The combination of methods like TOPSIS, WPM, WSM, and COCOSO offers a consistent approach to identifying the most suitable motor for a wheelchair, while methods like TODIM and CODAS could provide additional insights when considering specific criteria or preferences. This comprehensive approach enhances the robustness of the decision-making process for motor selection.

5.3 Sensitivity Analysis on the Proposed Method

The robustness and dependability of the two MCDM tools used in the study are assessed in this section. Sensitivity analysis is an important algorithmic procedure that is used to evaluate and confirm the reliability of the selected techniques. In some cases, stakeholders might have to provide their own perspectives and suggestions based on their experience and knowledge. While many considerations must be considered when making decisions, stakeholders' preferences are mostly influenced by cost-related metrics, especially in the early phases of developing electric wheelchair prototypes.

Previous research on the subject by Bhattacharya et al. [47] and Ghose et al. [48] often emphasizes the use of sensitivity testing as a reliable scientific method for assessing the dependability of results by modifying variables related to cost. The sensitivity score (β) in this study is 0.1-step increments from 0 to 1. The connection between the weight of the objective criteria and the selection index scores is graphically represented by equations 22 and 23. These formulas are the mainstay of the program, providing a clear visual representation of how changes in cost attributes might impact decision-making procedures. This strategy guarantees that the chosen MCDM techniques continue to be strong and dependable even in the face of varying cost situations, facilitating well-informed and efficient decision-making.

$$SIS_j = \left[\left(\beta \times SFI_j \right) + \left(1 - \beta \right) \times OFI_j \right] \tag{22}$$

$$OFI_j = \frac{1}{\left[OFC_j \times \sum_{j=1}^{n} OFC^{-1} \right]} \tag{23}$$

In this case, n denotes the motor's list of choices, SISj stands for selective index score, β indicates objective parameter choice weight, SFI for subjective factor indicator, OFI for objective factor indicator, and OFC for objective factor cost parameter. The OFCs are the costs associated with each motor, as seen in the decision matrix. Each motor in an OFI is designed to produce a non-dimensional number of cost components. The

MEREC-TODIM normalized overall dominance degree of alternative and the MEREC-CoCoSo assessment ranking value are the main factors influencing each motor's SFI ratings.

Equations 22 and 23 are used to create figures 3 and 4, as seen below. The most crucial elements in motor selection, as indicated by the MEREC MCDM approach, are torque (0.1408) and speed (0.1624), which emphasize performance. However, a careful examination of the crucial cost indicators (MRP, 0.1326) is being conducted to determine how cost-effective the final smart wheelchair will be. In order to create this sensitivity inquiry map, the weight of the objective parameter choice, or "beta," is changed in a 0–1 spectrum at intervals of 0.1. When the "beta" score changes, the corresponding SISi scores for the cost of motor transformation change. The robustness of the investigation findings is demonstrated by the "beta" scores, which show how variations in cost-related variables impact the research evidence from the MEREC-TODIM and MEREC-CoCoSo. The immediate score of "beta," with a lower score indicating a greater prevalence for motors and a lower SFI score, may be associated with the presence of a cost-related feature over other variables in the evaluation process.

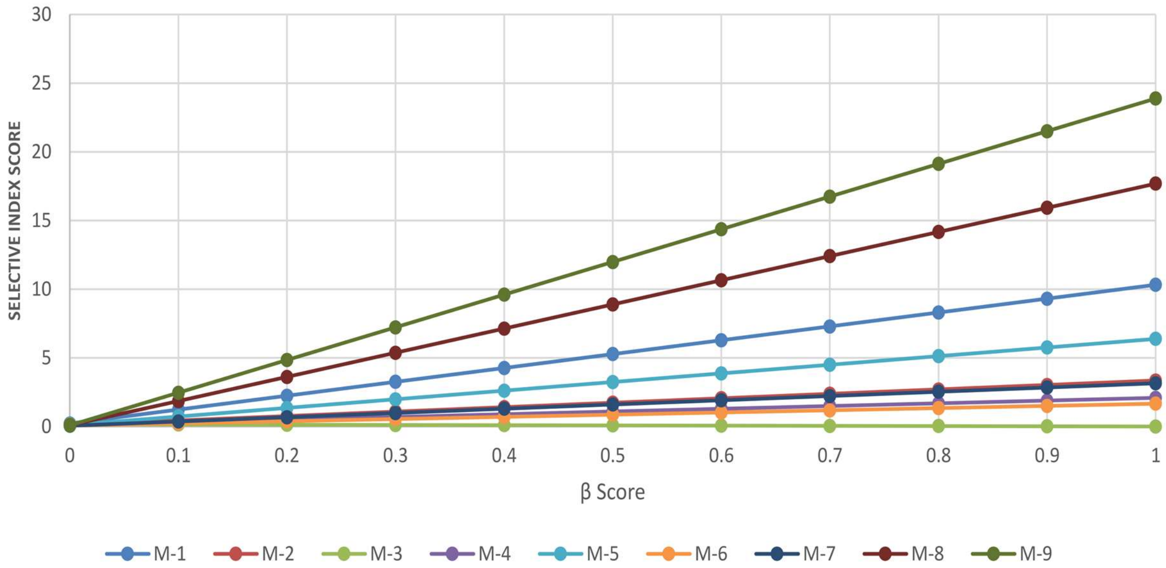

Figure 3. Sensitivity Investigation on MEREC-TODIM method.

In the context of motor selection for a wheelchair using the MEREC TODIM method, sensitivity analysis on the cost criterion reveals significant variations in the performance of different motor alternatives as shown in figure 3. The analysis starts with a low β value, indicating a heavier reliance on the objective factors (OFI). At β = 0, the scores for each motor alternative remain relatively low, suggesting that cost-based factors, when considered alone, do not heavily differentiate the alternatives. As β increases, the significance of the subjective factor indicator (SFI) grows, and the overall SIS values reflect greater variation between motor options. At β = 0.1, a sharp increase is observed, particularly for motors M-9 and M-8, showing their strong performance under subjective factor weighting.

As β continues to rise, a clear trend emerges where motors M-9, M-8, and M-7 progressively dominate in terms of SIS, with M-9 reaching the highest scores across most β values. On the other hand, motors such as M-3 and M-5 exhibit minimal improvement or even decline in SIS as β rises, indicating poor alignment with the subjective cost factors being considered.

Motor M-9 consistently outperforms the others, especially at higher β values, making it the most suitable choice when subjective cost factors are considered important in the decision-making process. Meanwhile, the steady but lower performance of motors like M-1 and M-2 suggests they may be better options when more weight is given to objective cost criteria, particularly at lower β values.

Overall, the sensitivity analysis using the MEREC TODIM method highlights the importance of balancing subjective and objective cost factors in motor selection for the wheelchair. The results suggest that certain motors perform well across a range of β values, with M-9 standing out as the most adaptable to varying cost sensitivities. This analysis provides valuable insight for optimizing cost-effectiveness while maintaining high performance in the wheelchair's motor system.

In the process of motor selection for a wheelchair, the MEREC CoCoSo method is applied to conduct a sensitivity analysis based on cost criteria as shown in Figure 4.

At β = 0, the analysis is entirely based on OFI, and the resulting SIS values are generally low across all motor alternatives, indicating limited differentiation when objective cost is considered alone. As β increases from 0 to 1, the influence of SFI becomes more prominent, and the SIS values gradually rise, especially for certain motors. Motors such as M-9, M-8, and M-7 show a significant increase in their SIS scores.

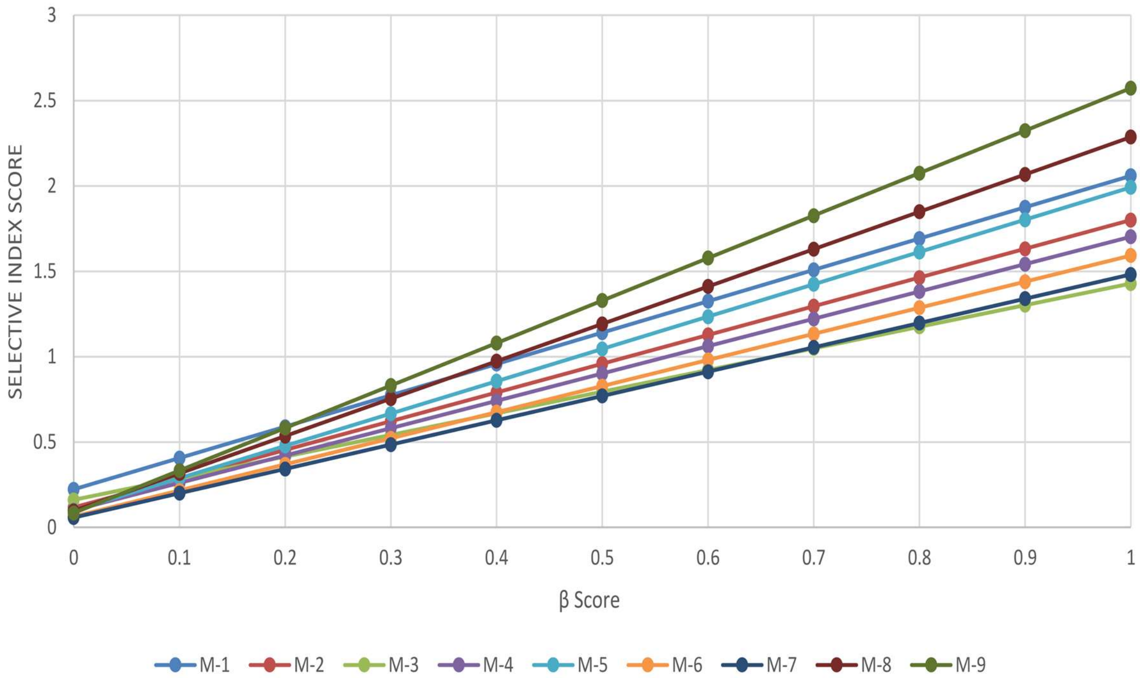

Figure 4. Sensitivity Investigation on MEREC-CoCoSo method.

Motor M-9 consistently ranks the highest in SIS as β increases, indicating that it performs well across both subjective and objective cost criteria. This makes M-9 a strong candidate for motor selection when a balanced approach is needed, considering both cost efficiency and other subjective factors. Similarly, motors M-8 and M-7 also demonstrate steady improvements in SIS, making them competitive options depending on the relative importance placed on subjective factors.

In contrast, motors like M-1 and M-2, which start with relatively lower SIS values at β = 0, show a more moderate increase as β rises, suggesting that these motors may be less sensitive to subjective cost factors. They perform better when objective cost considerations dominate the decision-making process.

Overall, the CoCoSo method reveals that the choice of motor for the wheelchair is highly sensitive to the balance between subjective and objective cost criteria. Motors like M-9 and M-8 are the most versatile, performing well across different weighting scenarios, while other motors may be better suited to contexts where either cost or subjective performance factors are prioritized. This sensitivity analysis provides valuable insights into how the selection process can be adjusted based on specific cost-related preferences.

6 Conclusion

This article uses a mathematical expression to determine the motor priority for the smart wheelchair prototype utilizing the MEREC-TODIM and MEREC-CoCoSo approaches. There are also a few further conclusions that may be drawn from this research, and they are as follows:

i. Integrated Decision-Making Framework: A smart wheelchair prototype's motor alternative evaluation process was conducted using the MEREC-TODIM and MEREC-CoCoSo methodologies. This illustrates how well several MCDM methods can be integrated. Because of this integration, a thorough examination of motor performance is possible, which facilitates the design and development of assistive mobility devices with better informed decision-making.

ii. Weight Determination: The MEREC method offers important insights into parameter significance because of its novel approach to weight determination by evaluating the effect of deleting criteria. The torque (0.1408) and speed (0.1624) weights that have been established underscore their crucial function in assessing performance and directing the design priorities of wheelchair motors in the future.

iii. Optimal Motor Selection: The determination that motor M-9 is the best option overall, with M-8 coming in second, highlights how well the MEREC TODIM method balances trade-offs and offers a methodical approach to decision-making. This methodical technique improves motor selection and can be used as a template for similar assessments in other technical contexts.

iv. Consistency across Methods: The consistency of the results obtained from the TODIM method and the MEREC CoCoSo method validates the dependability of the integrated approach. The robustness of the evaluation procedure is highlighted by the strong ranks of motors M-9 and M-8 across numerous parameters, which validates the selected methodologies.

v. Utility of Copeland Voting Principle: The importance of multifaceted evaluation strategies in decision-making is highlighted by the Copeland voting principle, which confirms M-9 as the ideal motor choice. The results indicate that the Copeland approach successfully combines assessments from many viewpoints, strengthening the validity of the motor selection procedure.

vi. Market Insights: The advice to steer clear of motors M-3, M-4, and M-6 because there are readily available alternatives on the market suggests that choosing a motor should take practicality into account. This realization implies that combining technical assessments with market dynamics can improve decision-making processes even further.

vii. Reliability through Correlation: The analysis of Spearman correlation indicates a high degree of consistency amongst evaluations, with values above 0.8 indicating significant agreement among MCDM approaches. This uniformity maintains the overall integrity of the decision-making framework in addition to improving the dependability of the chosen motors.

Therefore, in addition to offering a strong framework for motor selection in smart wheelchairs, the integration of the MEREC weighing method with the TODIM and CoCoSo methods also gives insightful information that can improve the functionality and design of assistive technology.

6.1 Limitation

This study has significant limitations because it relies on the TODIM-COCOSO approach in conjunction with MEREC weighting. Although this method has its uses, it might not cover every essential facet of motor performance that is necessary for applications involving smart wheelchairs. Because the chosen criteria and weighting system are intrinsically context-specific, it may be more difficult to extrapolate the results to other contexts or categories of assistive technology. Furthermore, bias may be introduced by the study's reliance on a particular dataset, which could reduce the conclusions' applicability in real-world scenarios. The evaluation's lack of qualitative elements like user comfort and simplicity of maintenance also makes it less thorough. To enable more comprehensive assessments, future research could benefit from utilizing a wider range of criteria and different MCDM methodologies.

6.2 Future work

By demonstrating the efficacy of the integrated TODIM-CoCoSo approach, the study's findings open up new avenues for research in assistive technologies. This approach can be modified to assess other parts or systems of smart wheelchairs, which will ultimately improve functionality and user experiences. Additionally, the approaches used here have the potential to have a big impact on assistive mobility device design methods. By giving structured, multi-criteria review process top priority, engineers can create more effective and efficient solutions that satisfy user goals. This integrated approach highlights the versatility and efficacy of addressing complex decision-making scenarios by addressing specific challenges in smart wheelchair design and showcasing potential applications across various domains, such as robotics, automotive engineering, and industrial automation.

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References

[1] S. Sahoo and B. Choudhury, "A review on smart robotic wheelchairs with advancing mobility and independence for individuals with disabilities," *J. Decis. Anal. Int. Comp.,* vol. 3, no. 1, pp. 221-242, 2023, doi: 10.31181/10001122023s.

[2] M. Kończak, M. Kukla, and D. Rybarczyk, "Design considerations concerning an innovative drive system for a manual wheelchair," *Appl. Sci.,* vol. 14, no. 15, p. 6604, 2024, doi: 10.3390/app14156604.

[3] A. Verma, S. Shrivastava, and J. Ramkumar, "Mapping wheelchair functions and their associated functional elements for stair climbing accessibility: A systematic review," *Disabil. Rehabil. Assist. Technol.*, vol. 19, no. 1, pp. 200-221, 2024, doi: 10.1080/17483107.2022.2075476.

[4] M. Subbarao, K. Dasari, S. S. Duvvuri, K. R. K. V. Prasad, B. K. Narendra, and V. M. Krishna, "Design, control and performance comparison of PI and ANFIS controllers for BLDC motor driven electric vehicles," *Meas. Sens*., vol. 31, p. 101001, 2024, doi: 10.1016/j.measen.2023.101001.

[5] J. C. García, M. Marrón-Romera, A. Melino, C. Losada-Gutiérrez, J. M. Rodríguez, and A. Fazakas, "Filling the gap between research and market: Portable architecture for an intelligent autonomous wheelchair," *Int. J. Environ. Res. Public Health*, vol. 20, no. 2, p. 1243, 2023, doi: 10.3390/ijerph20021243.

[6] S. K. Sahoo and B. B. Choudhury, "A fuzzy AHP approach to evaluate the strategic design criteria of a smart robotic powered wheelchair prototype," in *Intelligent Systems: Proc. ICMIB 2020, Singapore: Springer Singapore,* pp. 451-464, 2021, doi: 10.1007/978-981-33-6081-5_40.

[7] I. M. Hezam, P. Rani, A. R. Mishra, and A. Alshamrani, "Assessment of autonomous smart wheelchairs for disabled persons using hybrid interval-valued Fermatean fuzzy combined compromise solution method," *Sustain. Energy Technol. Assess.,* vol. 57, p. 103169, 2023, doi: 10.1016/j.seta.2023.103169.

[8] S. K. Sahoo and B. B. Choudhury, "Evaluating material alternatives for low-cost robotic wheelchair chassis: A combined CRITIC, EDAS, and COPRAS framework," *Jordan J. Mech. Ind. Eng.,* vol. 17, no. 4, pp. 653-669, 2023, doi: 10.59038/jjmie/170419.

[9] M. Chandra, F. Shahab, V. KEK, and S. Rajak, "Selection for additive manufacturing using hybrid MCDM technique considering sustainable concepts," *Rapid Prototyp. J.,* vol. 28, no. 7, pp. 1297-1311, 2022, doi: 10.1108/RPJ-06-2021-0155.

[10] S. Qahtan, A. A. Zaidan, H. A. Ibrahim, M. Deveci, W. Ding, and D. Pamucar, "A decision modeling approach for smart training environment with motor imagery-based brain computer interface under neutrosophic cubic fuzzy set," *Expert Syst. Appl.,* vol. 224, p. 119991, 2023, doi: 10.1016/j.eswa.2023.119991.

[11] S. Kumar, P. V. Ahijith Kumar, K. Bharti, L. Patnaik, S. Ranjan Maity, and M. Łepicka, "Coating material selection for bulk metal forming dies: A MEREC-integrated approach with multiple MCDM methods," *Int. J. Interact. Des. Manuf.,* pp. 1-16, 2024, doi: 10.1007/s12008-024-01983-z.

[12] M. Mohamed, A. Salam, J. Ye, and R. Yong, "Single-valued neutrosophic MCDM approaches integrated with MEREC and RAM for the selection of UAVs in forest fire detection and management," *Neutrosophic Syst. Appl.,* vol. 19, pp. 1-14, 2024, doi: 10.61356/j.nswa.2024.19319.

[13] G. Ö. Sönmez and P. Toktaş, "Supplier selection using the integrated MEREC–CoCoSo methods in a medical device company," *J. Sci. Rep. A,* no. 056, pp. 116-133, 2024, doi: 10.59313/jsr-a.1420728.

[14] A. Karbassi Yazdi, Y. Tan, R. Birau, D. Frank, and D. Pamučar, "Sustainable solutions: Using MCDM to choose the best location for green energy projects," *Int. J. Energy Sect. Manag.,* 2024,[Online] doi: 10.1108/IJESM-01-2024-0005.

[15] M. Z. Taşcı, "Multidimensional performance evaluation using the hybrid MCDM method: A case study in the Turkish non-life insurance sector," *J. Mehmet Akif Ersoy Univ. Econ. Adm. Sci. Fac.,* vol. 11, no. 2, pp. 854-883, 2024, doi: 10.30798/makuiibf.1439172.

[16] P. S. Ashofteh and M. P. Dougaheh, "Ranking the optimal combination of low-impact urban development systems under climate change with the TODIM multi-criteria decision-making method," *J. Clean. Prod*., vol. 434, p. 140108, 2024, doi: 10.1016/j.jclepro.2023.140108.

[17] V. Chawla, I. Itika, P. Singh, and S. Singh, "A fuzzy Pythagorean TODIM method for sustainable ABC analysis in inventory management," *J. Future Sustain.,* vol. 4, no. 2, pp. 85-100, 2024, doi: 10.5267/j.jfs.2024.5.003.

[18] L. Liu, Y. Tu, W. Zhang, and W. Shen, "Supplier selection for emergency material based on group exponential TODIM method considering hesitant fuzzy linguistic set: A case study of China," *Socio-Econ. Plann. Sci.,* vol. 94, p. 101944, 2024, doi: 10.1016/j.seps.2024.101944.

[19] Q. Yang, W. M. Yan, M. Liu, M. Deveci, H. Garg, and Z. S. Chen, "A hybrid generalized TODIM approach for sustainable 3PRLP selection in electronic manufacturing industry," *Adv. Eng. Informatics*, vol. 59, p. 102298, 2024, doi: 10.1016/j.aei.2023.102298.

[20] A. Thilagavathy and S. Mohanaselvi, "T-spherical fuzzy Hamacher Heronian mean geometric operators for multiple criteria group decision making using SMART based TODIM method," *Results Control Optim.,* vol. 14, p. 100357, 2024, doi: 10.1016/j.rico.2023.100357.

[21] K. Vijayananth, B. Paramasivam, and S. Raju, "Measurement of mechanical and thermal performance of cigarette filter fibres/eggshell particles reinforced polymer composite using integrated CRITIC-TODIM approach," *Measurement*, vol. 228, p. 114251, 2024, doi: 1016/j.measurement.2024.114251.

[22] A. Okursoy and D. T. Coşansu, "Zero emission electric vehicle selection using the MEREC-based CoCoSo method," *Alphanum. J.,* vol. 12, no. 1, pp. 39-58, 2024, doi: 10.17093/alphanumeric.1451556.

[23] V. Soumith, A. Biswas, and S. Nath, "Optimal selection of a sustainable passive heat transfer enhancement technique for circular pipe heat exchanger using MCDM framework," *Arab. J. Sci. Eng.*, pp. 1-22, 2024, doi: 10.1007/s13369-024-09289-8.

[24] A. Parsa Rad, M. Khalilzadeh, S. A. Banihashemi, D. Božanić, A. Milić, and G. Ćirović, "Supplier selection in downstream oil and gas and petrochemicals with the fuzzy BWM and gray CoCoSo methods considering sustainability criteria and uncertainty conditions," *Sustain.,* vol. 16, no. 2, p. 880, 2024, doi: 10.3390/su16020880.

[25] T. E. Saputro, T. Y. Rosiani, A. Mubin, S. K. Dewi, and T. Baroto, "Green supplier selection under supply risks using novel integrated fuzzy multi-criteria decision making techniques," *J. Clean. Prod.,* vol. 449, p. 141788, 2024, doi: 10.1016/j.jclepro.2024.141788.

[26] A. Hussain and K. Ullah, " An Intelligent Decision Support System for Spherical Fuzzy Sugeno-Weber Aggregation Operators and Real-Life Applications," *Spectrum Mech. Eng. Oper. Res.,* vol. 1, no. 1, pp. 177-188, 2024, doi: 10.31181/smeor11202415.

[27] E. Kawecka, A. Perec, and A. Radomska-Zalas, " Use of the Simple Multicriteria Decision-Making (MCDM) Method for Optimization of the High-Alloy Steel Cutting Processby the Abrasive Water Jet," *Spectrum Mech. Eng. Oper. Res.,* vol. 1, no. 1, pp. 111-120, 2024, doi: 10.31181/smeor11202411.

[28] S. Kousar, A. Ansar, N. Kausar, and G. Freen, " Multi-criteria decision-making for smog mitigation: a comprehensive analysis of health, economic, and ecological impacts," *Spectrum Decis. Mak. Appl.,* vol. *2*, no. 1, pp. 53-67, 2025, doi: 10.31181/sdmap2120258.

[29] S. Biswas, K. H. Gazi, P. M. Shankar, and A. Ghosh, " A Decision-Making Framework for sustainable Highway Restaurant Site Selection: AHP-TOPSIS Approach based on the Fuzzy Numbers," *Spectrum Oper. Res.,* vol. 2, no. 1, pp. 1-26, 2024, doi: 10.31181/sor2120256

[30] S. Biswas, D. Bozanic, D. Pamucer, and D. Marinkovic, " A spherical fuzzy based decision making framework with Einstein aggregation for comparing preparedness of SMES in quality 4.0," *Facta Univ., Ser. Mech. Eng.,* vol. 21, no. 3, pp. 453-478, 2023, doi: 10.22190/FUME230831037B.

[31] P. Wang, B. Zhu,Y. Yu, Z. Ali, and B. Almohsen, " Complex intuitionistic fuzzy DOMBI prioritized aggregation operators and their application for resilient green supplier selection," *Facta Univ., Ser. Mech. Eng.,* vol. 21, no. 3, pp. 339-357, 2023, doi: 10.22190/FUME230805029W.

[32] J. Kannan, V. Jayakumar, and M. Pethaperumal, " Advanced Fuzzy-Based Decision-Making: The Linear Diophantine Fuzzy CODAS Method for Logistic Specialist Selection," *Spectrum Oper. Res.,* vol. 2, no. 1, pp. 40-60, 2024, doi: 10.31181/sor2120259.

[33] U. Elraaid, I. Badi, and M. B. Bouraima, " Identifying and Addressing Obstacles to Project Management Office Success in Construction Projects: An AHP Approach," *Spectrum Decis. Mak. Appl.,* vol. 1, no. 1, pp. 33-45, 2024, doi: 10.31181/sdmap1120242.

[34] N. Deivanayagampillai, K. Jacob, G. V. Manohar and S. Broumi, " Investigation of industry 5.0 hurdles and their mitigation tactics in emerging economies by TODIM arithmetic and geometric aggregation operators in single value neutrosophic environment," *Facta Univ., Ser. Mech. Eng.,* vol. 21, no. 3, pp. 405-432, 2023, doi: 10.22190/FUME230616020D.

[35] A. Biswas, K. H. Gazi, and S. P. Mondal, "Finding Effective Factor for Circular Economy Using Uncertain MCDM Approach", *Manag. Sci. Adv.*, vol. 1, no. 1, pp. 31–52, Dec. 2024, doi: 10.31181/msa1120245.

[36] D. K. Tripathi, S. K. Nigam, P. Rani, and A. R. Shah, "New intuitionistic fuzzy parametric divergence measures and score function-based CoCoSo method for decision-making problems," *Decis. Making: Appl. Manag. Eng.,* vol. 6, no. 1, pp. 535-563, 2023, doi: 10.31181/dmame0318102022t.

[37] M. Keshavarz-Ghorabaee, M. Amiri, E. K. Zavadskas, Z. Turskis, and J. Antucheviciene, "Determination of objective weights using a new method based on the removal effects of criteria (MEREC)," *Symmetry,* vol. 13, no. 4, pp. 525, 2021, doi: 10.3390/sym13040525.

[38] L. F. A. M. Gomes and M. M. P. P. Lima, "TODIM: Basics and application to multi-criteria ranking of projects with environmental impacts," *Found. Comput. Decis. Sci.,* vol. 16, no. 3-4, pp. 113-127, 1991.

[39] M. Yazdani, P. Zarate, K. Zavadskas, and Z. Turskis, "A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems," *Manag. Decis.,* vol. 57, no. 9, pp. 2501-2519, 2019, doi: 10.1108/MD-05-2017-0458.

[40] H. Demirel, B. Şener, B. Yildiz, and A. Balin, "A real case study on the selection of suitable roll stabilizer type for motor yachts using hybrid fuzzy AHP and VIKOR methodology," *Ocean Eng.,* vol. 217, pp. 108125, 2020, doi: 10.1016/j.oceaneng.2020.108125.

[41] S. Sahoo and B. Choudhury, " Wheelchair Accessibility: Bridging the Gap to Equality and Inclusion," *Decis. Making Adv.,* vol. 1, no. 1, pp. 63-85, 2023, doi: 10.31181/dma1120239

[42] S. K. Sahoo, B. B. Choudhury, and P. R. Dhal, " A Bibliometric Analysis of Material Selection Using MCDM Methods: Trends and Insights," *Spectrum Mech. Eng. Oper. Res.,* vol. 1, no. 1, pp. 189-205, 2024, doi: 10.31181/smeor11202417.

[43] M. Azadfallah, "A new MCDM approach for ranking of candidates in voting systems," *Int. J. Soc. Syst. Sci.,* vol. 11, no. 2, pp. 119-133, 2019, doi: 10.1504/IJSSS.2019.100100.

[44] F. Ecer, "A consolidated MCDM framework for performance assessment of battery electric vehicles based on ranking strategies," *Renew. Sustain. Energy Rev*., vol. 143, p. 110916, 2021, doi: 10.1016/j.rser.2021.110916.

[45] A. Özdağoğlu, M. K. Keleş, and M. Şenefe, "Evaluation of banks in terms of customer preferences with fuzzy SWARA and fuzzy MOORA integrated approach", *J. Decis. Anal. Int. Comp.*, vol. 4, no. 1, pp. 216–232, Dec. 2024. https://doi.org/10.31181/jdaic10007122024o

[46] D. Tešić and D. Marinković, "Application of fermatean fuzzy weight operators and MCDM model DIBR-DIBR II-NWBM-BM for efficiency-based selection of a complex combat system," *J. Decis. Anal. Int. Comp.,* vol. 43, no. 17, pp. 3671-3685, 2005, doi: 10.1080/00207540500137217.

[47] A. Bhattacharya, B. Sarkar, and S. K. Mukherjee, "Integrating AHP with QFD for robot selection under requirement perspective," *Int. J. Prod. Res.,* vol. 43, no. 17, pp. 3671-3685, 2005, doi: 10.1080/00207540500137217.

[48] D. Ghose, S. Pradhan, P. Tamuli, and Shabbiruddin, "Optimal material for solar electric vehicle application using an integrated Fuzzy-COPRAS model," *Energy Sources Part A Recovery Util. Environ. Eff.*, pp. 1-20, 2019, doi: 10.1080/15567036.2019.1668879.