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A multi-criteria decision-making approach for wheelchair selection using intuitionistic fuzzy TOPSIS

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Abstract:

Introduction/purpose: Selecting an appropriate wheelchair is vital for ensuring mobility, comfort, and independence for individuals with disabilities. The primary objective is to assist in identifying the optimal wheelchair by considering a range of user-centric criteria and mitigating decision-making ambiguities.

Methods: The proposed framework leverages intuitionistic fuzzy sets to account for the hesitancy and imprecision often present in decision making.

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Criteria weights and alternative evaluations were determined with expert input. Sensitivity analysis was conducted to ensure the robustness and reliability of the ranking process. A case study was performed to validate the effectiveness of the methodology and to illustrate its practical application.

Results: The study demonstrated that AI-powered wheelchairs (APWs) outperformed other wheelchair options based on the selected criteria and sub-criteria.

Conclusion: The findings highlight the utility of the intuitionistic fuzzy TOPSIS approach in facilitating well-informed wheelchair selection decisions. This method benefits end users, caregivers, and medical professionals by addressing the complexities of subjective and uncertain decision making, ultimately leading to more inclusive and reliable outcomes. The framework proves to be an effective tool for improving the decision-making process in wheelchair selection.

Keywords: wheelchair selection, intuitionistic fuzzy, triangular fuzzy, TOPSIS, sensitivity analysis.

Introduction

Wheelchair selection is a pivotal decision for stakeholders, including users, caregivers, healthcare professionals, and manufacturers, as it profoundly influences the user's quality of life. A wheelchair is not merely a mobility device but a critical enabler of independence, comfort, and inclusion. Choosing the right wheelchair ensures users can move freely and participate actively in social, professional, and personal activities, thereby fostering autonomy and reducing dependence on others. Griggs (2024) emphasizes that when choosing a wheelchair, the user's comfort and health are among the most important factors. An ill-fitting wheelchair can lead to physical discomfort, pressure sores, and long-term musculoskeletal issues. Properly designed and selected wheelchairs promote optimal posture, reduce the risk of secondary health complications, and enhance overall well-being. For individuals with specific medical conditions or disabilities, the wheelchair must meet unique ergonomic and functional requirements to support their physical needs effectively by Kargi et al. (2023).

Rotschedl et al. (2024) highlight that economic factors significantly influence the decision-making process. Wheelchairs come in various designs and price ranges, and selecting an appropriate model ensures cost-effectiveness. Stakeholders must balance the user's specific requirements with budgetary constraints to maximize utility and longevity while avoiding overspending on unnecessary features. Furthermore, a suitable wheelchair contributes to accessibility and inclusivity by enabling users to navigate diverse environments seamlessly. Sahoo and Choudhury (2024) suggest that incorporating advanced features such as adjustable seats, lightweight frames, and smart technology can greatly enhance the user experience. For stakeholders, a thoughtful selection process is not just about mobility but about empowering users to lead fulfilling, independent lives while ensuring physical and emotional well-being.

Selecting an ideal wheelchair—manual (MW), electric (EW), or AI-powered (APW)—requires evaluating diverse criteria to address user-specific needs and circumstances. Manual wheelchairs suit those with sufficient upper body strength, while electric and AI-powered models cater for individuals needing greater assistance or advanced features like automated navigation. Factors such as cost, maintenance, terrain compatibility, and comfort are critical for ensuring usability and long-term satisfaction. Verma et al. (2024) explain that by evaluating these factors, stakeholders can align the wheelchair features with the user's physical condition, environment, and lifestyle, thereby improving mobility and independence. Wheelchair selection is widely recognized as a multi-criteria decision-making challenge. Recent research emphasizes the effectiveness of MCDM methods, particularly intuitionistic fuzzy techniques, in addressing uncertainties inherent in the decision-making process.

Most past studies on wheelchair selection used classical fuzzy numbers, such as fuzzy AHP. However, Sahoo and Choudhury (2021) argue that intuitionistic fuzzy numbers can provide better results. Introduced by Atanassov and Atanassov (1999), the intuitionistic fuzzy set (IFS) theory extends classical fuzzy sets, providing greater flexibility for handling imprecise situations. Imran et al. (2024) and Sarfraz (2024) have extensively used IFS to provide more reliable solutions when making decisions in challenging situations. Considering the issues discussed and insights from the reviewed literature, limited studies have integrated MCDM with IFS for wheelchair selection. For an actual-world wheelchair selection scenario, this study suggests an MCDM framework based on the intuitionistic fuzzy TOPSIS approach. TOPSIS assesses both positive-ideal and negative-ideal solutions and is renowned for its transparency and ease of use. Combining TOPSIS with IFS enhances decision making by addressing uncertainty and vagueness effectively, providing a robust and user-centric approach to wheelchair selection.

This paper is organized as follows. A thorough assessment of literature is provided first, followed by a description of the conceptual foundation of the suggested approach and the research methodology. The case study, implementation, comparison with triangular fuzzy TOPSIS, and sensitivity assessment of the suggested intuitionistic fuzzy TOPSIS approach are then discussed with research findings, implications, and managerial insights. Finally, the study is concluded with a conclusion and suggestions for future research directions.

Literature review

Wheelchair selection criteria and sub-criteria

For people with mobility problems, choosing an appropriate wheelchair is crucial. Zhang et al. (2024) emphasize in their study the importance of evaluating wheelchairs using multiple criteria due to significant differences in their features, designs, and capacities. By taking into account a number of variables that impact user experience, comfort, and general functionality, an MCDM approach offers an organized method for evaluating alternative wheelchair solutions. This approach enables users and healthcare professionals to make well-informed decisions based on specific needs and preferences. Below is a detailed explanation of the key criteria and sub-criteria to consider when selecting a wheelchair:

- *User's physical condition (C-1)*

Fasipe et al. (2024) assess this criterion based on the user's physical health, limitations, and needs. Different users have varying levels of strength, mobility, and coordination. The wheelchair must cater for the user's specific condition (e.g., paralysis, arthritis, or general weakness), ensuring that it provides the necessary support and ease of movement. It encompasses various factors such as strength and endurance (SC-1) which refers to the user's physical ability to propel or control the wheelchair over extended periods. By ensuring that the wheelchair offers appropriate alignment and comfort, posture support (SC-2) lowers the possibility of strain or pain. To guarantee that the wheelchair can securely carry the user's weight without sacrificing functionality or safety, weight capacity (SC-3) is crucial. For users with restricted mobility, range of motion (SC-4) is crucial because it guarantees that the wheelchair can adapt to their motions and make the required modifications to enhance comfort and usability. When combined, these sub-criteria guarantee that the wheelchair is customized to meet the individual physical requirements of the user.

- *Comfort (C-2)*

Mohebbi et al. (2024) highlight that comfort plays a vital role in influencing long-term wheelchair use. It includes various factors such as seat cushioning (SC-5) which plays a vital role in reducing pressure points and preventing discomfort or sores, ensuring a more comfortable sitting experience. Back support (SC-6) is equally important, providing the necessary lumbar or full-back support to maintain proper posture and alleviate back pain during extended use. Adjustability (SC-7) allows the user to customize the wheelchair to their specific needs, such as adjusting the seat depth or backrest angle for enhanced comfort. Ergonomics (SC-8) focuses on the overall design of the wheelchair, ensuring that it conforms to the user's body to reduce strain and improve ease of use.

- Ease of use (C-3)

The term "ease of use" describes how easy and straightforward it is for the user to operate the wheelchair, as by Kulich et al. (2024). It encompasses various factors such as maneuverability (SC-9) which focuses on how easily the wheelchair can be controlled and moved, especially in tight or crowded spaces. A wheelchair with an easy-to-use control interface simplicity (SC-10) ensures that users can quickly master the controls, whether they are manual or powered, without extensive training. Caregiver involvement (SC-11) highlights how accessible and manageable the wheelchair is for caregivers who assist the user, making tasks like pushing or adjusting settings easier. Last but not least, a low user learning curve (SC-12) guarantees that new users can quickly become accustomed to the wheelchair's functionality, reducing frustration and promoting independence.

- *Control interface (C-4)*

The control interface refers to the system that allows the user to operate the wheelchair, according to Kocejko et al. (2024). It encompasses various controls such as joystick control (SC-13), which is one of the most common options, providing intuitive, precise movement control for users, especially in powered wheelchairs. Voice or gesture control (SC-14) represents advanced technology, allowing users to control the wheelchair with spoken commands or hand movements, enhancing accessibility for individuals with limited dexterity. Manual control options (SC-15) ensure that users who prefer or need manual operation have simple, effective mechanisms to propel or steer the wheelchair. Lastly, a caregiver assist mode (SC-16) allows caregivers to control the wheelchair remotely, providing extra support when necessary.

- *Customization (C-5)*

Nace et al. (2023) define customization as the ability to adjust the wheelchair to meet the user's specific needs or preferences. It encompasses various elements such as adjustable footrests (SC-17) which enable users to modify the position of the footrests for optimal comfort and posture, reducing pressure on the legs and feet. Adjustable armrests (SC-18) provide flexibility in supporting the arms, ensuring comfort for users of varying heights and arm lengths. The seat size and configuration (SC-19) is another key factor, as it ensures the wheelchair fits the user’s body dimensions, promoting comfort and preventing issues like pressure sores. Finally, accessory options (SC-20), such as cushions, trays, or cup holders, offer additional customization to enhance functionality and comfort, allowing users to adapt the wheelchair to their lifestyle.

- *Mobility & maneuverability (C-6)*

Mobility and maneuverability focus on the wheelchair’s ability to navigate various environments, see de Vries et al. (2023). It encompasses various factors such as turning radius (SC-21) which refers to the wheelchair's ability to navigate tight spaces, which is especially important for users in confined areas like hallways or small rooms. Indoor and outdoor usability (SC-22) ensures that the wheelchair can function effectively in both settings, providing the necessary adaptability to various environments. Terrain compatibility (SC-23) is important for users who need to navigate different surfaces such as grass, gravel, or rough pavement. Finally, stability on uneven surfaces (SC-24) ensures that the wheelchair remains steady and safe, even on terrains like slopes or bumpy sidewalks. Together, these factors ensure that the wheelchair offers reliable and smooth mobility in a variety of settings.

- *Battery life/power supply (C-7)*

Nagde and Dhobe (2021) emphasize that battery life and power supply are crucial for powered wheelchairs to ensure continuous use throughout the day. It encompasses various factors such as battery capacity (SC-25) which refers to the total energy stored in the battery, which influences how long the wheelchair can operate before needing a recharge. Charging time (SC-26) measures how long it takes to fully charge the battery, with faster charging times enhancing convenience for users who require quick turnarounds. Wheelchair users who must travel long distances should be aware of the range per charge (SC-27), which shows how far the wheelchair can go on a single charge. Lastly, power durability (SC-28) assesses the battery’s long-term performance and ability to retain charge over time, ensuring reliable use without frequent battery replacements. Together, these factors ensure that the wheelchair provides sufficient power for daily activities and extended use.

- *Durability (C-8)*

Kim et al. (2024) describe durability as the wheelchair's ability to endure extended use and environmental conditions without failing. A durable wheelchair is made from high-quality materials that resist wear and tear, offering a long lifespan even under frequent use. Durability is especially important for users who rely on their wheelchair daily and in a variety of environments. It encompasses various factors such as frame strength (SC-29) which is essential for supporting the user's weight and providing structural integrity, preventing damage under stress. Wheel durability (SC-30) is equally important, as it ensures the wheels can handle regular use on various surfaces without wearing down prematurely. Long-term reliability (SC-31) refers to the wheelchair's ability to perform consistently over time, with minimum maintenance or repairs needed. Finally, resistance to wear and tear (SC-32) ensures that materials and components resist degradation from daily use, maintaining the wheelchair's function and appearance for an extended period. Together, these factors provide a reliable and long-lasting wheelchair solution.

- *Cost (C-9)*

Cost is a critical factor for most individuals and organizations when selecting a wheelchair, as by Rivas et al. (2024). It encompasses various factors such as initial purchase cost (SC-33) which refers to the upfront price of the wheelchair, which can vary depending on its features and functionality. Maintenance expenses (SC-34) involve the ongoing costs associated with repairs, part replacements, and servicing to keep the wheelchair in optimal condition. Insurance coverage (SC-35) plays a role in reducing out-of-pocket costs by covering a portion of the wheelchair's purchase or maintenance. Lastly, warranty (SC-36) provides peace of mind by ensuring that the wheelchair is protected against defects or malfunctions for a certain period, reducing potential unexpected costs. Together, these factors help balance affordability with quality and long-term investment.

- *Safety features (C-10)*

Sahoo and Choudhury (2024) stress that safety features are vital for preventing accidents and ensuring the user's well-being. They argue that a wheelchair must offer a safe riding experience, particularly when navigating ramps or slopes. It encompasses various factors such as an anti-tip mechanism (SC-37), which helps prevent the wheelchair from tipping over, especially when navigating slopes or uneven surfaces. Seat belts and harnesses (SC-38) provide additional support and security for users, reducing the risk of falls or injury during movement. Braking systems (SC-39) are vital for controlling the wheelchair’s movement, ensuring it remains stationary when needed, and preventing unintentional rolling. Lastly, collision detection (SC-40) technology can alert the user to obstacles or prevent collisions by automatically stopping or adjusting the wheelchair's movement. These safety features collectively enhance stability and minimize the risk of accidents during daily use.

- *Technology integration (C-11)*

Zhang et al. (2024) highlight that modern wheelchairs integrate advanced technology such as automated braking, tilt and recline mechanisms, GPS tracking, and mobile device connectivity for remote control. It encompasses various factors such as GPS navigation (SC-41), which allows users to navigate unfamiliar environments with ease, providing directions and real-time location tracking for greater independence. Sensor integration (SC-42) includes features like proximity sensors or obstacle detection, improving safety by alerting users to potential hazards or automatically adjusting the wheelchair's movement. Software updates (SC-43) ensure that the wheelchair's system remains up-to-date with new features, performance improvements, and bug fixes. Lastly, smartphone compatibility (SC-44) enables users to control or monitor their wheelchair via a mobile app, offering added convenience and customization options. These technological advancements make the wheelchair more adaptive, responsive, and efficient in meeting the user's needs.

Each of these criteria and sub-criteria plays a vital role in ensuring the selected wheelchair meets the user’s needs, providing a comprehensive solution for mobility, comfort, safety, and independence. A more informed and efficient decision process might result from consumers prioritizing these aspects according to their own needs and preferences by employing an MCDM strategy.

Wheelchair selection methods

A variety of models have been created to identify the ideal wheelchair, each incorporating diverse methodologies. Since wheelchair selection necessitates balancing several conflicting objectives and criteria under unknown circumstances, MCDM techniques are frequently employed.

Mao et al. (2024) highlighted that most wheelchair selection models have integrated fuzzy concepts into traditional MCDM methods due to the capability of fuzzy-based approaches to manage uncertainty and imprecision in human judgment. Unni et al. (2024) point out that, while extensive research has integrated the traditional fuzzy set theory (FST) with various MCDM methods, less attention has been given to intuitionistic fuzzy sets (IFSs). Kousar and Kausar (2025) and Dağıstanlı (2024) explain that, unlike traditional fuzzy sets, an IFS enhances the concept of fuzzy sets and is better suited for practical applications. An IFS is more flexible in complex decision-making situations since it is defined by a membership function, a non-membership function, and a hesitation degree (hesitation margin).

Saqlain and Saeed (2024) argue that, unlike traditional fuzzy sets, which rely solely on a membership function, IFSs offer a more precise representation of the fuzzy nature of data. The hesitation degree in IFSs effectively manages ambiguity and uncertainty regarding membership and non-participation in a set. Decision -makers (DMs) especially benefit from this hesitation characteristic. The fuzzy set theory has been effectively applied to wheelchair selection in a number of research studies. An overview of the strategies and tactics used in wheelchair selection is given in Table 1, with an emphasis on user-centered and sustainable criteria.

Our study differentiates itself from prior research studies in several key aspects:

i. To our knowledge, the application of IFS-TOPSIS in wheelchair selection remains underexplored, with limited real-world implementations. Görçün et al. (2024) and Sampathkumar (2024) have combined MCDM with IFSs to select assistive devices in their studies; these approaches tend to rely on empirical data rather than on real-world case studies. This paper presents a case study focused on wheelchair selection for individuals with mobility challenges.

ii. The criteria and sub-criteria were carefully chosen through an extensive review of the literature and then further validated with input from decision-makers. This process ensures a more practical and precise approach by bridging theoretical and real-world perspectives.

iii. On a theoretical level, by adding a component-wise matrix multiplication operator to aggregate the weights of the criterion and sub-criteria, the suggested approach improves upon the IFS-TOPSIS architecture. The idea improves the precision and dependability of the decision-making process when choosing the best wheelchair.

Research design

The methodology framework

The framework designed for selecting wheelchairs using the intuitionistic fuzzy TOPSIS method is presented in Figure 1.

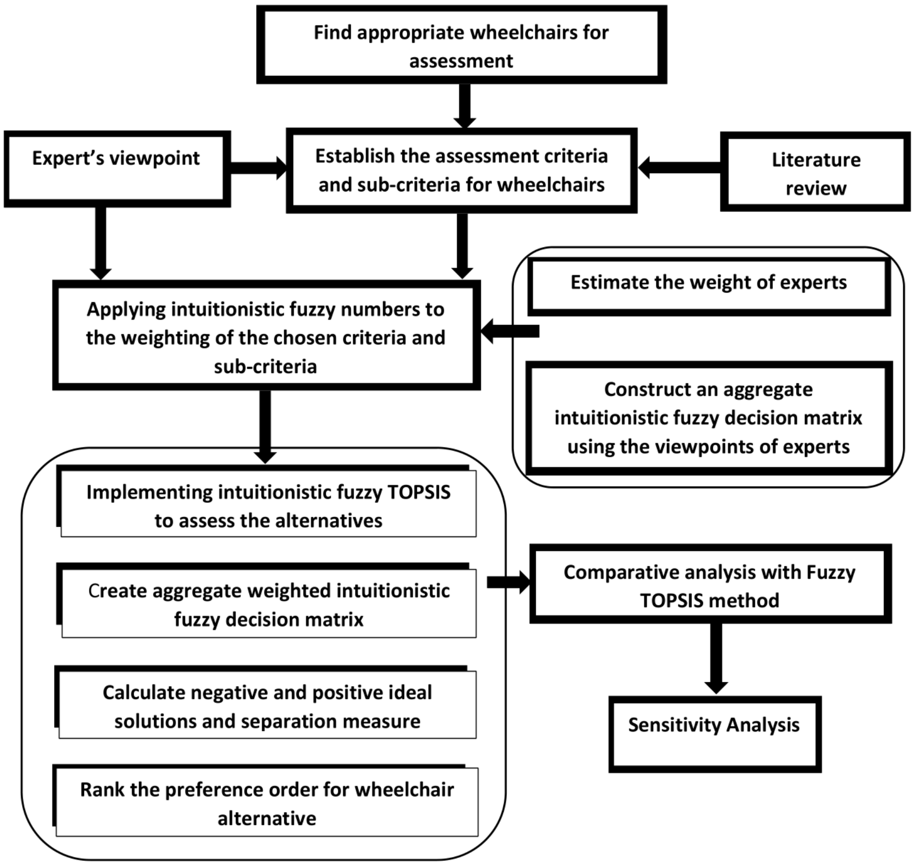

Figure 1 - Proposed wheelchair selection framework

The proposed wheelchair selection framework involves identifying suitable wheelchairs, gathering expert opinions, establishing criteria, and applying intuitionistic fuzzy TOPSIS for evaluation, with a comparison to fuzzy TOPSIS. A comparative analysis and sensitivity analysis ensure the robustness and reliability of rankings, making the framework effective for informed wheelchair selection decisions with the following steps:

Step 1 focuses on compiling different types of wheelchair models for evaluation.

Step 2 emphasizes defining the selection criteria and their associated sub-criteria. These are categorized under three main dimensions: performance, usability, and cost. The criteria were determined through an extensive literature review and validated by experts in assistive technology using the Nominal Group Technique (NGT). NGT ensures that the selection process is inclusive and unbiased by encouraging equal participation from all group members, thus eliminating dominant opinions and fostering a balanced evaluation.

Step 3 involves assigning weights to the criteria and sub-criteria. To accommodate for ambiguities and subjective variances, decision-makers (DMs) express their opinions using intuitionistic fuzzy numbers. These weights are essential for the evaluation stage and show how important each criterion is in relation to the others.

Step 4 entails evaluating the shortlisted wheelchairs using the intuitionistic fuzzy-TOPSIS method. After generating a weighted decision matrix, the best solutions and separation metrics are determined in order to rank and compare the options with fuzzy TOPSIS method. This guarantees a thorough and impartial selection procedure.

This framework offers a systematic and reliable approach to wheelchair selection, integrating expert input and robust decision-making tools.

Intuitionistic fuzzy sets

In order to overcome difficulties in human decision making, Zadeh (1978) created the idea of the fuzzy set theory. Subsequently, Atanassov and Atanassov (1999) created intuitionistic fuzzy sets (IFSs) which are used extensively in domains such as evaluation functions, preference relations, medical diagnosis, logic programming, and decision making. An overview of IFSs is given in this section.

An IFS can be defined by considering W as an IFS within a finite set D. The definition of an IFS W is expressed in Eq. (1):

$$W = \{d, \mu_w(d), \vartheta_w(d) | d \in D\} \qquad (1)$$

where $\mu_w(d): D \to [0,1]$ is a membership function and $\vartheta_w(d): D \to [0,1]$ is a non-membership function, in which $0 \le \mu_w(d) + \vartheta_w(d) \le 1$.

An IFS includes a third parameter called the hesitation degree. Let π_w(d) represent the hesitation degree regarding whether d belongs to W or not. The hesitation degree π_w(d) is expressed in Eq. (2):

$$\pi_w(d) = 1 - \mu_w(d) - \vartheta_w(d) \quad (2)$$

where for every $d \in D$: $0 \leq \pi_w(d) \leq 1$.

When W(d) has a low value, there is greater confidence in the information about d. Conversely, a high value of W(d) indicates greater uncertainty regarding d. The multiplication operator for IFSs, as shown in Eq. (3), applies to two IFSs, W and X, within the set D.

$$W \times X = \{\mu_w(d).\mu_x(d), \vartheta_w(d) + \vartheta_x(d) - \vartheta_w(d).\vartheta_x(d) | d \in D\} \quad (3)$$

Element-wise matrix multiplication is determined as shown in Eq. (4) and it applies to two IFSs, W and X, within the set D.

$$W * X = |[\min\{\mu_w(d), \mu_x(d)\}], [\max\{\vartheta_w(d), \vartheta_x(d)\}]| \quad (4)$$

Intuitionistic fuzzy TOPSIS

The TOPSIS method is a commonly used methodology that was first presented by Hwang and Yoon in 1981. An alternative that is closest to the positive-ideal solution is considered the best option by Shih et al. (2022). TOPSIS is preferred over AHP and PROMETHEE for its computational efficiency and straightforward ranking based on proximity to ideal solutions. Unlike AHP, which requires pairwise comparisons, and PROMETHEE, which involves preference functions, TOPSIS efficiently handles multiple criteria without extensive complexity.

Fuzzy numbers are frequently used in practical applications to handle the subjective judgments and inherent uncertainties in practical applications decision making. A more complex framework is offered by intuitionistic fuzzy sets (IFSs) which better capture decision-makers' acceptance, rejection, and hesitation levels, as by Naveed and Ali (2025). As suggested by Rouyendegh (2015), this section describes an intuitionistic fuzzy TOPSIS model for assessing options based on a variety of criteria. In this study, intuitionistic fuzzy TOPSIS (IF-TOPSIS) enhances traditional TOPSIS by incorporating IFNs, capturing acceptance, rejection, and hesitation levels. This improves expert judgment representation, making the approach more robust for complex decision-making environments.

Let the set of wheelchair alternatives be $W_A=\{W_{A1},W_{A2},\ldots,W_{Am}\}$, the set of criteria $W_C=\{W_{C1},W_{C2},\ldots,W_{Cn}\}$, and the set of experts $E=\{E_1,E_2,\ldots,E_k\}$. The ranking process follows a structured seven-step algorithm:

Step 1: Estimate the relative importance weights of the experts.

A group of E experts assigns relevance using linguistic terms represented as intuitionistic fuzzy numerals. Let the intuitionistic fuzzy number for the n_{th} expert be denoted as $E_k = [\mu_n, v_n, \pi_n]$, where μ_n, v_n, and π_n represent membership, non-membership, and hesitation degrees, respectively. The weight of the n_{th} expert can then be determined using Eq. (5).

$$\lambda_n = \left[\frac{\mu_n + \pi_n\left(\frac{\mu_n}{\mu_n + \vartheta_n}\right)}{\sum_{n=1}^{E}\left[\mu_n + \pi_n\left(\frac{\mu_n}{\mu_n + \vartheta_n}\right)\right]}\right] \quad (5)$$

where $\sum_{n=1}^{E}\lambda_n = 1$.

Step 2: Evaluate the criterion's weight based on the opinions of experts.

Eq. (6) is used to calculate the weight of the criteria based on the linguistic terms in Table 1.

$$w_j = IFWA_\lambda\left(w_j^1, w_j^2, \ldots w_j^E\right) = \lambda_1 w_j^1 \oplus \lambda_2 w_j^2 \oplus, \ldots, \oplus \lambda_n w_j^E = \left[1 - \prod_{E=1}^{n}\left(1 - \mu_{ij}^E\right)^{\lambda_E}, \prod_{E=1}^{n}\left(\vartheta_{ij}^E\right)^{\lambda_E}, \prod_{E=1}^{n}\left(1 - \mu_{ij}^E\right)^{\lambda_E} - \prod_{E=1}^{n}\left(1 - \vartheta_{ij}^E\right)^{\lambda_E}\right] \quad (6)$$

Step 3: Establish the intuitionistic fuzzy decision matrix (IFDM).

The weights of the potential alternate wheelchair are estimated using the numerical equivalents of the verbal terms mentioned in Table 2. Using the intuitionistic fuzzy weighted averaging (IFWA) operator, the weights of the decision-makers are integrated to produce the aggregated intuitionistic fuzzy decision matrix (AIFDM), by Panda and Pal (2015). Using Eq. (7), the AIFDM model is produced by integrating the many perspectives of a group of decision-makers into a single, coherent perspective.

$R^{(E)} = \left(r_{ij}^1\right)_{m*n}$ is the AIFDM of each expert.

$\lambda = \{\lambda_1, \lambda_2, \lambda_3, \ldots\ldots, \lambda_E\}$ is the weight of the expert.

$R = \left(r_{ij}\right)_{m'*n'}$

$$r_{ij} = IFWA_\lambda\left(r_{ij}^1, r_{ij}^2, \ldots r_{ij}^E\right) = \lambda_1 r_{ij}^1 \oplus \lambda_2 r_{ij}^2 \oplus, \ldots, \oplus \lambda_n r_{ij}^E$$

$$= \left[1 - \prod_{E=1}^{n}\left(1-\mu_{ij}^{E}\right)^{\lambda_E},\ \prod_{E=1}^{n}\left(\vartheta_{ij}^{E}\right)^{\lambda_E},\ \prod_{E=1}^{n}\left(1-\mu_{ij}^{E}\right)^{\lambda_E} - \prod_{E=1}^{n}\left(1-\vartheta_{ij}^{E}\right)^{\lambda_E}\right] \quad (7)$$

Table 1 - Linguistic terms for experts, criteria and sub-criteria

Linguistic terms	IFNs
Very Important (VI)	[0.90, 0.05, 0.05]
Important (I)	[0.70, 0.25, 0.05]
Medium (M)	[0.50, 0.40, 0.10]
Unimportant (U)	[0.30, 0.65, 0.05]
Very unimportant (VU)	[0.05, 0.90, 0.05]

Table 2 - Linguistic terms for ranking possible alternatives of wheelchairs

Linguistic terms	IFNs
Extremely high (EH)	[1.00, 0.00, 0.00]
Very high (VH)	[0.90, 0.05, 0.05]
High (H)	[0.70, 0.25, 0.05]
Medium high (MH)	[0.60, 0.35, 0.05]
Medium (M)	[0.50, 0.45, 0.05]
Medium low (ML)	[0.40, 0.55, 0.05]
Low (L)	[0.30, 0.65, 0.05]
Very low (VL)	[0.10, 0.85, 0.05]
Extremely low (EL)	[0.00, 1.00, 0.05]

Step 4: The S matrix computation.

This step involves determining the criteria weights (W) in respect to the IFD matrix (R) using Eq. (8).

$$S = R \otimes W = \left(\mu'_{ij}, \vartheta'_{ij}\right) = \left\{\langle x, \mu_{ij} \times \mu_{ij}, \left(\vartheta_{ij} + \vartheta_j\right) - \left(\vartheta_{ij} \times \vartheta_j\right)\rangle\right\} \quad (8)$$

Step 5: Compute the IF ideal positive and negative outcomes.

The benefit criterion is represented by J_1, and the cost criterion is indicated by J_2. The IF positive-ideal outcome is represented by A^+, whereas the IF negative-ideal outcome is represented by A^-. The following formula is used to obtain these outcomes, A^+ and A^-, using Eq. (9).

$$A^+ = \left(r_1'^+, r_2'^+, \dots, r_n'^+\right), r_j'^+ = \left(\mu_j'^+, \vartheta_j'^+, \pi_j'^+\right), j = 1,2,\dots,n$$

$$A^- = \left(r_1'^-, r_2'^-, \dots, r_n'^-\right), r_j'^- = \left(\mu_j'^-, \vartheta_j'^-, \pi_j'^-\right), j = 1,2,\dots,n \quad (9)$$

where

$\mu_j'^{+} = \{(max_i(\mu_{ij}')j\epsilon J_1), (min_i(\mu_{ij}')j\epsilon J_2)\}$,
$\vartheta_j'^{+} = \{(min_i(\vartheta_{ij}')j\epsilon J_1), (max_i(\vartheta_{ij}')j\epsilon J_2)\}$,
$\pi_j'^{+} = \{(1 - max_i(\mu_{ij}') - min_i(\vartheta_{ij}')j\epsilon J_1), (1 - min_i(\mu_{ij}') - max_i(\vartheta_{ij}')j\epsilon J_2)\}$,
$\mu_j'^{-} = \{(min_i(\mu_{ij}')j\epsilon J_1), (max_i(\mu_{ij}')j\epsilon J_2)\}$,
$\vartheta_j'^{-} = \{(max_i(\vartheta_{ij}')j\epsilon J_1), (min_i(\vartheta_{ij}')j\epsilon J_2)\}$,
$\pi_j'^{-} = \{(1 - min_i(\mu_{ij}') - max_i(\vartheta_{ij}')j\epsilon J_1), (1 - max_i(\mu_{ij}') - min_i(\vartheta_{ij}')j\epsilon J_2)\}$.

Step 6: Estimate the separation measures between different possible wheelchairs.

Ashraf et al. (2021) explain that various distance metrics are used to assess the separation between alternatives in an IFS. These metrics include normalized versions of the Euclidean and Hamming distances as well as their generalizations. The separation measurements for each option are calculated after a particular distance measure has been chosen. These metrics express how far an option is from the negative ideal solution (S_i^+) and the positive ideal solution (S_i^-) using Eq. (10).

$$S_i^+ = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_{ij}' - \mu_j'^{*}\right)^2 + \left(\vartheta_{ij}' - \vartheta_j'^{*}\right)^2 + \left(\pi_{ij}' - \pi_j'^{*}\right)^2\right]}$$

$$S_i^- = \sqrt{\frac{1}{2n}\sum_{j=1}^{n}\left[\left(\mu_{ij}' - \mu_j'^{-}\right)^2 + \left(\vartheta_{ij}' - \vartheta_j'^{-}\right)^2 + \left(\pi_{ij}' - \pi_j'^{-}\right)^2\right]} \qquad (10)$$

Step 7: Estimate the final ranking of different possible wheelchairs.

The following Eq. (11) is the expression for the relative closeness coefficient of an alternative, A_i, with respect to the intuitionistic fuzzy positive ideal solution, A^+:

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-}, and\ 0 \le C_i^* \le 1 \qquad (11)$$

The preference ranking is then calculated by sorting the C_i^* values in the descending order. Higher values indicate better success. The alternative's performance within the sector is reflected in the C_i value.

Triangular fuzzy TOPSIS

Jana et al. (2024) validate and confirm the outcomes of the intuitionistic fuzzy TOPSIS technique by applying the fuzzy TOPSIS method with triangular fuzzy integers in this section. The process consists of the following steps:

Step 1: Specify the criteria and sub-criteria weights.

Triangular fuzzy numbers are used to assess each criterion and sub-criterion's relevance.

Step 2: Aggregate the weights of the sub-criteria and criteria.

Taking $\overline{X_E} = (p_{iE}, q_{iE}, r_{iE})$ is a triangular fuzzy number indicated by the weight of the wheelchair criteria $\overline{X_E}$ determined by the expert E, and $\overline{Y_E} = (p_{jE}, q_{jE}, r_{jE})$ is also a triangular fuzzy number indicated by the weight of the wheelchair sub-criteria $\overline{Y_E}$ of criteria $\overline{X_E}$ calculated by the Eth expert. The aggregate weight (AW_E) of the Eth criteria and its respective sub-criteria can be estimated using Eq. (12) [9].

$$AW_E = (\alpha, \beta, \gamma) \qquad (12)$$

where

$\alpha = min(p_{iE}, p_{jE})$,

$\beta = \sqrt[E]{\prod_{E=1}^{n} q_{ik}, q_{jk}}$ and

$\alpha = max(r_{iE}, r_{jE})$.

Step 3: Integrate the expert's views.

Using the same procedure described in Step 2, the combined weights of the criterion and sub-criteria from each expert are combined in this phase.

Step 4: Normalize the aggregated decision matrix.

A linear scale transformation is used to normalize the fuzzy decision matrix ($\overline{FB}$). The following Eq. (13) is used for the normalization procedure.

$$\overline{FB} = [fb_{ij}]_{m\times n}$$

$$fb_{ij} = \left(\frac{p_{ij}}{q_j^+}, \frac{q_{ij}}{q_j^+}, \frac{r_{ij}}{q_j^+}\right) \text{ for the benefit criteria}$$

$$fb_{ij} = \left(\frac{p_j^-}{p_{ij}}, \frac{p_j^-}{q_{ij}}, \frac{p_j^-}{r_{ij}}\right) \text{ for the cost criteria} \qquad (13)$$

Step 5: Develop a fuzzy aggregated fuzzy decision matrix.

Let a_{ij} represent the rate of the given aggregated weights of the criterion and sub-criteria (determined in Step 3); the aggregated fuzzy decision matrix of the options $\overline{AFB}$ can be constructed using Eq.(14).

$$\overline{AFB} = \begin{bmatrix} a_{11}\ a_{12}\ a_{1j}\ a_{1m} \\ a_{i1}\ a_{i2}\ a_{ij}\ a_{im} \\ a_{n1}\ a_{n2}\ a_{nj}\ a_{nm} \end{bmatrix} \quad (14)$$

Step 6: Normalize the aggregate fuzzy decision matrix of the alternatives.

Using the same equations as in Step 4, the aggregated fuzzy decision matrix is normalized in Step 5.

Step 7: Establish the weighted normalized decision matrix (WN) by multiplying the weights of the aggregated criteria's normalized elements by the aggregated fuzzy decision matrix $\overline{AFB}$ by the sub-criteria using Eq. (15).

$$WN = a_{ij} \times \overline{AFB} \quad (15)$$

Step 8: Identify the fuzzy positive ideal solution and the fuzzy negative ideal solution.

The fuzzy positive ideal solution (I^+) and the fuzzy negative ideal solution (I^-) are calculated using Eq. (16).

$$I^+ = \{\theta_1^+, \theta_j^+, \dots, \theta_m^+\}$$
$$I^- = \{\theta_1^-, \theta_j^-, \dots, \theta_m^-\} \quad (16)$$

where $\theta_j^+ = (1,1,1)$ and $\theta_j^- = (0,0,0)$.

Step 9: Compute each alternative's distance from the fuzzy positive and negative ideal solutions.

Let (S_i^+) and (S_i^-) denote the distances of each alternative wheelchair from $\theta_j^+$and θ_j^-, respectively, and calculated using Eq. (17).

$$S_i^+ = \sum_{j=1}^{n} d_v\left(\theta_{ij}, \theta_j^+\right)$$
$$S_i^- = \sum_{j=1}^{n} d_v\left(\theta_{ij}, \theta_j^-\right) \quad (17)$$

where dv (.,.) uses the vertex method to display the distance between two fuzzy numbers. When triangular fuzzy numbers are involved, it can be computed using Eq. (18) as follows:

$$S(x,y) = \sqrt{\frac{1}{3}\left[\left(p_x - p_y\right)^2 + \left(q_x - q_y\right)^2 + \left(r_x - r_y\right)^2\right]} \tag{18}$$

Step-10: Ranking of the wheelchair alternatives.

The alternatives are ranked in the descending order of the closeness coefficient C_i^*.

Numerical example

The proposed case study

For those with physical limitations, mobility solutions are crucial, and wheelchairs continue to be a vital tool for enhancing their quality of life. Depending on the demands of the user, different wheelchair types—such as manual (MW), electric (EW), or AI-powered (APW) wheelchairs—offer unique benefits and drawbacks. The Educational Institute (EI) tries to develop a wheelchair prototype and aims to choose the best wheelchair type for its customers by balancing cost, usefulness, and user-specific needs.

The EI wants to enhance its wheelchair prototype by switching to contemporary, eco-friendly, and effective wheelchair solutions in light of growing awareness of user-centered design and wheelchair technological breakthroughs. The Institute is dedicated to meeting various demands of its users while ensuring that its services are in line with the WHO standards for assistive technology. In order to do this, the EI started a methodical assessment to determine which wheelchair type would work best for various user groups.

Three wheelchair models were selected for further evaluation. Manual wheelchairs are affordable, lightweight, and appropriate for people with strong upper bodies. Electric wheelchairs are battery-powered devices with sophisticated functions which are ideal for anyone with poor physical strength or movement. AI-powered wheelchairs are designed for people with severe mobility issues or cognitive impairments. These wheelchairs have voice control, intelligent navigation, and obstacle avoidance features. An in-depth comprehension of user profiles, environmental factors, and financial limitations was necessary for the evaluation.

To evaluate the choices, a team of three experts—robotic engineers, biomedical engineers, and occupational therapists—was selected for their expertise in wheelchair technology, human mobility, and user-centered design. This multidisciplinary team ensures a balanced evaluation by integrating technical innovation, medical considerations, and practical usability. While a larger panel could provide broader insights, three experts were deemed sufficient for an initial assessment, ensuring efficiency without compromising decision quality. In order to identify the most qualified wheelchair, the following process was taken into consideration.

Establishing the criteria and sub- criteria for choosing a qualified wheelchair

These criteria and their sub-criteria were chosen based on the literature research, and they were then validated and modified in response to DMs' feedback, as indicated in Table 3.

Table 3 - Identified criteria and sub- criteria

Dimension	**Criteria**	**Sub-criteria**
User-centric factors	User's physical condition (C-1)	Strength and endurance (SC-1)
		Posture support (SC-2)
		Weight capacity (SC-3)
		Range of motion (SC-4)
	Comfort (C-2)	Seat cushioning (SC-5)
		Back support (SC-6)
		Adjustability (SC-7)
		Ergonomics (SC-8)
	Ease of use (C-3)	Maneuverability (SC-9)
		Control interface simplicity (SC-10)
		Caregiver involvement (SC-11)
		User learning curve (SC-12)
	Control interface (C-4)	Joystick control (SC-13)
		Voice or gesture control (SC-14)
		Manual control options (SC-15)
		Caregiver assist mode (SC-16)
	Customization (C-5)	Adjustable footrests (SC-17)
		Adjustable armrests (SC-18)
		Seat size and configuration (SC-19)
		Accessory options (SC-20)
Performance & durability	Mobility & maneuverability (C-6)	Turning radius (SC-21)
		Indoor and outdoor usability (SC-22)
		Terrain compatibility (SC-23)
		Stability on uneven surfaces (SC-24)

Dimension	Criteria	Sub-criteria
	Battery life/power supply (C-7)	Battery capacity (SC-25)
		Charging time (SC-26)
		Range per charge (SC-27)
		Power durability (SC-28)
	Durability (C-8)	Frame strength (SC-29)
		Wheel durability (SC-30)
		Long-term reliability (SC-31)
		Resistance to wear and tear (SC-32)
Cost, safety & technology	Cost (C-9)	Initial purchase cost (SC-33)
		Maintenance expenses (SC-34)
		Insurance coverage (SC-35)
		Warranty (SC-36)
	Safety features (C-10)	Anti-tip mechanism (SC-37)
		Seat belts and harnesses (SC-38)
		Braking systems (SC-39)
		Collision detection (SC-40)
	Technology integration (C-11)	GPS navigation (SC-41)
		Sensor integration (SC-42)
		Software updates (SC-43)
		Smartphone compatibility (SC-44)

Selection of wheelchairs using intuitionistic fuzzy TOPSIS and its results

The linguistic terms from Table 1 were used to estimate the criteria and the experts. The significance of each expert in the group decision-making process is seen in Table 4. Furthermore, the significance of the criteria and sub-criteria was evaluated using the linguistic phrases listed in Table 1. Using Eq. (5), the expert weights were determined.

Table 4 - Significance of professionals and their weights

	E1	E2	E3
Linguistic terms	Very Important	Important	Very Important
Weights	0.36	0.28	0.36

Table 5 - Ratings of the alternatives, ratings of the alternatives based on IFNs, AIFD matrix

		Ratings			Ratings based on IFNs			AIFD matrix
Criteria	Types	E-1	E-2	E-3	E-1	E-2	E-3	
C1	MW	L	ML	VL	[0.30, 0.65]	[0.40, 0.55]	[0.10, 0.85]	[0.266, 0.683, 0.051]
	EW	M	MH	ML	[0.50, 0.45]	[0.60, 0.35]	[0.40, 0.55]	[0.498, 0.451, 0.051]
	APW	H	VH	MH	[0.70, 0.25]	[0.90, 0.05]	[0.60, 0.35]	[0.755, 0.180, 0.065]
C2	MW	ML	L	M	[0.40, 0.55]	[0.30, 0.65]	[0.50, 0.45]	[0.413, 0.536, 0.050]
	EW	M	MH	H	[0.50, 0.45]	[0.60, 0.35]	[0.70, 0.25]	[0.609, 0.339, 0.051]
	APW	H	EH	VH	[0.70, 0.25]	[1.00, 0.00]	[0.90, 0.05]	[1.000, 0.000, 0.000]
C3	MW	L	ML	VL	[0.30, 0.65]	[0.40, 0.55]	[0.10, 0.85]	[0.266, 0.683, 0.051]
	EW	M	MH	MH	[0.50, 0.45]	[0.60, 0.35]	[0.60, 0.35]	[0.539, 0.383, 0.078]
	APW	EH	VH	EH	[1.00, 0.00]	[0.90, 0.05]	[1.00, 0.00]	[1.000, 0.000, 0.000]
C4	MW	EL	EL	EL	[0.00, 1.00]	[0.00, 1.00]	[0.00, 1.00]	[0.000, 1.000, 0.000]
	EW	ML	M	M	[0.40, 0.55]	[0.50, 0.45]	[0.50, 0.45]	[0.466, 0.484, 0.050]
	APW	VH	EH	VH	[0.90, 0.05]	[1.00, 0.00]	[0.90, 0.05]	[1.000, 0.000, 0.000]
C5	MW	EL	VL	EL	[0.00, 1.00]	[0.10, 0.85]	[0.00, 1.00]	[0.029, 0.956, 0.015]
	EW	M	MH	M	[0.50, 0.45]	[0.60, 0.35]	[0.50, 0.45]	[0.530, 0.419, 0.050]
	APW	H	EH	VH	[0.70, 0.25]	[1.00, 0.00]	[0.90, 0.05]	[0.781, 0.000, 0.219]
C6	MW	VL	EL	VL	[0.10, 0.85]	[0.00, 1.00]	[0.10, 0.85]	[0.073, 0.890, 0.037]
	EW	H	H	VH	[0.70, 0.25]	[0.70, 0.25]	[0.90, 0.05]	[0.798, 0.140, 0.062]
	APW	H	VH	EH	[0.70, 0.25]	[0.90, 0.05]	[1.00, 0.00]	[1.000, 0.000, 0.000]
C7	MW	EL	EL	EL	[0.00, 1.00]	[0.00, 1.00]	[0.00, 1.00]	[0.000, 1.000, 0.000]
	EW	M	M	ML	[0.50, 0.45]	[0.50, 0.45]	[0.40, 0.55]	[0.466, 0.484, 0.050]
	APW	VH	H	H	[0.90, 0.05]	[0.70, 0.25]	[0.70, 0.25]	[0.798, 0.140, 0.062]
C8	MW	MH	M	MH	[0.60, 0.35]	[0.50, 0.45]	[0.60, 0.35]	[0.574, 0.376, 0.050]
	EW	MH	MH	H	[0.60, 0.35]	[0.60, 0.35]	[0.70, 0.25]	[0.639, 0.310, 0.051]
	APW	MH	H	VH	[0.60, 0.35]	[0.70, 0.25]	[0.90, 0.05]	[0.776, 0.158, 0.066]
C9	MW	EL	VL	L	[0.00, 1.00]	[0.10, 0.85]	[0.30, 0.65]	[0.146, 0.818, 0.036]
	EW	H	MH	MH	[0.70, 0.25]	[0.60, 0.35]	[0.60, 0.35]	[0.639, 0.310, 0.051]
	APW	EH	VH	EH	[1.00, 0.00]	[0.90, 0.05]	[1.00, 0.00]	[1.000, 0.000, 0.000]
C10	MW	L	VL	VL	[0.30, 0.65]	[0.10, 0.85]	[0.10, 0.85]	[0.178, 0.772, 0.050]
	EW	H	MH	MH	[0.70, 0.25]	[0.60, 0.35]	[0.60, 0.35]	[0.639, 0.310, 0.051]
	APW	EH	EH	VH	[1.00, 0.00]	[1.00, 0.00]	[0.90, 0.05]	[1.000, 0.000, 0.000]
C11	MW	VL	L	VL	[0.10, 0.85]	[0.30, 0.65]	[0.10, 0.85]	[0.161, 0.788, 0.050]
	EW	M	M	ML	[0.50, 0.45]	[0.50, 0.45]	[0.40, 0.55]	[0.466, 0.484, 0.050]
	APW	MH	H	MH	[0.60, 0.35]	[0.70, 0.25]	[0.60, 0.35]	[0.631, 0.319, 0.051]

Table 2 lists the linguistic terms that were used to rank the wheelchair alternatives. Table 5 summarizes the expert's ratings for the three wheelchair options: manual, electric, and AI-powered and also displays the IFNs that were created from these ratings. By integrating the views of the experts, the AIFD matrix (Eq. (7)) was produced as shown in Table 5.The significance of the wheelchair selection criteria and sub-criteria, as stated in linguistic terms, is shown in Tables 6 and 7. Subsequently, these linguistic terms were transformed into IFNs which are also displayed in Table 7. To calculate the weight of each criterion, the opinions of the decision-makers were compiled using Eq. (5.) The ultimate weight of the combined criterion and sub-criteria, as well as their final combined importance, are displayed in Table 8.

Table 6 - Ratings of the criteria

Criteria	Ratings of the criteria		
	E-1	E-2	E-3
C1	I	M	I
C2	M	I	I
C3	I	VI	I
C4	I	I	M
C5	M	I	M
C6	VI	I	VI
C7	I	M	I
C8	M	I	VI
C9	VI	VI	I
C10	I	VI	I
C11	I	M	VI

Table 7 - Ratings of the sub-criteria, and ratings of the sub-criteria based on IFNs

Sub-criteria	Ratings			Ratings of the sub-criteria based on IFNs		
	E-1	E-2	E- 3	E-1	E-2	E-3
SC-1	M	U	M	(0.50, 0.40)	(0.30, 0.65)	(0.50, 0.40)
SC-2	I	M	VI	(0.70, 0.25)	(0.50, 0.40)	(0.90, 0.05)
SC-3	I	M	I	(0.70, 0.25)	(0.50, 0.40)	(0.70, 0.25)
SC-4	I	I	VI	(0.70, 0.25)	(0.70, 0.25)	(0.90, 0.05)
SC-5	I	VI	I	(0.70, 0.25)	(0.90, 0.05)	(0.70, 0.25)
SC-6	M	VI	M	(0.50, 0.40)	(0.90, 0.05)	(0.50, 0.40)
SC-7	M	I	I	(0.50, 0.40)	(0.70, 0.25)	(0.70, 0.25)
SC-8	I	I	M	(0.70, 0.25)	(0.70, 0.25)	(0.50, 0.40)
SC-9	VI	VI	I	(0.90, 0.05)	(0.90, 0.05)	(0.70, 0.25)
SC-10	I	VI	M	(0.70, 0.25)	(0.90, 0.05)	(0.50, 0.40)
SC-11	U	VU	U	(0.30, 0.65)	(0.05, 0.90)	(0.30, 0.65)
SC-12	M	M	I	(0.50, 0.40)	(0.50, 0.40)	(0.70, 0.25)
SC-13	I	M	M	(0.70, 0.25)	(0.50, 0.40)	(0.50, 0.40)
SC-14	VI	VI	I	(0.90, 0.05)	(0.90, 0.05)	(0.70, 0.25)
SC-15	M	U	U	(0.50, 0.40)	(0.30, 0.65)	(0.30, 0.65)
SC-16	M	U	M	(0.50, 0.40)	(0.30, 0.65)	(0.50, 0.40)
SC-17	I	VI	I	(0.70, 0.25)	(0.90, 0.05)	(0.70, 0.25)
SC-18	VI	I	VI	(0.90, 0.05)	(0.70, 0.25)	(0.90, 0.05)
SC-19	VI	I	VI	(0.90, 0.05)	(0.70, 0.25)	(0.90, 0.05)
SC-20	VI	I	VI	(0.90, 0.05)	(0.70, 0.25)	(0.90, 0.05)
SC-21	I	M	I	(0.70, 0.25)	(0.50, 0.40)	(0.70, 0.25)

Sub-criteria	E-1	E-2	E- 3	E-1	E-2	E-3
SC-22	I	VI	VI	(0.70, 0.25)	(0.90, 0.05)	(0.90, 0.05)
SC-23	VI	VI	VI	(0.90, 0.05)	(0.90, 0.05)	(0.90, 0.05)
SC-24	VI	VI	VI	(0.90, 0.05)	(0.90, 0.05)	(0.90, 0.05)
SC-25	I	VI	I	(0.70, 0.25)	(0.90, 0.05)	(0.70, 0.25)
SC-26	M	I	M	(0.50, 0.40)	(0.70, 0.25)	(0.50, 0.40)
SC-27	VI	VI	I	(0.90, 0.05)	(0.90, 0.05)	(0.70, 0.25)
SC-28	I	I	I	(0.70, 0.25)	(0.70, 0.25)	(0.70, 0.25)
SC-29	VI	I	VI	(0.90, 0.05)	(0.70, 0.25)	(0.90, 0.05)
SC-30	M	M	I	(0.50, 0.40)	(0.50, 0.40)	(0.70, 0.25)
SC-31	I	I	M	(0.70, 0.25)	(0.70, 0.25)	(0.50, 0.40)
SC-32	U	I	M	(0.30, 0.65)	(0.70, 0.25)	(0.50, 0.40)
SC-33	VI	VI	I	(0.90, 0.05)	(0.90, 0.05)	(0.70, 0.25)
SC-34	U	M	VU	(0.30, 0.65)	(0.50, 0.40)	(0.05, 0.90)
SC-35	VI	M	VU	(0.90, 0.05)	(0.50, 0.40)	(0.05, 0.90)
SC-36	I	M	I	(0.70, 0.25)	(0.50, 0.40)	(0.70, 0.25)
SC-37	I	VI	VI	(0.70, 0.25)	(0.90, 0.05)	(0.90, 0.05)
SC-38	VI	M	I	(0.90, 0.05)	(0.50, 0.40)	(0.70, 0.25)
SC-39	VI	VI	VI	(0.90, 0.05)	(0.90, 0.05)	(0.90, 0.05)
SC-40	VI	I	VI	(0.90, 0.05)	(0.70, 0.25)	(0.90, 0.05)
SC-41	I	I	I	(0.70, 0.25)	(0.70, 0.25)	(0.70, 0.25)
SC-42	I	I	M	(0.70, 0.25)	(0.70, 0.25)	(0.50, 0.40)
SC-43	VI	M	I	(0.90, 0.05)	(0.50, 0.40)	(0.70, 0.25)
SC-44	VI	M	I	(0.90, 0.05)	(0.50, 0.40)	(0.70, 0.25)

Table 8 - Final aggregated significance of the criteria and the sub-criteria

Combined	E-1	E-2	E-3	Final weight aggregated criteria and sub-criteria
C-1	(0.50, 0.40)	(0.30, 0.65)	(0.50, 0.40)	(0.451, 0.458, 0.091)
C-2	(0.50, 0.40)	(0.70, 0.25)	(0.50, 0.40)	(0.567, 0.351, 0.083)
C-3	(0.30, 0.65)	(0.05, 0.90)	(0.30, 0.65)	(0.238, 0.712, 0.050)
C-4	(0.50, 0.40)	(0.30, 0.65)	(0.30, 0.65)	(0.380, 0.546, 0.074)
C-5	(0.70, 0.25)	(0.70, 0.25)	(0.70, 0.25)	(0.700, 0.250, 0.050)
C-6	(0.70, 0.25)	(0.50, 0.40)	(0.70, 0.25)	(0.654, 0.285, 0.061)
C-7	(0.50, 0.40)	(0.70, 0.25)	(0.50, 0.40)	(0.567, 0.351 0.083)
C-8	(0.30, 0.65)	(0.50, 0.40)	(0.50, 0.40)	(0.436, 0.476, 0.088)
C-9	(0.30, 0.65)	(0.50, 0.40)	(0.05, 0.90)	(0.289, 0.638, 0.073)
C-10	(0.70, 0.25)	(0.50, 0.40)	(0.70, 0.25)	(0.654, 0.285,0.061)
C-11	(0.70, 0.25)	(0.50, 0.40)	(0.50, 0.40)	(0.584, 0.338, 0.078)

For the wheelchair selection C-1, C-2, C-3, C-4, C-5, C-6, C-7, C-8, C-10, and C-11 are the benefit criteria where C-9 is the cost criteria. The IF positive-ideal solution (A^+) and the IF negative-ideal solution (A^-) for the wheelchair selection were determined using Eqs. (8) and (9) as its results are shown in Table 9.

Table 9 - Intuitionistic fuzzy positive and negative ideal solutions

	A^+	A^-
C-1	(0.341, 0.556, 0.104)	(0.120, 0.828, 0.052)
C-2	(0.567,0.351, 0.082)	(0.234, 0.699, 0.067)
C-3	(0.238, 0.712, 0.050)	(0.063, 0.909, 0.028)
C-4	(0.380, 0.546, 0.074)	(0.000, 1.000, 0.000)
C-5	(0.547, 0.250, 0.203)	(0.020, 0.967, 0.013)
C-6	(0.654, 0.285, 0.061)	(0.048, 0.921, 0.031)
C-7	(0.452, 0.442, 0.106)	(0.000, 1.000, 0.000)
C-8	(0.338, 0.559, 0.103)	(0.279, 0.638, 0.083)
C-9	(0.042, 0.934, 0.024)	(0.289, 0.638, 0.073)
C-10	(0.654, 0.285, 0.061)	(0.116, 0.837, 0.047)
C-11	(0.369, 0.549, 0.082)	(0.094, 0.860, 0.046)

The normalized Euclidean distance was used to determine the positive (S^+) and negative (S^-) separation measures for each wheelchair alternative, and the results are shown in Table10 using Eq. (10). The relative closeness coefficients C_i^* were initially computed in order to rank the wheelchair options using Eq. (11). After that, the options were arranged in accordance with their C_i^* values in the descending order.

The wheelchair types in this case study were ranked as follows: AI-Powered >Electric > Manual. As a result, the electric AI-powered wheelchair was chosen as the best choice out of the available options.

Table 10 - Separation measures and the relative closeness coefficient for each wheelchair alternative

Wheelchair	S^+	S^-	C_i^*	Rank
MW	0.410	0.083	0.169	3rd
EW	0.179	0.256	0.589	2nd
APW	0.083	0.409	0.832	1st

Selection of the wheelchair using fuzzy TOPSIS

The weights assigned to the criteria and sub-criteria were determined in order to begin the evaluation procedure. The linguistic terms listed in Table 11 were used to do this. The same table shows the TFNs that were used to quantify these linguistic phrases. TFNs, which offer a range of values to better capture the subjective assessments of experts, are frequently used to manage uncertainty and imprecision in decision-making processes.

Table 11 - Linguistic terms for the criteria and sub-criteria

Linguistic terms	TFNs
Very important (VI)	(0.75, 0.90, 1.00)
Important (I)	(0.60, 0.75, 0.90)
Medium (M)	(0.30, 0.45, 0.60)
Unimportant (U)	(0.15, 0.30, 0.45)
Very unimportant (VU)	(0.00, 0.15, 0.30)

As shown in Tables 12 and 13, the experts first used linguistic terms to represent the priority levels of the criterion and the sub-criteria. The experts' qualitative inputs are compiled in these tables which also represent their opinions on the relative importance of each criterion and sub-criterion.

Table 12 - Linguistic terms and TFNs for the criteria

Criteria	Linguistic terms			TFNs for the criteria		
	E-1	E-2	E-3	E-1	E-2	E-3
C1	I	M	I	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
C2	M	I	I	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)
C3	I	VI	I	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
C4	I	I	M	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)
C5	M	I	M	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)
C6	VI	I	VI	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)
C7	I	M	I	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
C8	M	I	VI	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)
C9	VI	VI	I	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
C10	I	VI	I	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
C11	I	M	VI	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)	(0.75, 0.90, 1.00)

Table 13 - Linguistic terms and TFNs for the sub-criteria

Sub-criteria	Linguistic terms			TFNs for the sub-criteria		
	E-1	E-2	E-3	Expert 1	Expert 2	Expert 3
SC-1	M	U	M	(0.30, 0.45, 0.60)	(0.15, 0.30, 0.45)	(0.30, 0.45, 0.60)
SC-2	I	M	VI	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)	(0.75, 0.90, 1.00)
SC-3	I	M	I	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
SC-4	I	I	VI	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)
SC-5	I	VI	I	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
SC-6	M	VI	M	(0.30, 0.45, 0.60)	(0.75, 0.90, 1.00)	(0.30, 0.45, 0.60)
SC-7	M	I	I	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)
SC-8	I	I	M	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)
SC-9	VI	VI	I	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
SC-10	I	VI	M	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)	(0.30, 0.45, 0.60)
SC-11	U	VU	U	(0.15, 0.30, 0.45)	(0.00, 0.15, 0.30)	(0.15, 0.30, 0.45)
SC-12	M	M	I	(0.30, 0.45, 0.60)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
SC-13	I	M	M	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)	(0.30, 0.45, 0.60)
SC-14	VI	VI	I	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
SC-15	M	U	U	(0.30, 0.45, 0.60)	(0.15, 0.30, 0.45)	(0.15, 0.30, 0.45)
SC-16	M	U	M	(0.30, 0.45, 0.60)	(0.15, 0.30, 0.45)	(0.30, 0.45, 0.60)
SC-17	I	VI	I	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
SC-18	VI	I	VI	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)
SC-19	VI	I	VI	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)
SC-20	VI	I	VI	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)
SC-21	I	M	I	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
SC-22	I	VI	VI	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)
SC-23	VI	VI	VI	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)
SC-24	VI	VI	VI	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)
SC-25	I	VI	I	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
SC-26	M	I	M	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)
SC-27	VI	VI	I	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
SC-28	I	I	I	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)
SC-29	VI	I	VI	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)
SC-30	M	M	I	(0.30, 0.45, 0.60)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
SC-31	I	I	M	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)
SC-32	U	I	M	(0.15, 0.30, 0.45)	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)
SC-33	VI	VI	I	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)
SC-34	U	M	VU	(0.15, 0.30, 0.45)	(0.30, 0.45, 0.60)	(0.00, 0.15, 0.30)
SC-35	VI	M	VU	(0.75, 0.90, 1.00)	(0.30, 0.45, 0.60)	(0.00, 0.15, 0.30)
SC-36	I	M	I	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
SC-37	I	VI	VI	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)

Sub-criteria	E-1	E-2	E-3	Expert 1	Expert 2	Expert 3
SC-38	VI	M	I	(0.75, 0.90, 1.00)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
SC-39	VI	VI	VI	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)	(0.75, 0.90, 1.00)
SC-40	VI	I	VI	(0.75, 0.90, 1.00)	(0.60, 0.75, 0.90)	(0.75, 0.90, 1.00)
SC-41	I	I	I	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)
SC-42	I	I	M	(0.60, 0.75, 0.90)	(0.60, 0.75, 0.90)	(0.30, 0.45, 0.60)
SC-43	VI	M	I	(0.75, 0.90, 1.00)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)
SC-44	VI	M	I	(0.75, 0.90, 1.00)	(0.30, 0.45, 0.60)	(0.60, 0.75, 0.90)

Further, the ratings of the combined criteria and sub-criteria (CCS) based on the triangular fuzzy numbers and the aggregated decision using Eq. (12) are shown in Table 14. This table provides a thorough assessment of the options in accordance with the predetermined criteria and sub-criteria by synthesizing the data acquired in the previous steps.

Table 14 - Aggregated decision matrix of the experts

CCS	Expert 1	Expert 2	Expert 3	Aggre. decision
CCS 1	(0.30, 0.68, 0.90)	(0.15, 0.46, 0.90)	(0.30, 0.73, 1.00)	(0.15, 0.61, 1.00)
CCS 2	(0.30, 0.55, 0.90)	(0.60, 0.80, 1.00)	(0.30, 0.61, 0.90)	(0.30, 0.64, 1.00)
CCS 3	(0.15, 0.58, 1.00)	(0.00, 0.58,1.00)	(0.15, 0.56, 0.90)	(0.00, 0.57, 1.00)
CCS 4	(0.30, 0.63, 1.00)	(0.15, 0.49, 1.00)	(0.15, 0.46, 0.90)	(0.15, 0.52, 1.00)
CCS 5	(0.30, 0.76, 1.00)	(0.60, 0.78, 1.00)	(0.30, 0.76, 1.00)	(0.30, 0.77, 1.00)
CCS 6	(0.60, 0.84, 1.00)	(0.30, 0.76, 1.00)	(0.60, 0.87, 1.00)	(0.30, 0.82, 1.00)
CCS 7	(0.30, 0.70, 1.00)	(0.30, 0.73, 1.00)	(0.30, 0.68, 0.90)	(0.30, 0.70, 1.00)
CCS 8	(0.15, 0.53, 1.00)	(0.30, 0.68, 0.90)	(0.30, 0.66, 1.00)	(0.15, 0.62, 1.00)
CCS 9	(0.15, 0.70, 1.00)	(0.30, 0.59, 1.00)	(0.00, 0.39, 0.90)	(0.00, 0.54, 1.00)
CCS 10	(0.60, 0.84, 1.00)	(0.30, 0.76, 1.00)	(0.60, 0.84, 1.00)	(0.30, 0.81, 1.00)
CCS 11	(0.60, 0.81, 1.00)	(0.30, 0.55, 0.90)	(0.30, 0.70, 1.00)	(0.30, 0.68, 1.00)

The fuzzy TOPSIS methodology's Step 4 equations are used to calculate the normalized values of the created decision matrix. Table 15 presents the normalized results. The language terms used to rate the alternatives are also shown in Table 16.

Table 15 - Normalized aggregated score of the experts

Criteria	Normalized score		
C1	0.15	0.61	1.00
C2	0.30	0.64	1.00

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Criteria	Normalized score		
C3	0.00	0.57	1.00
C4	0.15	0.52	1.00
C5	0.30	0.77	1.00
C6	0.30	0.82	1.00
C7	0.30	0.70	1.00
C8	0.15	0.62	1.00
C9	0.00	0.00	0.00
C10	0.30	0.81	1.00
C11	0.30	0.68	1.00

Table 16 – Ranking of the alternatives in linguistic terms

Linguistic terms	TFNs
Extremely high (EH)	[0.80, 0.90, 1.00]
Very high (VH)	[0.70, 0.80, 0.90]
High (H)	[0.60, 0.70, 0.80]
Medium high (MH)	[0.50, 0.60, 0.70]
Medium (M)	[0.40, 0.50, 0.60]
Medium low (ML)	[0.30, 0.40, 0.50]
Low (L)	[0.20, 0.30, 0.40]
Very low (VL)	[0.10, 0.20, 0.30]
Extremely low (EL)	[0.00, 0.10, 0.20]

Table 17 summarizes the evaluations given to the three wheelchairs by the experts based on the language terms included in Table 16. To account for the subjectivity and inherent ambiguity of the assessments, these ratings are then converted into triangular fuzzy numbers. Table 17 provides the options' comprehensive fuzzy representations, allowing for additional investigation.

The fuzzy aggregated decision matrix based on the collective views of the experts is displayed in Table 18. Tables 19 and 20 display the normalized version and the related weighted normalized fuzzy aggregated decision matrix, respectively. The calculations used adhere to the same methodology described in Eq. (12) which is used for the aggregation of the criterion and the sub-criteria.

For each aggregated criterion and sub-criterion, the ratings of each alternative were then calculated in relation to the fuzzy positive ideal solution (I^+) and the fuzzy negative ideal solution (I^-). The proximity of each alternative to the ideal and non-ideal solutions is measured by these computations. Tables 21 and 22 provide an evaluation of the outcomes of these calculations.

Table 17 - Rating and TFNs of the alternatives

Criteria	Types	Linguistic terms			TFNs for the alternatives		
		E-1	E-2	E-3	E-1	E-2	E-3
C1	MW	L	ML	VL	[0.20, 0.30, 0.40]	[0.30, 0.40, 0.50]	[0.10, 0.20, 0.30]
	EW	M	MH	ML	[0.40, 0.50, 0.60]	[0.50, 0.60, 0.70]	[0.30, 0.40, 0.50]
	APW	H	VH	MH	[0.60, 0.70, 0.80]	[0.70, 0.80, 0.90]	[0.50, 0.60, 0.70]
C2	MW	ML	L	M	[0.30, 0.40, 0.50]	[0.20, 0.30, 0.40]	[0.40, 0.50, 0.60]
	EW	M	MH	H	[0.40, 0.50, 0.60]	[0.50, 0.60, 0.70]	[0.60, 0.70, 0.80]
	APW	H	EH	VH	[0.60, 0.70, 0.80]	[0.80, 0.90, 1.00]	[0.70, 0.80, 0.90]
C3	MW	L	ML	VL	[0.20, 0.30, 0.40]	[0.30, 0.40, 0.50]	[0.10, 0.20, 0.30]
	EW	M	MH	MH	[0.40, 0.50, 0.60]	[0.50, 0.60, 0.70]	[0.50, 0.60, 0.70]
	APW	EH	VH	EH	[0.80, 0.90, 1.00]	[0.70, 0.80, 0.90]	[0.80, 0.90, 1.00]
C4	MW	EL	EL	EL	[0.00, 0.10, 0.20]	[0.00, 0.10, 0.20]	[0.00, 0.10, 0.20]
	EW	ML	M	M	[0.30, 0.40, 0.50]	[0.40, 0.50, 0.60]	[0.40, 0.50, 0.60]
	APW	VH	EH	VH	[0.70, 0.80, 0.90]	[0.80, 0.90, 1.00]	[0.70, 0.80, 0.90]
C5	MW	EL	VL	EL	[0.00, 0.10, 0.20]	[0.10, 0.20, 0.30]	[0.00, 0.10, 0.20]
	EW	M	MH	M	[0.40, 0.50, 0.60]	[0.50, 0.60, 0.70]	[0.40, 0.50, 0.60]
	APW	H	EH	VH	[0.60, 0.70, 0.80]	[0.80, 0.90, 1.00]	[0.70, 0.80, 0.90]
C6	MW	VL	EL	VL	[0.10, 0.20, 0.30]	[0.00, 0.10, 0.20]	[0.10, 0.20, 0.30]
	EW	H	H	VH	[0.60, 0.70, 0.80]	[0.60, 0.70, 0.80]	[0.70, 0.80, 0.90]
	APW	H	VH	EH	[0.60, 0.70, 0.80]	[0.70, 0.80, 0.90]	[0.80, 0.90, 1.00]
C7	MW	EL	EL	EL	[0.00, 0.10, 0.20]	[0.00, 0.10, 0.20]	[0.00, 0.10, 0.20]
	EW	M	M	ML	[0.40, 0.50, 0.60]	[0.40, 0.50, 0.60]	[0.30, 0.40, 0.50]
	APW	VH	H	H	[0.70, 0.80, 0.90]	[0.60, 0.70, 0.80]	[0.60, 0.70, 0.80]
C8	MW	MH	M	MH	[0.50, 0.60, 0.70]	[0.40, 0.50, 0.60]	[0.50, 0.60, 0.70]
	EW	MH	MH	H	[0.50, 0.60, 0.70]	[0.50, 0.60, 0.70]	[0.60, 0.70, 0.80]
	APW	MH	H	VH	[0.50, 0.60, 0.70]	[0.60, 0.70, 0.80]	[0.70, 0.80, 0.90]
C9	MW	EL	VL	L	[0.00, 0.10, 0.20]	[0.10, 0.20, 0.30]	[0.20, 0.30, 0.40]
	EW	H	MH	MH	[0.60, 0.70, 0.80]	[0.50, 0.60, 0.70]	[0.50, 0.60, 0.70]
	APW	EH	VH	EH	[0.80, 0.90, 1.00]	[0.70, 0.80, 0.90]	[0.80, 0.90, 1.00]
C10	MW	L	VL	VL	[0.20, 0.30, 0.40]	[0.10, 0.20, 0.30]	[0.10, 0.20, 0.30]
	EW	H	MH	MH	[0.60, 0.70, 0.80]	[0.50, 0.60, 0.70]	[0.50, 0.60, 0.70]
	APW	EH	EH	VH	[0.80, 0.90, 1.00]	[0.80, 0.90, 1.00]	[0.70, 0.80, 0.90]
C11	MW	VL	L	VL	[0.10, 0.20, 0.30]	[0.20, 0.30, 0.40]	[0.10, 0.20, 0.30]
	EW	M	M	ML	[0.40, 0.50, 0.60]	[0.40, 0.50, 0.60]	[0.30, 0.40, 0.50]
	APW	MH	H	MH	[0.50, 0.60, 0.70]	[0.60, 0.70, 0.80]	[0.50, 0.60, 0.70]

Table 18 - Experts' fuzzy aggregated assessment matrix for each choice

Criteria	MW	EW	APW
AC1	[0.10, 0.29, 0.50]	[0.30, 0.49, 0.70]	[0.50, 0.69, 0.90]
AC2	[0.20, 0.39, 0.60]	[0.40, 0.59, 0.80]	[0.60, 0.80, 1.00]
AC3	[0.10, 0.29, 0.50]	[0.40, 0.56, 0.70]	[0.70, 0.86, 1.00]
AC4	[0.00, 0.10, 0.20]	[0.30, 0.46, 0.60]	[0.70, 0.83, 1.00]
AC5	[0.00, 0.13, 0.30]	[0.40, 0.53, 0.70]	[0.60, 0.78, 1.00]
AC6	[0.00, 0.16, 0.30]	[0.60, 0.73, 0.90]	[0.60, 0.80, 1.00]
AC7	[0.00, 0.10, 0.20]	[0.30, 0.46, 0.60]	[0.60, 0.73, 0.90]
AC8	[0.40, 0.56, 0.70]	[0.50, 0.63, 0.80]	[0.50, 0.69, 0.90]
AC9	[0.00, 0.18, 0.40]	[0.50, 0.63, 0.80]	[0.70, 0.86, 1.00]
AC10	[0.10, 0.23, 0.40]	[0.50, 0.66, 0.80]	[0.70, 0.86, 1.00]
AC11	[0.10, 0.23, 0.40]	[0.30, 0.46, 0.60]	[0.50, 0.63, 0.80]

Table 19 - Experts' normalized fuzzy aggregated assessment matrix for each choice

Criteria	MW	EW	APW
AC1	[0.10, 0.29, 0.50]	[0.30, 0.49, 0.70]	[0.50, 0.69, 0.90]
AC2	[0.20, 0.39, 0.60]	[0.40, 0.59, 0.80]	[0.60, 0.80, 1.00]
AC3	[0.10, 0.29, 0.50]	[0.40, 0.56, 0.70]	[0.70, 0.86, 1.00]
AC4	[0.00, 0.10, 0.20]	[0.30, 0.46, 0.60]	[0.70, 0.83, 1.00]
AC5	[0.00, 0.13, 0.30]	[0.40, 0.53, 0.70]	[0.60, 0.78, 1.00]
AC6	[0.00, 0.16, 0.30]	[0.60, 0.73, 0.90]	[0.60, 0.80, 1.00]
AC7	[0.00, 0.10, 0.20]	[0.30, 0.46, 0.60]	[0.60, 0.73, 0.90]
AC8	[0.40, 0.56, 0.70]	[0.50, 0.63, 0.80]	[0.50, 0.69, 0.90]
AC9	[0.00, 0.00, 0.00]	[0.00, 0.00, 0.00]	[0.00, 0.00, 0.00]
AC10	[0.10, 0.23, 0.40]	[0.50, 0.66, 0.80]	[0.70, 0.86, 1.00]
AC11	[0.10, 0.23, 0.40]	[0.30, 0.46, 0.60]	[0.50, 0.63, 0.80]

Table 20 - Experts' weighted normalized fuzzy aggregated assessment matrix for each choice

Criteria	MW	EW	APW
AC1	[0.015, 0.177, 0.500]	[0.045, 0.299, 0.700]	[0.075, 0.421, 0.900]
AC2	[0.060, 0.249, 0.600]	[0.120, 0.377, 0.800]	[0.180, 0.512, 1.000]
AC3	[0.000, 0.165, 0.500]	[0.000, 0.319, 0.700]	[0.000, 0.490, 1.000]
AC4	[0.000, 0.052, 0.200]	[0.045, 0.239, 0.600]	[0.105, 0.432, 1.000]
AC5	[0.000, 0.100, 0.300]	[0.120, 0.408, 0.700]	[0.180, 0.600, 1.000]
AC6	[0.000, 0.131, 0.300]	[0.180, 0.598, 0.900]	[0.018, 0.656, 1.000]

Criteria	MW	EW	APW
AC7	[0.000, 0.070, 0.200]	[0.090, 0.322, 0.060]	[0.180, 0.511, 0.900]
AC8	[0.060, 0.347, 0.700]	[0.075, 0.390, 0.800]	[0.075, 0.428, 0.900]
AC9	[0.000, 0.000, 0.000]	[0.000, 0.000, 0.000]	[0.000, 0.000, 0.000]
AC10	[0.030, 0.186, 0.400]	[0.150, 0.535, 0.800]	[0.210, 0.696, 1.000]
AC11	[0.030, 0.156, 0.400]	[0.090, 0.313, 0.600]	[0.150, 0.428, 0.800]

Table 21 – Rating the distances between every choice and the fuzzy positive ideal solution I^+

Criteria	MW	EW	APW
AC1	0.795	0.706	0.633
AC2	0.732	0.633	0.551
AC3	0.806	0.720	0.648
AC4	0.920	0.742	0.612
AC5	0.876	0.636	0.527
AC6	0.865	0.530	0.601
AC7	0.914	0.851	0.554
AC8	0.683	0.650	0.631
AC9	1.000	1.000	1.000
AC10	0.809	0.571	0.489
AC11	0.819	0.698	0.603
SI^+	9.219	7.737	6.847

Table 22 - Rating the distances between each choice and the fuzzy negative ideal solution I^-

Criteria	MW	EW	APW
AC1	0.306	0.440	0.575
AC2	0.377	0.515	0.657
AC3	0.304	0.444	0.643
AC4	0.119	0.374	0.632
AC5	0.183	0.473	0.681
AC6	0.189	0.632	0.691
AC7	0.122	0.196	0.606
AC8	0.452	0.516	0.577
AC9	0.000	0.000	0.000
AC10	0.255	0.562	0.714
AC11	0.248	0.394	0.531
SI^-	2.556	4.547	6.307

Table 23 - Each wheelchair ranking, separation metrics, and relative closeness coefficient

Alternatives	SI^+	SI^-	Ci*	Rank
MW	9.219	2.556	0.217	3rd
EW	7.737	4.547	0.370	2nd
APW	6.847	6.307	0.479	1st

The three options were ordered in descending order of the relative proximity coefficients (Ci*), which were computed in order to rate the different options. According to the fuzzy TOPSIS analysis results in Table 30, APW > EW > MW is the ranking. As a result, APW was determined to be the wheelchair option that was the most preferred.

Sensitivity analysis

A sensitivity analysis that looked at how different factors affected the ranking of the wheelchairs is presented in this section. Three different circumstances were examined in the analysis, each concentrating on a different set of criteria. A thorough summary of these situations is given in Table 24 which also highlights the variables assessed in each scenario. In order to rank the alternatives, the analysis additionally analyzes the results of the intuitionistic fuzzy TOPSIS and fuzzy TOPSIS methodologies; the results are shown in Table 24.

Table 24 - Sensitivity analysis results for multiple circumstances

Circumstance	Decision criteria	Experts	Wheelchair ranking	
			Intuitionistic fuzzy TOPSIS	Triangular fuzzy TOPSIS
Current circumstance	C-1, C-2, C-3, C-4, C-5, C-6, C-7, C-8, C-9, C-10, C-11	E1, E2, E3	APW > EW > MW	APW > EW > MW
Circumstance 1	C-1, C-2, C-3, C-4, C-5 (User-centric factors)	E1, E2, E3	APW > EW > MW	APW > EW > MW
Circumstance 2	C-6, C-7, C-8 (Performance & durability)	E1, E2, E3	APW > EW > MW	APW > EW > MW
Circumstance 3	C-9, C-10, C-11 (Cost, safety & technology)	E1, E2, E3	APW > EW > MW	APW > EW > MW

Figures 2 and 3 provide a visual representation of the sensitivity analysis findings. These numbers show how well the two approaches perform in comparison under various conditions. In contrast to the conventional fuzzy TOPSIS approach, the intuitionistic fuzzy TOPSIS method exhibits an equivalent sensitivity to scenario modifications, as illustrated. The intuitionistic fuzzy TOPSIS method's increased sensitivity is especially useful in situations where criteria are very subjective and need intricate assessments. The intuitionistic fuzzy TOPSIS approach gives decision-makers a more thorough and reliable way to distinguish between options when criteria are qualitative in nature, including user-centric factors, performance & durability, and cost, safety & technology for nuanced decision making. This feature promotes more educated wheelchair selection decisions and improves the dependability of the rating process. Overall, the findings highlight how crucial it is to use cutting-edge techniques like intuitionistic fuzzy TOPSIS when dealing with situations involving subjective criteria since they provide more accuracy and flexibility in supplier evaluation for the selection of sustainable wheelchairs.

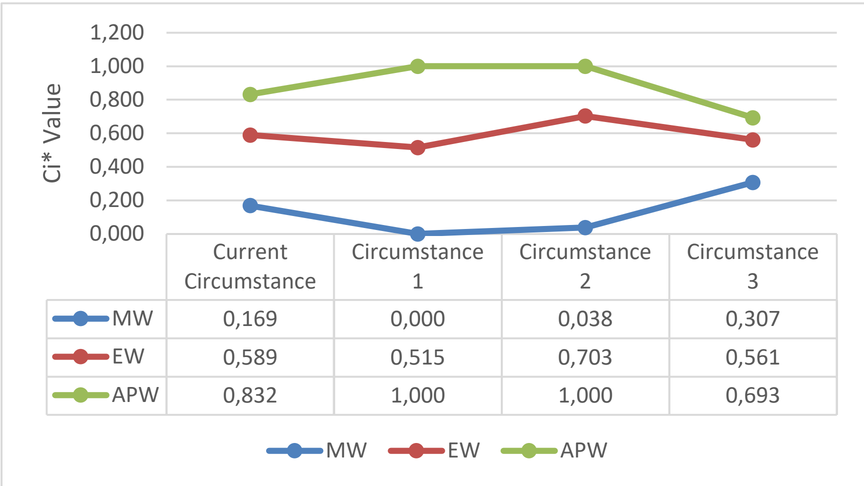
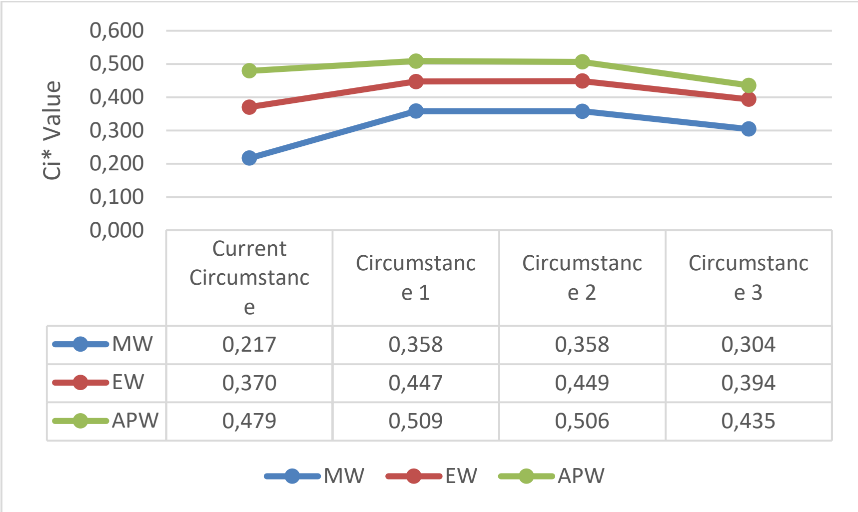


Figure 2 - Intuitionistic fuzzy TOPSIS approach sensitivity analysis results



	Current Circumstance	Circumstance 1	Circumstance 2	Circumstance 3
MW	0,217	0,358	0,358	0,304
EW	0,370	0,447	0,449	0,394
APW	0,479	0,509	0,506	0,435

Figure 3 - Triangular fuzzy TOPSIS approach sensitivity analysis results

Discussion

Research findings

The MCDM method based on intuitionistic fuzzy TOPSIS is introduced in this study, adding to the body of knowledge on wheelchair selection. The approach successfully tackles the subjectivity and ambiguity of wheelchair evaluation. A thorough sensitivity analysis was conducted, contrasting the results of intuitionistic fuzzy TOPSIS with those of conventional fuzzy TOPSIS, in order to verify its robustness.

The sensitivity analysis for wheelchair selection was performed across three distinct circumstances to evaluate how varying decision criteria influence the rankings generated by the intuitionistic fuzzy TOPSIS and triangular fuzzy TOPSIS methods. The "Current circumstance" considered all decision criteria (C-1 to C-11) and expert opinions (E1, E2, E3), with both methods yielding the same ranking: APW > EW > MW. In "Circumstance 1," which focused on user-centric factors (C-1 to C-5), the rankings remained unchanged across both methods, highlighting the consistency of the alternatives under user-specific priorities. Similarly, "Circumstance 2," emphasizing performance and durability (C-6 to C-8), and "Circumstance 3," addressing cost, safety, and technology (C-9 to C-11), also produced identical rankings across both methods: APW > EW > MW. This consistency across all circumstances indicates that both methods are robust under varying criteria; however, intuitionistic fuzzy TOPSIS is better equipped to detect subtle variations and differences in certain subjective scenarios, as it incorporates a higher degree of sensitivity and adaptability. This capability makes intuitionistic fuzzy TOPSIS particularly advantageous when dealing with highly subjective and nuanced decision-making contexts.

The selected wheelchair alternatives differ significantly in functionality, making their ranking relatively intuitive, even for non-experts. However, this example serves as an illustration to demonstrate the applicability of intuitionistic fuzzy TOPSIS and to highlight the importance of various criteria in the selection process. The true value of this approach lies in its ability to handle complex decision-making scenarios where differences are less obvious. Intuitionistic fuzzy TOPSIS enhances sensitivity and adaptability, making it particularly useful for nuanced and highly subjective decision-making contexts.

Research implications

This method is unique in that it uses intuitionistic fuzzy numbers in conjunction with the TOPSIS method to solve imprecise decision making. With an emphasis on wheelchair selection, it assesses the aspects related to cost, safety, and technology, as well as user-centric factors including performance and durability. The study helps stakeholders grasp the fundamentals of a thorough wheelchair assessment for improved decision making by rating and choosing the best choices based on these criteria.

Real-world applications and managerial perspectives

The application of Intuitionistic Fuzzy TOPSIS and Triangular Fuzzy TOPSIS in wheelchair selection provides significant managerial insights by emphasizing the effectiveness of APW over EW and MW. Both methods address uncertainties and subjective judgments in evaluating user-centric factors, performance & durability, and cost, safety & technology dimensions. The consistent superiority of APW highlights its ability to prioritize criteria effectively, leading to accurate and user-aligned decisions. While APW may suggest options with higher initial costs, these selections typically offer better durability, safety, and user satisfaction, reducing long-term expenses. These approaches empower managers to make holistic, data-driven, and sustainable decisions, balancing economic, functional, and technological priorities.

Conclusion and future work

Adopting sustainable and user-centric techniques is essential when choosing wheelchairs in order to satisfy a variety of needs while taking durability and long-term cost effectiveness into consideration. The intricacy and subjectivity of decision making make it difficult to choose the best wheelchair model based on predetermined criteria. Using an intuitionistic fuzzy TOPSIS approach, this paper proposes a useful decision-making framework to investigate the wheelchair choosing process. The most pertinent criteria and sub-criteria across the user-centric factors, performance & durability, and cost, safety & technology aspects were found by a thorough literature research. The collective views of experts led to the finalization of these criteria. The suggested approach takes subjective assessments and uncertainties into consideration when ranking and choosing the best wheelchair model. A comparison with the fuzzy TOPSIS method under three distinct scenarios was carried out to verify the robustness of the strategy and show the model's sensitivity and dependability.

Although practitioners in other contexts would need to reinterpret the criteria and ratings based on expert judgments to meet their particular needs, the system can be modified for new fields. Because of its adaptability, the framework can be used in a variety of industries while still being accurate and relevant. This study's absence of interdependencies between the criterion and the sub-criteria, which could affect results, is a limitation. In order to account for these interdependencies and further improve the selection process, future research could address this by including approaches like the Analytic Hierarchy Process.

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Un enfoque de toma de decisiones de múltiples criterios para la selección de sillas de ruedas utilizando topsis difuso intuicionista

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CAMPO: ciencias de la decisión, ingeniería mecánica
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: Seleccionar una silla de ruedas adecuada es vital para garantizar la movilidad, la comodidad y la independencia de las personas con discapacidad. El objetivo principal es ayudar a identificar la silla de ruedas óptima considerando diversos criterios centrados en el usuario y minimizando las ambigüedades en la toma de decisiones.
Métodos: El marco propuesto aprovecha conjuntos difusos intuicionistas para abordar la indecisión y la imprecisión que suelen presentarse en la toma de decisiones. La ponderación de los criterios y las evaluaciones de alternativas se determinaron con la participación de expertos. Se realizó un análisis de sensibilidad para garantizar la robustez y fiabilidad del proceso de clasificación. Se realizó un estudio de caso para validar la eficacia de la metodología e ilustrar su aplicación práctica.
Resultados: El estudio demostró que las sillas de ruedas impulsadas por IA (APW) superaron a otras opciones de sillas de ruedas según los criterios y subcriterios seleccionados.
Conclusión: Los hallazgos resaltan la utilidad del enfoque intuicionista difuso TOPSIS para facilitar la toma de decisiones bien informadas en la selección de sillas de ruedas. Este método beneficia a usuarios finales, cuidadores y profesionales médicos al abordar las complejidades de la toma de decisiones subjetiva e incierta, lo que en última instancia conduce a resultados más inclusivos y confiables. El marco demuestra ser una herramienta eficaz para mejorar el proceso de toma de decisiones en la selección de sillas de ruedas.

Palabras claves: selección de silla de ruedas, difuso intuicionista, difuso triangular, TOPSIS, análisis de sensibilidad.

Многокритериальный подход к принятию решений при выборе инвалидной коляски с использованием интуиционистского нечеткого topsis метода

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РУБРИКА ГРНТИ: 73.47.12 Организация управления и автоматизированные системы управления транспортом,
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Выбор подходящей инвалидной коляски имеет жизненно важное значение для обеспечения мобильности, комфорта и независимости людей с ограниченными возможностями. Основная цель статьи – помочь в выборе наиболее подходящей инвалидной коляски, принимая во внимание ряд критериев, ориентированных на пользователя, и сводя к минимуму неопределенность при принятии решений.

Методы: В предлагаемой структуре используется интуиционистские нечеткие множества, объясняющие неопределенность и неточность часто присутствующих в процессе принятия решений. Веса критериев и оценки альтернатив были утверждены экспертами. Для обеспечения надежности и устойчивости процесса ранжирования применялся анализ чувствительности. Для подтверждения эффективности методологии и иллюстрации ее практического применения было проведено тематическое исследование.

Результаты: Исследование показало, что инвалидные коляски с искусственным интеллектом (APW) превосходят другие варианты инвалидных колясок по выбранным критериям и подкритериям.

Вывод: Результаты показывают, что подход интуиционистских нечетких множеств TOPSIS облегчает процесс принятия решений при выборе инвалидной коляски, основанный на обширной информации. Этот метод приносит пользу конечным пользователям, лицам, осуществляющим уход, и медицинским работникам, поскольку устраняет сложности субъективного и неопределенного процесса принятия решений, что в конечном итоге приводит к более надежным и всеобъемлющим результатам. Доказано, что данная система является эффективным инструментом для оптимизации процесса принятия решений при выборе инвалидной коляски.

Ключевые слова: выбор инвалидной коляски, интуиционистское нечеткое множество, треугольная нечеткое множество, TOPSIS, анализ чувствительности.

Вишекритеријумски приступ одлучивању при избору инвалидских колица помоћу интуитивне фази TOPSIS методе

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ОБЛАСТ: операциона истраживања, механика
КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Избор одговарајућих инвалидских колица од суштинске је важности за обезбеђивање мобилности, удобности и независности особа са инвалидитетом. Примарни циљ рада је да помогне да тај избор буденајпогоднији узимајући у обзир низ критеријума који се односе на корисника и да се притом неизвесност при одлучивању сведе на што мању меру.
Методе: Предложени оквир примењује интуитивне фази скупове да би објаснио неодлучност и непрецизност честе при одлучивању. Тежине критеријума и процене алтернатива одређене су уз помоћ експерата. Примењена је анализа осетљивости како би се обезбедила робустност и поузданост процеса рангирања. Урађена је студија случаја која потврђује ефикасност методологије и илуструје њену практичну примену.
Резултати: Студија је показала да су се инвалидска колица на погон помоћу вештачке интелигенције показала бољим од осталих опција на основу изабраних критеријума и поткритеријума.
Закључак: Налази показују да је интуитивни фази TOPSIS приступ користан при одлучивању на основу обиља информација при избору инвалидских колица. Крајњи корисници, неговатељи и медицински радници имају користи од ове методе која се бави сложеношћу субјективног и неизвесног одлучивања, што у крајњој линији води ка инклузивнијим и поузданијим резултатима. Овај оквир се показао као ефикасно средство за побољшање процеса одлучивања при избору инвалидских колица.

Кључне речи: избор инвалидских колица, интуитивни фази, троугласти фази, TOPSIS, анализа осетљивости

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