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RESEARCH ARTICLE

Farm Tractor Selection Aligned with Universal Design Principles: A Fuzzy Vikor Approach

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ABSTRACT

Universal Design (UD) promotes the development of goods and atmospheres that are usable by individuals of all ages and abilities, ensuring inclusivity without the demand for appropriated assistance, eliminating the need for assistance during usage. While UD is guided by a set of principles, it remains challenging to assess or visualize whether a product, system, environment, building, or transportation method exemplifies these principles effectively. As a multi-criterion decision-making (MCDM) method, fuzzy VIKOR is well-suited to solve problems within a fuzzy atmosphere, where uncertainty and ambiguity often cloud the decision-making process. This method effectively maximizes group utility and facilitates the identification of a mediatory solution, thus contributing to the resolution of complex decision-making challenges. To address this challenge, the current study proposes the use of the fuzzy VIKOR method for evaluating UD. There is a clear opportunity to develop research that combines UD principles with tractor selection criteria, considering factors like ease of use, accessibility, and adaptability for a broad-ranging of users, bearing those with differing physical abilities. Specifically, the tractor selection process is analyzed using fuzzy VIKOR, with the criteria reflecting key principles of UD. An empirical study was conducted to illustrate the practicality and efficiency of the proposed model in resolving these challenges.

Keywords: Universal design, fuzzy VIKOR, defuzzification, multi-criteria decision making

1. Introduction

The concepts of UD is applied across various areas, counting building, outlook design, and produce development, and has garnered significant recognition from facility managers who acknowledge its advantages in enhancing workplace accessibility (Chou, 2012). UD is a plan thought that researches to generate goods and lands that are reachable to the generous possible scope of people to the detriment of their age, ability, or disability, without requiring special modifications or adaptations (Story, Mueller & Mace, 1998). The goal is to ensure usability for all individuals, fostering inclusivity and enhancing functionality in everyday environments and products. This approach extends beyond simple accessibility to embrace universal usability, aiming for environments that everyone can navigate and engage with comfortably. Often referred to as "real life design" or "lifespan design," among other terms, UD extends beyond earlier design concepts such as accessible, barrier-free, and adaptable designs. The core intention of UD is to eliminate the need for "special features" or spaces designed exclusively for individuals with specific needs, which often carry a stigma, appear different, and are frequently more expensive (Wolford, 2000).

UD enlarges the advantages of effective useful model to a wide range of individuals who may not be categorized as owning a weakness, yet who regularly face physiological challenges in their everyday living (Giuliani, 2001). These challenges can be faced by individuals of varying characteristics, including short or tall people, those who are large or frail, pregnant women, left-side dominant individuals, and children, among others. Moreover, UD takes into account those who carry packages, parents with children in strollers, individuals who are ill or fatigued, and those who may experience orientation difficulties.

In essence, UD benefits everyone by helping individuals navigate and overcome obstacles that are routinely encountered in everyday life. For example, a tractor designed with adjustable seating, intuitive controls, and low step heights ensures that farmers of varying physical abilities can operate the machinery with ease. This thoughtful design not only facilitates easier access for individuals with mobility challenges but also makes the tractor more accessible to a broader range of users, demonstrating the inclusive nature of UD in agricultural equipment. MCDM mentions making priority determination (e.g., estimation, prioritization, and election) over the existing options (Yücenur & Demirel, 2012).

Decision-making often requires considering a variety of perspectives from different individuals, as many organizational decisions are made collectively. In multi-expert decision-making (MEDM) scenarios, experts' judgments are frequently expressed in qualitative terms, making it difficult to quantify their assessments with precise numerical values. As a result, linguistic assessments, utilizing semantic variants in place of scalar ones, present a more practical and effective alternative (Ansari & Kannan, 2010). In many situations, the available data is often imprecise, vague, or uncertain, making traditional modeling techniques insufficient or inaccurate. Moreover, decision-making processes in such scenarios are typically based on uncertain and ill-defined information. Fuzzy set theory is widely recognized as one of the most effective methods for addressing issues related to vagueness and uncertainty. Introduced to mathematically represent data that contain non-statistical uncertainties, fuzzy sets provide formalized tools for handling imprecision that are inherent in many real-world problems. To model these types of situations, fuzzy set theory was applied to represent the linguistic terms used in decision-making processes (Liau & Kao, 2011). A linguistic variable is defined by its values, which are typically expressed as words in natural language. To effectively use this variable, the set of linguistic terms associated with it and their meanings must be clearly defined for the experts applying them. The process of constructing a linguistic term set (S) involves selecting basic linguistic terms (such as "high" or "low") as the foundation, and then applying linguistic hedges (like "very," "rather," or "more or less") as modifiers or unary operations to refine these terms (Ansari & Kannan, 2010).

The VIKOR method was developed as a multi-criterion decision-making (MCDM) technique specifically designed to address discrete problems involving noncommensurable and conflicting criteria (Yücenur & Demirel, 2012). Its primary focus is on ranking and selecting the most appropriate alternative from a set of options, providing compromise solutions to conflicts between criteria, thereby supporting decision-makers in reaching a final choice. A compromise solution is defined as the most feasible option that is closest to the ideal solution, drawing from the principles of compromise programming. Building on this, the fuzzy VIKOR method extends the original approach to handle fuzzy, multi-criteria problems with similar challenges of noncommensurable and conflicting criteria, offering a robust framework for decision-making in uncertain environments (Opricovic, 2012).

In this research, the fuzzy VIKOR method is applied to tackle the challenge of selecting the most appropriate tractor for cultivated areas from a range of alternatives. The paper is structured as follows: Sections 2 and 3 provide an overview of the theoretical foundation and relevant literature, respectively. Section 4 describes the proposed methodology in detail, while Section 5 showcases an empirical study to validate the practicality and effectiveness of the approach. Lastly, Section 6 concludes with the key findings and implications of the study.

2. Universal design and applications

UD a concept introduced by architect Ron Mace in 1985, emphasizes creating products and environments that are usable by all individuals, regardless of their abilities or needs. It aims to eliminate the need for specialized adaptations by designing for the widest possible audience, including those with disabilities, children, and older adults. This inclusive approach views abilities on a spectrum, ensuring access for everyone, from the most capable to those with the greatest limitations (Story, Mueller & Mace, 1998; Story, 2006).

UD focuses on creating spaces and products usable by all individuals, reducing the need for specialized adaptations (Hoyt, 1993). This concept of UD encompasses both a vision and a tangible effort to plan and implement buildings, environments, and products in such a way that they can, to the greatest extent possible, be used by everyone, including children, older adults, individuals of varying sizes and abilities, as well as both disabled and non-disabled persons (Aslaksen & Bergh, 1997).

UD is defined as a global movement focused on designing products, environments, and communications to meet the diverse spectrum of human needs. Rather than being a style, UD represents an orientation to design based on two fundamental premises (Al-Tal, 2002):

1. Disability is not an exceptional condition affecting only a few; it is a common experience that most of us will encounter at some point in our lives.
2. If a design is effective for people with disabilities, it is likely to be even more beneficial for everyone.

Central to UD are the principles of equal status, equal treatment, and equal merit, which advocate that all individuals should have the same opportunities to engage in various aspects of life, such as education, work, and leisure. These ideals are embedded in both the philosophy and practical application of UD, which asserts that all items, structures, and surroundings should be designed to be usable by as many people as possible, under equal conditions (Aslaksen & Bergh, 1997).

The seven UD principles, developed by Connell et al. in the mid-1990s, go beyond providing a simple definition; they specifically identify the characteristics of UD, as well as universally designed objects and spaces. These principles, which are detailed in Table 1 (Chou, 2012), serve to guide designers in three primary ways: 1) facilitating the evolution of designs by evaluating how universally usable existing features and products are; 2) enabling the creation of new designs that are more universally accessible; and 3) raising awareness among both creators and users (Wolford, 2000).

Unluckily, UD as a notion has not just reached significant attention in the literature related to tractor selection. While UD principles have been extensively applied to architecture, product design, and transportation, their integration into agricultural machinery selection, such as tractors, remains underexplored. In the literature, Tokar (2003) pointed out essential policy for museums being eligible and the changes to increase satisfaction of visitors of all ages and with disabilities. Connolly (2006) carried out a study in order to ensure compliance students who are not native English speakers and from different cultures in UK with the curriculum. She applied UD approach for learning. UD used in the space of education considering the goal of accessible building structures to all individuals. Fuente (2006) carried out a study which lets in the principles of UD in the improvement of children-resistant pharmaceutical boxes. Drug boxes tested on a group which includes disabled, child and elderly people and tried to get the proper design of UD. Kadir and Jamaludin (2012) pointed out applicability of the principles of UD and Malaysian standards in public buildings. It shows designers and architects as a guide. Afacan and Demirkan (2011) developed a plug-in that will help designers to computer-based UD. Odeck et al. (2010) referred to UD in public transportation, benefits and costs of UD applications, the evaluation of cost and benefit. They concluded that the considering UD principles in the problem of selection of public transportation would be useful. Fearnley et al. (2011) assessed the public transportation in terms of UD. Passengers evaluated the public transportation with questionnaire. The study has been useful to improve and increase the quality of public transport. Toy properties needs to be expanded in order to access all children with and without disabilities. To enhance the implementation of the principles of UD toy design features enhance the usability of toys for all the kids. Hajare (2006) intended to set the psychometric attributes of UD for toys. Kadiret al. (2012) evaluated the perspectives of managers in regards to accessibility and UD implementation. Interviews were conducted with managers of three state building in Putrajaya. The results revealed that there is a need for improvement of UD among managers.

3. VIKOR method and applications

The VIKOR method, introduced by Opricovic and later refined with Tzeng, addresses discrete MCDM problems involving contradictory and incomparable criteria. By ranking alternatives, it identifies a compromise solution nearest to the optimal, balancing conflicting criteria and providing a systematic framework for resolving complex decisions (Yücenur & Demirel, 2012).

The reconciliation ranking in multi-criteria decision-making is calculated using the PLp-metric, which serves as an aggregation function within the reconciliation programming method. The advancement of the VIKOR technique arose with Eq. 1, utilizing the Lp distance in the following form (Sayadi & Heydari, 2009):

$$L_j^p = \left\{\sum_{i=1}^{n}\left[w_i(|f_i^* - f_{ij}|)/(|f_i^* - f_i^-|)\right]^p\right\}^{\frac{1}{p}} \quad 1 \le p \le \infty, \; j=1,2,\ldots j \qquad (1)$$

$L_{1,i}$ and $L_{\infty,i}$ are employed to construct the ordering dimension. The answer derived from $L_{1,i}$ represents the option with maximum group utility (the "majority" rule), while the answer derived from minimizing $L_{\infty,i}$ corresponds to the option with the least individual regret of the "opponent" (Yücenur & Demirel, 2012).

The fuzzy VIKOR method is particularly effective for ranking and selecting alternatives in a fuzzy environment, enabling decision-makers to address uncertainty and imprecision during the evaluation process (Opricovic, 2011). In the fuzzy VIKOR framework, linguistic preferences expressed by the experts can be easily converted into fuzzy numbers, making it adaptable for situations where qualitative judgments are required (Kaya & Kahraman, 2011). Thus, the fuzzy VIKOR method enables more flexible and realistic decision-making by accommodating the inherent uncertainty present in many real-world problems. The fuzzy VIKOR method has been devised to address fuzzy multi-criteria decision-making problems, focusing on identifying a balanced resolution among competing criteria. The balanced resolution is computed using Equation 2, which incorporates the aggregation of decision-maker assessments under fuzzy conditions (Opricovic, 2011).

Table 1. List of universal design principles (Story, Müeller and Mace, 1998)

Principles	Details
Principle 1. Equitable use	The design is useful and marketable to people with diverse abilities
Guidelines	1a Provide the same means of use for all users: identical whenever possible; equivalent when not
	1b Avoid segregating or stigmatizing any users
	1c Provisions for privacy, security, and safety should be equally available to all users
	1d Make the design appealing to all users
Principle 2. Flexibility in	The design accommodates a wide range of individual preferences and abilities

use	
Guidelines	2a Provide choice in methods of use
	2b Accommodate right- or left-handed access and use
	2c Facilitate the user’s accuracy and precision
	2d Provide adaptability to the user’s pace
Principle 3. Simple and intuitive use	Use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level
Guidelines	3a Eliminate unnecessary complexity
	3b Be consistent with user expectations and intuition
	3c Accommodate a wide range of literacy and language skills
	3d Arrange information consistent with its importance
	3e Provide effective prompting and feedback during and after task completion
Principle 4. Perceptible information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities
Guidelines	4a Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information
	4b Provide adequate contrast between essential information and its surroundings
	4c Maximize ‘‘legibility’’ of essential information
	4d Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions)
	4e Provide compatibility with a variety of techniques or devices used by people with sensory limitations
Principle 5. Tolerance for error	The design minimizes hazards and the adverse consequences of accidental or unintended actions
Guidelines	5a Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded
	5b Provide warnings of hazards and errors
	5c Provide fail-safe features
	5d Discourage unconscious action in tasks that require vigilance
Principle 6. Low physical effort	The design can be used efficiently and comfortably and with a minimum of fatigue
Guidelines	6a Allow user to maintain a neutral body position
	6b Use reasonable operating forces
	6c Minimize repetitive actions
	6d Minimize sustained physical effort
Principle 7. Size and space for approach and use	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user’s body size, posture, or mobility
Guidelines	7a Provide a clear line of sight to important elements for any seated or standing user
	7b Make reach to all components comfortable for any seated or standing user
	7c Accommodate variations in hand and grip size
	7d Provide adequate space for the use of assistive devices or personal assistance

$$mco_j\{(\widetilde{f_{ij}}(A_j), j = 1, \dots j), i = 1, \dots n\} \tag{2}$$

where j represents the number of possible options; mco refers to the operator of a multi-criteria decision-making process used to select the finest option (Opricovic, 2011).

The usage of the VIKOR method has significantly increased in recent years. In their pioneering study, Opricovic et al. (2005) first applied the method to solve the problem of selecting the most suitable fuel for public transportation, considering emerging fuel technologies. Subsequently, Opricovic and Tzeng (2007) enhanced the method by introducing a dynamic weighting system, where the criteria weights change at fixed intervals, and compared the results of five different scoring systems, thus improving the method's reliability. Shemshadi et al. (2011) utilized the fuzzy VIKOR method for supplier selection, collecting decision-makers' opinions expressed as linguistic terms and subsequently converting them into trapezoidal fuzzy numbers. The entropy approach was utilized to determine the weights of the criteria. Similarly, Buyukozkan et al. (2008) successfully used fuzzy VIKOR to rank five different ERP software, collecting data through a survey based on selected criteria. Opricovic and Tzeng (2004) exerted a contrasting investigation of VIKOR and TOPSIS, highlighting differences in normalization methods, aggregation functions, and solutions owned by them. Later, Opricovic (2012) extended this comparison by evaluating VIKOR alongside three other MCDM methods—TOPSIS, PROMETHEE, and ELECTRE—and examined the results produced by each approach. Additionally, James et al. (2010) introduced a hybrid model integrating VIKOR with ANP and DEMATEL for selecting airline partners. Kuo and Liang (2011) applied fuzzy VIKOR to assess service quality, emphasizing its effectiveness in addressing multiple requirements under fuzzy conditions. Their work also proposed a novel MCDM technique by combining fuzzy VIKOR with GRA to overcome limitations in service monitoring and enhancement. Ertugrul and Karakasoglu (2008) utilized the VIKOR method to rank the performance of 18 bank branches, addressing a critical issue in the banking sector. Kaya and Kahraman (2011) applied both fuzzy VIKOR and AHP methods to select urban forest locations, emphasizing cost efficiency and the management of limited site options. Hasan and Jaber (2024), present a framework combining the Fuzzy Best-Worst Method with VIKOR to prioritize road maintenance, emphasizing its utility in handling complex decision-making environments.

4. Outline of the proposed approach

The framework for the proposed approach is illustrated in Figure 1, with a systematic process comprising several steps.

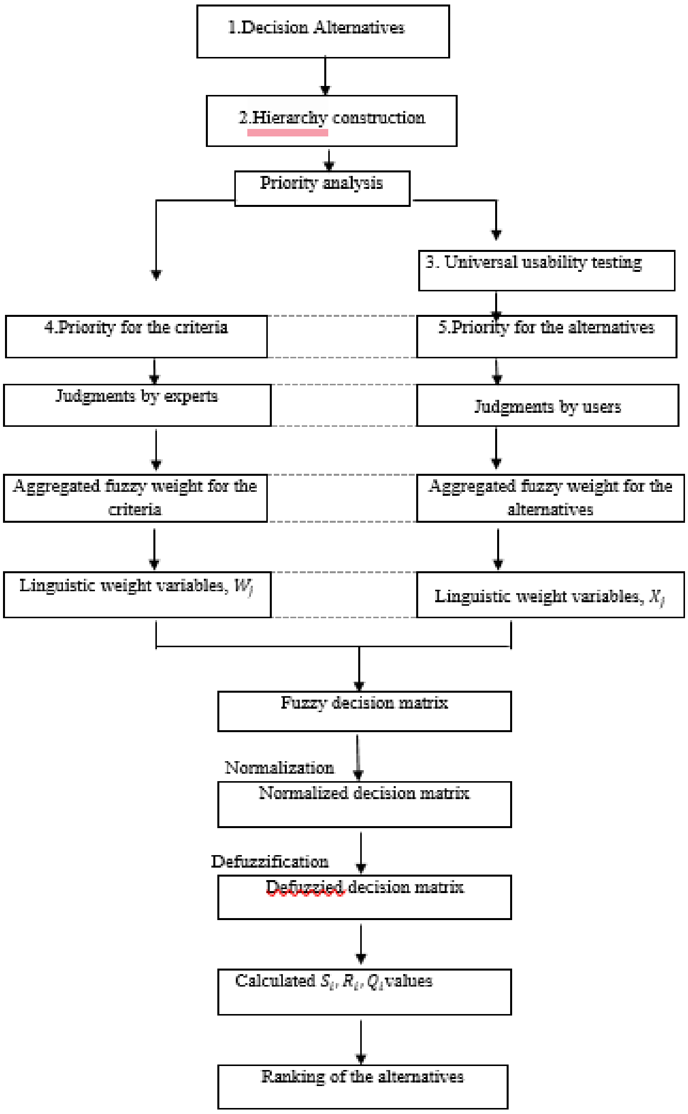

Figure 1. The framework of the proposed approach.

Step 1: In the initial step, relevant alternatives and criteria are identified, and the variables *n*, *m*, and *k* are defined to represent the number of evaluators, options, and assessment criteria, respectively.

Step 2: A simple hierarchy, constructed based on the UD principles, is presented in Figure 2. The primary goal is to assess the selected product alternatives based on their compliance with the principles of UD which are placed at Level 1 of the hierarchy. In the second level, seven criteria are outlined based on the UD principles, while the third level consists of the five product alternatives under evaluation.

Step 3: Usability testing is integral to evaluating a man-made product's ability to fulfill its deliberate function. This process is crucial as it provides direct insights into how actual users engage with the product (Chou, 2012). The primary aim of universal usability testing is to evaluate how effectively test participants interact with product alternatives based on the criteria established by the seven UD principles. Participants are divided into user groups, and their evaluations help determine preference variables for each alternative. Upon completion of the usability testing, participants are asked to fill out a post-test questionnaire to provide feedback on the products. The responses are analyzed using a 7-point Likert scale, ranging from 'strongly disagree' to 'strongly agree,' facilitating a comprehensive assessment of each product's performance relative to the UD principles.

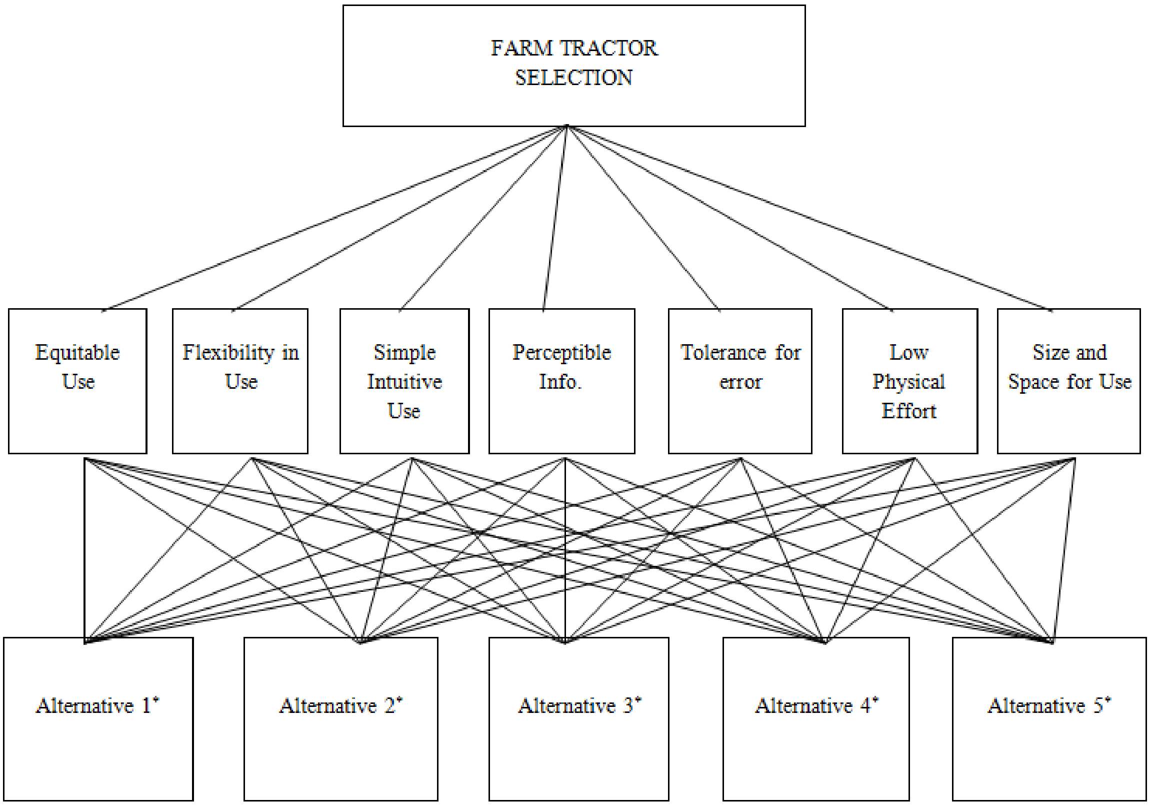

Figure 2. Hierarchical structure of the farm tractor selection.

* The tractor brands being evaluated have been concealed to avoid generating public opinion about them

Step 4: Linguistic variables are used to assign importance to each criterion and rank the alternatives, with these variables being linked to fuzzy numbers for further analysis. These fuzzy numbers are used to quantify the evaluators' inputs, including lingual locution. The fuzzy values associated with each criterion and alternative are provided in Tables 2 and 3, where the linguistic terms are linked to their corresponding fuzzy numbers. Trapezoidal fuzzy numbers are commonly used to represent the uncertainty in decision-making, where the values are defined by four parameters, $\{(n_1,n_2,n_3,n_4) \mid n_1,n_2,n_3,n_4 \; \mathcal{E} \; R;\ n_1 \leq n_2 \leq n_3 \leq n_4 \}$. These values correspond to the lowest, more likely to occur, and fullest potential outcomes. The membership function for trapezoidal fuzzy numbers is formulated using Eq. (3) and depicted in Figure 3 (Girubha & Vinodh, 2012). Trapezoidal fuzzy numbers are a generalization of triangular fuzzy numbers, with the latter being a special case of the former (Shemshadi et al., 2011).

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-n_1}{n_2-n_1}, & x \in [n_1, n_2] \\ 1, & x \in [n_2, n_3] \\ \frac{n_4-x}{n_4-n_3}, & x \in [n_3, n_4] \\ 0, & otherwise. \end{cases} \tag{3}$$

Table 2. Linguistic terms and corresponding fuzzy numbers for each criterion

Linguistic Variable	Fuzzy Number
Very Poor (VP)	(0.0, 0.0, 0.1, 0.2)
Poor (P)	(0.1, 0.2, 0.2, 0.3)
Medium Poor (MP)	(0.2, 0.3, 0.4, 0.5)
Fair (F)	(0.4, 0.5, 0.5, 0.6)
Medium Good (MG)	(0.5, 0.6, 0.7, 0.8)
Good (G)	(0.7, 0.8, 0.8, 0.9)
Very Good (VG)	(0.8, 0.9, 1.0, 1.0)

Table 3. Linguistic terms and corresponding fuzzy numbers for each alternative

Linguistic Variable	Fuzzy Number
Very Low (VL)	(0.0, 0.0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.2, 0.3)
Fairly Low (FL)	(0.2, 0.3, 0.4, 0.5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)
Fairly High (FH)	(0.5, 0.6, 0.7, 0.8)
High (H)	(0.7, 0.8, 0.8, 0.9)
Very High (VH)	(0.8, 0.9, 1.0, 1.0)

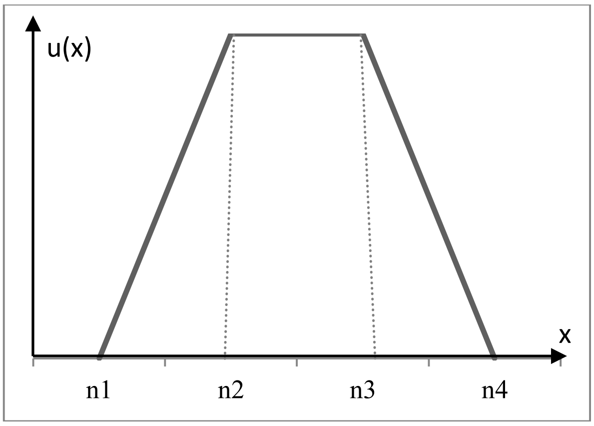

Figure 3. Trapezoidal fuzzy number

Step 5: The views and inputs from the evaluators are combined, and the overall importance for each criterion is calculated using Equation 4. In this context, ***k*** represents the group of evaluators involved in the assessment process. By incorporating their individual judgments, the method ensures a collective and comprehensive assessment, which reflects the diversity of perspectives brought by each participant. This aggregated weight serves as a foundation for subsequent analysis and decision-making steps, ultimately guiding the selection process based on the group's consensus. (Girubha & Vinodh, 2012).

$$W_j = \{W_{j1} ; W_{j2}; W_{j3} W_{j4}\} \tag{4}$$

where $W_{j1} = min \{W_{jk1}\}$; $W_{j2} = 1/k \sum W_{jk2}$; $W_{j3} = 1/k \sum W_{jk3}$; $W_{j4} = max \{W_{jk4}\}$.

The fuzzy ratings X_{ij} for each alternative in relation to the criteria are computed using Eq.5.

$$X_{ij} = \{X_{ij1}; X_{ij2}; X_{ij3}; X_{ij4}\} \tag{5}$$

where $X_{ij1} = min \{X_{ijk1}\}$; $X_{ij2} = 1/k \sum X_{ijk2}$; $X_{ij3} = 1/k \sum X_{ijk3}$; and $X_{ij4} = max \{X_{ijk4}\}$.

Step 6: Fuzzy decision matrix is generated as following Eq.6-7.

$$\widetilde{D} = \begin{bmatrix} \tilde{X}_{11} & \cdots & \tilde{X}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{X}_{m1} & \cdots & \tilde{X}_{mk} \end{bmatrix} i = 1,2,\ldots,m;\ j = 1,2,\ldots,k \tag{6}$$

$$\widetilde{W}_j = [\widetilde{W}_1, \widetilde{W}_2, \ldots, \widetilde{W}_k],\quad j = 1,2\ldots,k \tag{7}$$

Step 7: Normalization is a critical process to ensure that non-commensurable criteria, which may have different units or dimensions, are converted into a common scale for comparison. This conversion removes the dtableimensional differences across criteria and allows for a more straightforward evaluation. To achieve this, normalization is typically employed, with linear normalization being the most commonly used method within the VIKOR approach (Girubha & Vinodh, 2012). This technique ensures that the various criteria are dimensionless, allowing them to be compared on a uniform scale, as demonstrated in Eq. 8-11. By employing such a method, the decision-making process becomes more consistent and accurate, helping to eliminate potential distortions caused by disparate units or magnitudes. The cost criterion (C) is normalized by dividing it by its lowest value, while the benefit criterion (B) is normalized by dividing it by its highest value. This process ensures that both criteria are adjusted within a comparable scale (Shemshadi et al., 2011).

$$u_{ij} = \left(\frac{x_{ij1}}{x_{ij4}^{|}}, \frac{x_{ij2}}{x_{ij4}^{|}}, \frac{x_{ij3}}{x_{ij4}^{|}}, \frac{x_{ij4}}{x_{ij4}^{|}}\right), C_j \in B \tag{8}$$

$$u_{ij} = \left(\frac{x_{ij1}}{x_{ij1}^{-}}, \frac{x_{ij2}}{x_{ij1}^{-}}, \frac{x_{ij3}}{x_{ij1}^{-}}, \frac{x_{ij4}}{x_{ij1}^{-}}\right), C_j \in C \tag{9}$$

$$x_{ij4}^{|} = max_i\{kararmatrisi\}, C_j \in B \tag{10}$$

$$x_{ij1}^{-} = min_i\{kararmatrisi\}, C_j \in C \tag{11}$$

Step 8: The fuzzy weights of the criteria and the significance of each criterion, along with alternative ratings, are converted into crisp values through defuzzification using Eq. 12. This process enables the transformation of fuzzy values into precise, actionable numbers (Shemshadi et al., 2011).

$$Defuzz(X_{ij}) = \frac{\int \mu(x).xdx}{\int \mu(x)dx}$$

$$= \frac{\int_{x_{ij1}}^{x_{ij2}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}}\right).xdx + \int_{x_{ij2}}^{x_{ij3}} xdx + \int_{x_{ij3}}^{x_{ij4}} \left(\frac{x_{ij4} - x}{x_{ij4} - x_{ij3}}\right).xdx}{\int_{x_{ij1}}^{x_{ij2}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}}\right) dx + \int_{x_{ij2}}^{x_{ij3}} dx + \int_{x_{ij3}}^{x_{ij4}} \left(\frac{x - x_{ij1}}{x_{ij2} - x_{ij1}}\right) dx}$$

$$= \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \frac{1}{3}(x_{ij4} - x_{ij3})^2 - \frac{1}{3}(x_{ij2} - x_{ij1})^2}{-x_{ij1} - x_{ij2} + x_{ij3} + x_{ij4}} \tag{12}$$

Step 9: The finest value f_i^* and the poorest value f_i^- of crisp values are determined by Eq. 13.

$$f_i^* = max_j\, x_{ij},\ \ f_i^- = min_j\, x_{ij} \tag{13}$$

Step 10: S_i, R_i and Q_i are calculated by Eq. 14-16, respectively.

$$S_i = \sum_{j=1}^{n} w_j (f_i^* - f_{ij}) / (f_i^* - f_i^-) \tag{14}$$

$$R_i = max_i\, [w_j\, (f_i^* - f_{ij}) / (f_i^* - f_{ij}^-)] \tag{15}$$

$$Q_i = v\ (S_i - S^*)\ /\ S^{-}S^{*} + (1-v)\ (R_i - R^*)/R^{-}R^{*} \tag{16}$$

where, S_i values refer to group utility. Maximum S_i denotes maximum group utility. R_i values refer to regret of dissident. Minimum R_i denotes minimum regret. Q_i represents the VIKOR value of the ith alternative, where i ranges from 1 to m. The parameter v is assigned as a weight for the strategy focused on the "majority of criteria" (or "maximum group utility"), while $1-v$ serves as the weight for individual regret. The alternative with the lowest VIKOR value is chosen as the most advantageous solution (Chou, 2012; Opricovic & Tzeng, 2004).

Step 11: To identify the finest option, A(1) is proposed as the optimal strategy based on its highest rank according to the Q measure (minimum), provided the following two conditions are met (Girubha & Vinodh, 2012; Opricovic & Tzeng, 2004).

C1. Acceptable advantage

Acceptable advantage of alternatives calculated by Eq. 17.

$$Q(A^{(2)})-Q(A^{(1)})\geq 1/m-1 \tag{17}$$

where $A^{(2)}$ refers to the alternative ranked second according to Q, and m represents the total number of decision-makers involved.

C2. Consistent reliability

The alternative $A^{(1)}$ should be measured the highest according to *S* or/and *R*. The stability can be achieved through various strategies, such as maximizing collective benefit (when $v > 0.5$), shared opinion (when $c \approx 0.5$), or implementing rejection (when $v < 0.5$).

The solution pools that balance the alternatives is outlined as follows:

1. $A^{(1)}$ and $A^{(2)}$ will be selected if condition *C2* is the only one that is not fulfilled (or)

2. $A^{(1)}$, $A^{(2)}$,…, $A^{(m)}$ will be selected if condition *C1* is not satisfied. $A^{(m)}$; $Q(A^{(m)}) – Q(A^{(1)}) < 1/m-1$ is calculated for the highest M.

4. Empirical study

The following part provides a practical analysis aimed at illustrating the application of the proposed approach. The main purpose of this research is to evaluate and select the most suitable alternatives based on the UD perspective. The study involved 5 experts and 10 users who participated in the UD analysis. Each expert possessed a minimum of five years of expertise in their specialized fields. The group of users consisted of 10 individuals, including 3 able-bodied and 7 physically disabled users. The users were aged between 18 and 68 years, with an equal gender distribution (5 females and 5 males). The criteria for the problem were assessed by the expert group, with the weighted values of the criteria determined based on their collective knowledge and experience. The qualitative variables and their associated fuzzy set values for each criterion are outlined in Tables 4 and 5, respectively.

Table 4. Importance weight of criteria assessed by decision makers (linguistic variable)

	D1	**D2**	**D3**	**D4**	**D5**
C1(Equitable use)	VG	G	G	VG	VG
C2(Flexibility use)	G	MG	G	G	MG
C3(Simple use)	MG	MG	MG	G	MG
C4(Perceptible info.)	MG	G	F	MG	MG
C5(Tolerance for err.)	G	MG	MG	G	VG
C6(Low effort)	VG	MG	G	G	VG
C7(Size and space)	G	MG	G	MG	G

Table 5. Importance weight of criteria assessed by decision makers (fuzzy set)

	D1	**D2**	**D3**	**D4**	**D5**
C1	(.8,.9,1,1)	(.7,.8,.8,.9)	(.7,.8,.8,.9)	(.8,.9,1,1)	(.8,.9,1,1)
C2	(.7,.8,.8,.9)	(.5,.6,.7,.8)	(.7,.8,.8,.9)	(.7,.8,.8,.9)	(.5,.6,.7,.8)
C3	(.5,.6,.7,.8)	(.5,.6,.7,.8)	(.5,.6,.7,.8)	(.7,.8,.8,.9)	(.5,.6,.7,.8)
C4	(.5,.6,.7,.8)	(.7,.8,.8,.9)	(.4,.5,.5,.6)	(.5,.6,.7,.8)	(.5,.6,.7,.8)
C5	(.7,.8,.8,.9)	(.5,.6,.7,.8)	(.5,.6,.7,.8)	(.7,.8,.8,.9)	(.8,.9,1,1)
C6	(.8,.9,1,1)	(.5,.6,.7,.8)	(.7,.8,.8,.9)	(.7,.8,.8,.9)	(.8,.9,1,1)
C7	(.7,.8,.8,.9)	(.5,.6,.7,.8)	(.7,.8,.8,.9)	(.5,.6,.7,.8)	(.7,.8,.8,.9)

Usability tests were conducted where participants were asked to perform predefined tasks using each of the selected vehicles. An overall survey was administered to the user group, and the results from this survey were analyzed to assess the comparative significance of each alternative. The combined framework for criterion importance and material evaluations was derived using Eq. (4) to Eq. (7) and is displayed in Table 6 which significantly contributed to constructing the decision matrix for the criteria.

Table 6. Aggregated fuzzy values of alternative ratings and criterion weights.

	C1	C2	C3	C4	C5	C6	C7
W	(.7,.86,.92,1)	(.5,.72,.76,.9)	(.5,.64,.72,.9)	(.4,.62,.68,.9)	(.5,.74,.8,1)	(.5,.8,.86,1)	(.5,.72,.76,.9)
A1	(.2,.69,.73,1)	(.4,.63,.67,.9)	(.4,.65,.68,.9)	(.2,.66,.73,1)	(.2,.6,.67,.9)	(.1,.66,.67,.9)	(.2,.67,.72,1)
A2	(.1,.59,.62,.9)	(.2,.53,.59,.9)	(.1,.48,.55,.9)	(.2,.58,.6,1)	(.1,.54,.55,.9)	(.1,.46,.48,.9)	(.1,.55,.57,.9)
A3	(.1,.55,.6,1)	(.2,.6,.67,1)	(.1,.52,.57,.9)	(0,.48,.52,.9)	(0,.59,.65,1)	(.1,.64,.66,1)	(0,.59,.62,.9)
A4	(.1,.58,.63,1)	(.1,.59,.62,1)	(.2,.54,.61,.9)	(.2,.57,.64,1)	(.2,.53,.56,.9)	(.1,.49,.51,1)	(.1,.57,.64,1)
A5	(.2,.56,.59,.9)	(.2,.52,.57,.9)	(.1,.51,.55,.9)	(.2,.46,.51,1)	(.1,.47,.5,.9)	(.1,.43,.48,.8)	(.1,.43,.48,.8)

In the normalization procedure, the cost criterion (C) was adjusted by dividing it by its lowest value, while the benefit criterion (B) was normalized by dividing it by the highest value in the decision matrix, as outlined in Eq. (8) to Eq. (11) (Shemshadi et al., 2011; Aghaee et al., 2020). The fuzzy importance values assigned to the criteria, along with their importance and material ratings, were defuzzified using Eq. (12) to obtain crisp values which shown in Table 7 (Shemshadi et al., 2011). The optimal (f_i^*) and least favorable (f_i^-) values for the crisp material ratings were identified, as outlined in Eq. (13). Finally, key decision metrics were calculated using Eq. (14) – Eq. (16), with the results presented in Table 8. In this context, both conditions (C1-C2) have been met, which leads to the conclusion that the alternative with the lowest VIKOR index (A1) should be selected as the optimal tractor, as demonstrated in Table 9.

Table 7. Crisp values for weight and ratings

	C1	C2	C3	C4	C5	C6	C7
W	0.865	0.715	0.770	0.642	0.757	0.780	0.715
A1	0.638	0.650	0.727	0.796	0.581	0.556	0.634
A2	0.536	0.649	0.560	0.597	0.515	0.490	0.520
A3	0.701	0.735	0.573	0.467	0.542	0.584	0.503
A4	0.569	0.569	0.621	0.602	0.548	0.533	0.570
A5	0.559	0.548	0.567	0.559	0.495	0.452	0.452

Table 8. Calculation of utility, regret measure and VIKOR index

	A1	A2	A3	A4	A5
S	0.82	3.94	2.21	3.04	4.91
R	0.33	0.86	0.71	0.69	0.74
Q *(v=0.2)*	0	0.95	0.64	0.65	0.82
Q *(v=0.5)*	0	0.88	0.53	0.61	0.89
Q *(v=0.8)*	0	0.81	0.42	0.57	0.95

Table 9. Ranking of the alternatives

	1	2	3	4	5
S	A1	A3	A4	A2	A5
R	A1	A4	A3	A5	A2
Q *(v=0.2)*	A1	A3	A4	A5	A2
Q *(v=0.5)*	A1	A3	A4	A2	A5
Q *(v=0.8)*	A1	A3	A4	A2	A5

5. Conclusions

UD represents a comprehensive approach to creating goods and atmospheres that accommodate the diverse needs of individuals, ensuring usability for individuals across various age groups and skill levels across various contexts. By integrating UD principles, services, products, buildings, environments, and transportation systems can be designed to prioritize safety, accessibility, and ease of use for all individuals without exception. For instance, the development of tractors with adjustable seating and intuitive controls exemplifies the application of UD in agricultural machinery. By allowing farmers of varying physical abilities or sizes to operate the equipment with ease, such designs ensure that farming tasks, such as plowing fields or transporting goods can be performed efficiently and comfortably. This inclusive approach not only empowers individuals with disabilities but also enhances usability for all operators, reflecting the broad benefits of universally designed tools.

Tractors play a crucial role in various farming activities, facilitating productivity and contributing to the social and cultural dimensions of rural life. By providing access to essential resources such as water and enabling efficient food production, these tools support the livelihoods of farming communities. Their significance in modern agriculture cannot be overlooked, as they enhance the ability to sustain both social and economic stability in rural areas. Moreover, ensuring that such equipment is accessible to individuals with disabilities is essential, as it enables them to work independently and participate fully in farming activities. Tasks like plowing fields, transporting goods, or engaging in agricultural markets and community events become manageable without reliance on others, highlighting the transformative impact of well-designed and inclusive machinery in fostering self-sufficiency.

In many real-life scenarios, the presence of uncertainty and ambiguity creates challenges in representing the opinions and preferences of decision-makers through precise numerical values. This complexity is further compounded in situations involving multiple decision-makers, where differing opinions and conflicting preferences often arise. The Fuzzy VIKOR method offers a systematic approach to addressing these issues, providing a robust framework for resolving such conflicts. By incorporating elements of uncertainty into the decision-making process, this method effectively manages ambiguity while facilitating solutions that balance competing interests. Through its focus on maximizing group utility and identifying a mediatory solution, the Fuzzy VIKOR approach ensures equitable outcomes, even in complex, multi-criteria decision-making environments.

This study aimed to evaluate tractors through the lens of UD principles, employing the VIKOR method as a solution framework due to the inherently conflicting nature of the criteria involved. The weighted values assigned to each criterion, which were integral to the decision-making process, were determined based on the knowledge and experience of the decision-makers. These weights could also be derived using other multi-criteria decision-making techniques if necessary, emphasizing the flexibility of the approach. The study incorporated the expertise of decision-makers to construct a hierarchical structure comprising seven main criteria and five alternatives. The aggregated fuzzy ratings of each alternative, relative to each criterion, and the aggregated fuzzy weights of the criteria were calculated to facilitate the analysis. Following the processes of normalization and defuzzification, key decision metrics were determined.

The results of the assessment revealed that the criterion of "equitable use" held the highest weight value at 0.865, whereas "perceptible information" received the lowest weight value at 0.642. To account for varying decision-maker preferences, three proposed solutions were developed for different values of the parameter "v" (0.2, 0.5, and 0.8). Across all scenarios, Alternative 1 consistently emerged as the optimal solution, demonstrating its superior alignment with the principles of UD and decision-making priorities.

For future studies, the outcomes of our study could be confronted with those obtained using other MCDM methods to evaluate the robustness and flexibility of the proposed approach.

Appendix A. Questionnaire for Universal Design Testing for Farm Tractors

(A 7-point Likert scale, ranging from "strongly disagree" to "strongly agree." This questionnaire is adapted from the study of Chou (2012).)

1. This farm tractor is both useful and visually appealing to me. *(Equitable use)*
2. This farm tractor meets my preferences, and I feel confident using it. *(Flexibility in use)*
3. I can operate this farm tractor easily and intuitively. *(Simple and intuitive use)*
4. The information displayed is clearly visible and understandable, regardless of environmental conditions. *(Perceptible information)*
5. This farm tractor allows me to correct errors in real-time when ascending or descending. *(Tolerance for error)*
6. I can use this farm tractor efficiently and comfortably with minimum physical strain. *(Low physical effort)*
7. The seat's size and arrangement are suitable for me, and I can use it in various postures. *(Size and space for approach and use)*

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