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An Integrated MCDM Framework for Optimizing Rotary Actuator Selection in Smart Robotic Power Wheelchair Prototypes

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Abstract

A rotary actuator effectively drives the motion of a power wheelchair, which distinguishes it from manual wheelchairs. For the design and development of a smart robotic power wheelchair (SRPW) prototype, the choice of rotary actuators (RA) is critical. However, the wide range of RA features available commercially make it challenging to choose an appropriate and valuable device for a SRPW prototype. This article employs four multi-criteria decision-making (MCDM) approaches, including (Additive Ratio Assessment) ARAS, (Complex Proportional Assessment) COPRAS, (Evaluation Based on Distance from Solution) EDAS, and (Grey Relation Analysis) GRA, along with the (Criteria Importance through Inter-Criteria Correlation) CRITIC weight assignment technique, to rank 10 alternatives RAs with 7 competing criteria such as cost, weight, voltage, current, power, torque, and speed. Due to the different rankings generated by these methods, Spearman's rank correlation coefficient is used to resolve disagreements and highlight the optimum ranking for the decision matrix. Based on the Copeland voting rule, RA-6 is the most suitable alternative, while RA-10 is found to be the least ideal of the ten alternatives. The rankings have been robustly analyzed with sensitivity analysis on cost parameters and found to be quite helpful in leading future research communities and prototype developers.

Keywords: CRITIC, ARAS, COPRAS, EDAS, GRA, Sensitivity Analysis, Rotary Actuator Selection, Power Wheelchair.

1. Introduction

According to the reports by the World Health Organization, the wheelchair is one of most widely used assistive devices, capable of meeting the needs of 65 million people with disabilities (PWDs) on a daily basis. As the disability population grows worldwide, the demand for assistive devices for PWDs grows each year [1].The market for impaired assistive devices, which was valued at USD 22,439.00 million in 2022, is predicted by Data Bridge Market Research to grow at a compound annual growth rate (CAGR) of 5.9% from 2023 to 2030, reaching USD 37,263.00 million. PWDs are a diverse community, with varying medical needs depending on their limitations and the condition of their impairments. In the world of disabled people, a wheelchair has a special meaning that can make life easier for them and end up making specific everyday tasks feasible. Wheelchair accessibility is more than just a commodity. It is about empowering PWDS to become mobile, fit and active, and fully engage in social activities. A wheelchair can help disabled person gain freedom and social inclusion [2]. There is no single standard model, or even standard size, of wheelchair that can meet the needs of all users, resulting in the demand for a variety of wheelchairs.

The major classification of wheelchairs can be categorized into three types: manual wheelchairs, power wheelchairs, and smart robotic wheelchairs. This classification is based on propulsion methods, mechanisms of control, and the technology used, depending on the needs of individuals with disabilities (PWDs). Manual wheelchairs are simpler, with fewer parts than electric wheelchairs, and thus require less regular maintenance. However, they still necessitate proper upkeep. One significant advantage is the independence from battery systems, as users do not need to charge them. Nevertheless, users must possess a certain level of fitness and stability to propel themselves effectively.

In comparison to manual wheelchairs, power wheelchairs, which use rotary actuators or motors, significantly enhance the quality of life for those with disabilities. Current power wheelchairs in the market typically employ the differential drive motor principle, utilizing two motors to enable forward and backward movement, as well as right and left rotations. While effective, this traditional approach has its limitations and potential for improvement. The advent of smart robotic wheelchairs marks a significant advancement, integrating

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sophisticated technologies and control mechanisms to provide superior mobility solutions. The selection of appropriate rotary actuators is critical in this context, as they directly impact the efficiency and functionality of these advanced wheelchairs.

1.1. Importance of selecting appropriate rotary actuators

Selecting the appropriate rotary actuator for smart robotic power wheelchairs is of paramount importance due to several key reasons:

- Functionality and Performance: The SRPW's performance and functionality are directly impacted by the rotary actuator. The wheelchair's ability to maneuver, avoid obstacles, and give the rider a smooth and comfortable ride depends on the actuator's characteristics, which include torque, speed, and precision.
- User Experience: The total user experience is impacted by the rotary actuator selection. A carefully chosen actuator can provide more fluid movements, precise control, and improved safety features, making the wheelchair user's experience more relaxing and secure.
- Safety: Power wheelchairs need to be extremely safe. The proper rotary actuator ought to offer accurate and dependable control, avoiding abrupt jerks or unexpected movements that can endanger the user's safety. Selecting the right actuator can help with stability, collision avoidance, and overall safety mechanisms.
- Cost-Effectiveness: While picking the ideal rotary actuator is crucial, it is also critical to strike a balance between usefulness and affordability.

Rotary actuators or motors are very important parts for the construction of a smart robotic wheelchair prototype (SRWP) that actuates the wheelchair for the desired mobility of disabled individuals. Permanent magnet direct current (PMDC) motors and brushless direct current (BLDC) motors with or without gear system are the most often utilized rotary actuators or motors for SRWP design.

The selection of factors on rotary actuator (RA) or motors that affect the design and development of smart robotic wheelchair prototype (SRWP) is very vital in order to continue the study. First, based on RA product specifications available on online websites, frequently asked questions from customers on an online page, literature data on motors, and mathematical model on the power requirement of SRPW, seven most critical characteristics that impact RA selection has been identified. These are the most important factors that a SRWP designer considers when choosing an RA, according to a discussion with a panel of SRWP designers. Because there are so many RA models on the industry, it is hard to test all of them. Based on product reviews and ratings on online purchasing websites such as www.amazon.in, www.robu.in, www.flyrobo.in and www.electronicscomp.com, it has been concluded that all these 10 designs are now in high popular. It is interesting to note that these products have received overwhelmingly positive consumer feedback and ratings, indicating that people prefer them to others for design prototyping.

The ARAS, COPRAS, EDAS, and GRA approaches, as well as their integration with the CRITIC method, are used in this research to assess the top RAs on the market. The main purpose of this research is to select the best RA model from among these ten alternatives using seven criteria or parameters. The CRITIC method is used to determine the parameter's weight, which are then incorporated with ranking tools as the above mentioned methods to select the best design, eliminating the role of human factors on indicator weighting. All ARAS, COPRAS, EDAS, and GRA are covered in the methodology section, and their ranks are evaluated. A spearman rank correlation and sensitivity investigation are used to confirm the model's robustness, leading to a full alternative assessment of RA's model. SRWP designers will benefit from this research because they will have a good handle of the finest RA models available and will be able to legitimately select optimal one.

2. Literature Review

Different assessment techniques exist when a person or group wants to assess multiple competing parameters in decision-making in everyday situations or in a design approach for prototypes. Inside the MCDM framework, this evaluation approach is a sub-division of operational research. The research community has successfully used MCDM methodologies in product evaluation processes. While Pintelon et al. evaluated a medical equipment prototype using a new hybrid MCDM approach [3], Sahoo and Choudhury, investigated optimal selections of electric wheelchair utilizing COPRAS and EDAS MCDM methods [4]. Senthilkannan and Parameshwaren created a method for rolling mill optimisation using fuzzy MCDM. Using MCDM approaches [5], problems with prototype design are also resolved. While Sahoo and Choudhury evaluate the strategic design criteria for a robotic wheelchair prototype [6], Biswas and Gupta employ a hybrid MCDM method to discover the optimal design for a vertical axis wind turbine [7].

Since its introduction, a wide range of academics and researchers have used the concept of MCDM to recommend sensible and lucrative decisions in a variety of scenarios, including design of quantitative risk assessment system by Jia et al. [8]. Sahoo and Goswami analyze a variety of MCDM applications in their review work [9]. Al-Theeb et al. discuss the use of the mcdm approach to select the best alternative for waste to energy technology [10], while Singh et al. select the optimization on manufacturing processes at Indian industries [11]. Industrial applications frequently use MCDM implementation. Agarwal et al. evaluate for arc welding robot selection using MCDM method [12]where asZhang et al. carried out a comparison of MCDM approach for Hybrid Electric Vehicles [13]. Obeidat et al. used a PSI based MCDM method for selecting a cleaning method to solar panels [14]. The usage of MCDM techniques has increased in popularity in the field of education as educational institutions strive to make educated judgments that take into account a range of criteria. Nafteh et al. applied fuzzy method for selecting a sustainable supplier MCDM techniques [15], whereas Sahu and Jena presented an MCDM-based strategy for damage estimation in structural member [16]. Stevic et al. investigated sustainable supplier selection in healthcare industries with MCDM techniques [17]. MCDM methods are also applied to logistics sectors. Çıkmak et al. uses the Best-Worst Method to assess the difficulties in using drones in the logistics sector [18] while Keles and Pekkaya explore the function of logistic centers in the context of sustainability [19]. Puška and Stojanović use fuzzy SWARA method that are applied to green supplier selection (GSS) in an agri-food industry to minimize the environmental impact for acquisition of raw materials [20].

The section that follows includes examples of successful implementations of several MCDM approaches to the MCDM domain. The five recognized tools, namely CRITIC, ARAS, CORRAS, EDAS, and GRA, have served as potential decision-making instruments in a range of industries from its establishment. Nevertheless, the researchers sought to capture a few of the desirable effects achieved utilizing those five methodologies in Table 1. Nevertheless, in contrast to these implementations, numerous authors have adopted and utilized numerous MCDM methodologies in decision-making.

2.1. Research Gap and Novelty of the presented work

As per the previous research work, the use of the MCDM idea for making successful judgments in design and development of new prototype is exceedingly unusual, but very few research studies have came forward to incorporate the methodologies for the best selection of integral part like rotary actuators or electric motors for design and development problems [34]. The list of research gaps and novelty of this research is described as follows:

- The rotary actuators, which aid in the motion of the SRWP, is an essential component for the creation of a wheelchair in which no scientific investigation was conducted to find the best alternative decision.
- There have been no detailed studies on mathematical modelling of the power need of SRWP, which is one of the key criteria for evaluating RAs among the alternatives available in the market.
- This research assesses the rankings of four distinct integrated techniques to RAs selection such as CRITIC-ARAS, CRITIC-COPRAS, CRITIC-EDAS, and CRITIC-GRA, without relying on human judgement.
- Sensitivity investigation on cost criteria is performed to demonstrate the stability and robustness of the defined procedures, which will assist stakeholders in reducing overall SRWP costs.

2.2. Identification of Criteria for the proposed Study

The central emphasis of MCDM investigation is on a restricted set of potential criteria and alternatives. For this investigation, ten alternate RA and seven conflicting factors are being addressed. Identifying essential criteria is critical prior researchers use MCDM to acquire the best possible RA for implementing on a prototype. A focus group of seven members, including two Professors, two Ph.D. students, and three research associates, who are working on a prototype development of SRWP, was organized to discuss the important criteria that will help in decision making on the purchase of RA that are currently available on the market. The outcome of the discussion resulted in 2 folds. First a mathematical model is developed to calculate the power requirement for SRPW prototype. Secondly, facts and information were gathered from a variety of resources, including websites, literature from various publications, different YouTube channels, bloggers, comments, and focus group discussions. Anand et al. demonstrate the selection of electric motor for E-rickshaw using 7 parameters such volts, current, power, torque, rpm, weight, and cost [35]. So, this study also implements seven parameters to select on the basis of data availability of different RAs available on product specification page on online shopping websites. The seven crucial and contradictory parameters are as follows, as mentioned in detail.

- Cost (Co): This is a non-beneficial characteristic since the authors aim to keep cost as low as feasible to reduce the overall cost of the final product or the final design of the prototype. According to Sahoo and Choudhury (2021), cost was a critical element for prototype creation.
- Weight (W): This is also a non-beneficial attribute because the researchers want to maintain the weight of rotary actuator or motor as low as possible to lower the overall weight of the final product. Kalwar et al. performed an analysis on tracked robot weight optimization based on optimal choice motor drive, with weight as the study's parameter [36].
- Voltage (V): This is a beneficial attribute because the researchers want to maintain the voltage of rotary actuator or motor as high as possible to provide more power for proper traction force transmission to SRWP motion. Hammod et al. carried out a simulation study on DC motors by increasing the voltage of the system to generate more power [37].
- Rated Current (RC):This is a useful feature since the researchers want to keep the rotary actuator's or motor's rated current as high as feasible to give greater torque for proper traction force transmission to the SRWP inclined motion. The current flowing through the coils determines the output torque of a rotary actuator powered by a DC or BLDC motor.
- Power (P): This is a useful feature since the investigators want to maintain the rotary actuator's or motors rated power as large as possible to obtain necessary traction to the SRWP wheels and overcome resistance encountered during travel in a flat area or road grading.
- Torque (T): This is also beneficial criteria because the researchers want to maintain the torque of rotary actuator or motor as high as possible to provide more torque the SRWP system. It might become harder to anticipate the torque (M) necessary than the desired operating wheel speed.
- Rated Speed (RS): This is also beneficial parameter as the authors want to maintain the rated speed of rotary actuator or motor as high as possible to provide adequate speed to SRWP system based on need of PWDs daily uses.

This study represents 10 different RA models with expenditures varying from cheap to high be picked from a variety of manufacturers and have variable qualities that can be obtained on different online stores, as indicated in Table 2.

Table 1. Previous research based on CRITIC, ARAS, COPRAS, EDAS, and GRA MCDM models.

References	Weight Calculation Method	Priority Ranking Method	Observation
Asante et al. [21]	Fuzzy MCDM method	EDAS, MULTIMOORA	Evaluation of hurdles to the use of renewable energy
Jafarzadeh et al. [22]	SWARA	GRA	Evaluation of failure in Solar panel
Bekraoui et al. [23]	AHP	-	Selection of Natural Fiber Composites Material
Pan et al. [24]	CRITIC	-	Analyzing the Operational Characteristics of Three Unusual Crossing points under Strong Traffic
Goswami et al. [25]	CRITIC	ARAS-TOPSIS, ARAS-COPRAS	Assessment of a Robot Selection Problem
Gök-Kısa et al. [26]	ENTROPY	ARAS-TOPSIS	Port selection evaluation
Ren et al. [27]	Fuzzy MCDM method	EDAS	Assessment for micro and small business owners
Nguyen et al. [28]	CRITIC	TOPSIS	Assessment of Banks' financial results under the consequences of Covid-19
Roy et al. [29]	CRITIC	TOPSIS, VIKOR, PROMETHEE-II	Assessment of mHealth Applications
Ozcalici [30]	CRITIC	ARAS	Evaluation of Asset Location
Mohata et al. [31]	CRITIC	COPRAS	Optimal selection of commercially viable alternative fuel passenger vehicle
Sahoo and Choudhury [32]	CRITIC	EDAS and COPRAS	Selection of material for robotic wheelchair chassis
Al-Shalabi et al. [33]	AHP	-	Selecting the Best Material for Hydrogen Storage

Table 2. Selected RA products with their specifications.

Products/Criteria	Co	W	V	RC	P	T	RS
RA-1	5800	1.20	12	6.00	60	3.00	1200
RA-2	2999	1.90	24	11.00	250	10.00	2650
RA-3	4683	2.77	24	14.80	250	15.00	3700
RA-4	3999	2.56	24	19.20	350	11.10	2750
RA-5	4899	4.10	24	27.40	500	19.70	2500
RA-6	5472	5.44	36	21.40	600	18.35	3200
RA-7	4599	2.98	24	19.20	350	11.00	3000
RA-8	11000	4.50	36	15.00	350	10.00	2250
RA-9	10856	3.30	36	14.00	350	9.00	1500
RA-10	17184	15.00	24	14.50	340	12.00	4400

Despite the fact that there are few research papers on the specific criteria, the prototype developer always looks at the specifications displayed on the product information on buying platforms. So, the following section includes material and methods, results and discussion, conclusion, and future work of the current study, fulfilling the purpose of the study that aim to get the following objective:

- To estimate the power requirement of SRWP under different loading condition.
- To calculate the weight of each criterion through CRITIC tool.
- To provide the ranking of 10 RA alternative using ARAS, COPRAS, EDAS, and GRA MCDM methods.
- To perform the sensitivity investigation on the cost criteria to see how the variation of objective parameter choice weight results in different ranking of RAs.

3. Material and Methods

The numerical calculations and instruments are all included in the subsection described. In the next section, the entire selection technique has been thoroughly examined, including SRWP power analysis, which will aid on the search for RAs in the online market. The CRITIC tool is then used to calculate the criterion or parameter weights that will aid in prioritizing different RAs. To determine the rank of RAs, the ARAS, COPRAS, EDAS, and GRA techniques are utilized as shown in figure 1.

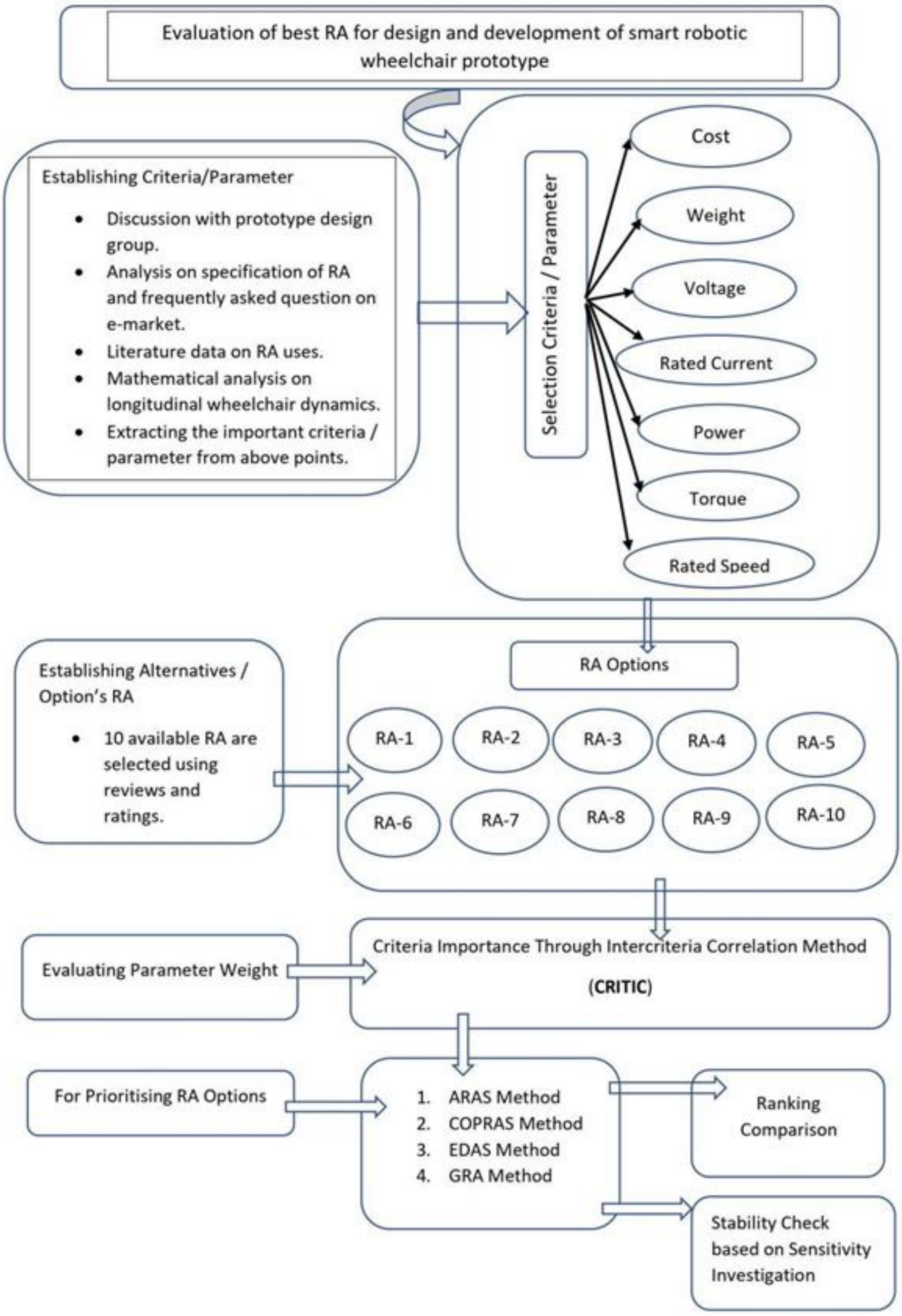

Figure 1. Flowchartoftheentireframeworkof researchpaper.

3.1. Power requirement of SRWP

SRWP is a prototype model that is to be designed for which rotary actuators are selected from various sources, which is going to be an integrated part of SRWP design. So, the power requirement of SRWP model is determined from the prospective of longitudinal dynamics of wheelchair using the following steps.

Step-1: Configuration or specification of SRWP model: SRWP model specification for longitudinal dynamic analysis is a crucial aspect before entering into the investigation RAs selection as shown in table 3.

Step-2: Power equation of SRWP model: SRWP dynamics are at the heart of wheelchair design and development since they influence the vehicle's effectiveness. To construct an SRWP model, wheelchair drive needs and performance specifications must be addressed. The SRWP tractive force must exceed all opposing forces for the SRWP to move, as shown in equation 1 and figure 2. Sun and Zhu described the concept of toal power estimation of vehicles [38]. The aerodynamics resistance owing to air and wheelchair interaction, rolling resistance due to tyre and road interaction, grade resistance due to varying road slopes, and acceleration resistance due to the requirement to accelerate the gross wheelchair mass are examples of typical resistance forces. So, the overall power needed to overcome all the resistance is calculated using equation 2.

Table 3. SRWP configuration.

Parameters under Consideration	Range or Fixed value of Parameter
Curb weight of wheelchair	34 kg -102 kg
Weight of SRWP user	70 kg – 130 kg
SRPW Frontal Area	$0.952m^3$
Air Density	$1.2 kg/m^3$
Drag Coefficient	0.62
Speed of SRWP model	6 kmph – 12 kmph
Acceleration due to gravity	9.8 m/s
Rolling resistance coefficient	0.01
Gradeability	6 degree – 12 degrees

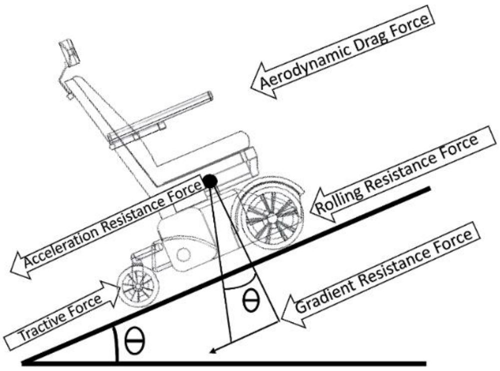

Figure 2. Different Forces acting on SRWP Model.

$$F_t = F_{aero} + F_{rr} + F_{gr} + F_{ar} \quad (1)$$

Where, $F_t, F_{aero}, F_{rr}, F_{gr}, and\ F_{ar}$ represents total tractive force, aerodynamics resistance force, rolling resistance force, grading resistance force, and acceleration resistance force respectively.

$$P_t = P_{aero} + P_{rr} + P_{gr} + P_{ar} \quad (2)$$

Where, $P_t, P_{aero}, P_{rr}, P_{gr},$ and P_{ar}represents total power, aerodynamics resistance power, rolling resistance power, grading resistance power, and acceleration resistance power respectively.

Furthermore, as indicated in equation 3, the air resistance force is dependent on the SRWP's frontal area A_{front}, the wheelchair's velocity or speed (V), the air drag coefficient C_d, and the air density (ρ).

$$F_{aero} = \frac{1}{2} \times \rho \times C_d \times A_{front} \times V^2 \quad (3)$$

Similarly, as indicated in equation 4, the air resistance power is dependent on the SRWP's wheelchair's speed and aerodynamics resistance force(F_{aero}).

$$P_{aero} = F_{aero} \times V \quad (4)$$

As shown in Eq. 5, the rolling resistance force is determined by the gross SRWP's mass, rolling resistance coefficient (μ) and grade angle in which m is the gross wheelchair's mass and g is the acceleration due to gravity.

$$F_{rr} = \mu \times m \times g \times \cos\theta \quad (5)$$

Similarly, as indicated in equation 6, the rolling resistance power is dependent on the SRWP's wheelchair's speed and rolling resistance force(F_{rr}).

$$P_{rr} = F_{rr} \times V \quad (6)$$

Eq. 7 provides the grade resistance force which is calculated by the gross SRWP's mass and grade angle of the contact surface.

$$F_{gr} = m \times g \times \sin\theta \quad (7)$$

Similarly, as indicated in equation 8, the grading resistance power is dependent on the SRWP's wheelchair's speed and grade resistance force(F_{gr}).

$$P_{gr} = F_{gr} \times V \quad (8)$$

Eq. 9 provides the acceleration resistance force which is calculated by acceleration wheelchair on condition specified and the gross SRWP's mass.

$$F_{ar} = m \times a \quad (9)$$

Similarly, as indicated in Eq. 10, the acceleration resistance power is dependent on the SRWP's wheelchair's speed and acceleration resistance force(F_{ar}).

$$P_{ar} = F_{ar} \times V \quad (10)$$

3.2. Criteria Importance through intercriteria correlation (CRITIC)

CRITIC is a correlation-based method that analyses underlying decision data from decision parameters. It computes the weight of criteria by taking advantage of contrast intensity as well as the contradicting essence of the parameters. CRITIC is superior to other objective criteria weighting methods such as ENTROPY and AHP due to its unique ability to consider both the contrast intensity and the intercriteria correlation. CRITIC captures the importance of each criterion by measuring the variability and the conflict between criteria, ensuring a more balanced and objective weighting. Unlike ENTROPY, which focuses solely on the variability of information, and AHP, which relies on subjective pairwise comparisons, CRITIC provides a more comprehensive and unbiased evaluation of criteria importance. The weightage of conflict criteria through CRITIC technique was proposed to MCDM by Diakoulaki et al. [39]. It is widely used to produce objectives weights for MCMD methods which rate various alternatives. This method doesn't consider the decision maker's suggestions, knowledge, or viewpoint in subjective terms. This is a feature of CRITIC that makes it impartial and greater compared to subjective weighting method. The CRITIC technique involves the following steps:

Step-1: The decision matrix C is created using Eq. (11), which displays the behaviour of individual alternative based on multiple parameters. 'Cij' represents the performance entity grades of the ten RA alternatives. Where 'm' denotes the array of choices or RA alternatives, and 'n' denotes the set of criteria or preference parameters.

$$C = (C_{ij})_{m\times n} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & \cdots & C_{1j} & \cdots & C_{1n} \\ C_{21} & C_{22} & C_{23} & \cdots & C_{2j} & \cdots & C_{2n} \\ C_{31} & C_{32} & C_{33} & \cdots & C_{3j} & \cdots & C_{3n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_{i1} & C_{i2} & C_{i3} & \cdots & C_{ij} & \cdots & C_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ C_{m1} & C_{m2} & C_{m3} & \cdots & C_{mj} & \cdots & C_{mn} \end{bmatrix} \quad (11)$$

Step-2: Eq. (12) employs the best-worst form of decision matrix into a normalization, which is used by this objective weighting method. The normalized performance grades C_{ij}^{N} is determined after using Eq. (12) and standard deviation (σ_j) for the column of each parameter using Eq. (13) and Eq. (14).

$$C_{ij}^{N} = \frac{C_{ij} - \text{Worst}\,(X_{ij})}{\text{Best}(C_{ij}) - \text{Worst}(C_{ij})} \quad (12)$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(C_{ij}^{T} - \bar{C}_j)^2}{m-1}}, \; j = 1, 2 \ldots\ldots\ldots\ldots n \quad (13)$$

$$\text{Where, } \bar{C}_j = \frac{\sum_{i=1}^{m} C_{ij}^{T}}{m-1}, \; j = 1, 2 \ldots\ldots\ldots\ldots n \quad (14)$$

Step-3: A symmetric matrix (S) based on Eq. (15) and Eq. (16) is developed which represents each entity of this matrix is a linear correlation coefficient (LCC) between the column of the j_{th} parameter and the column of $(j+1)_{th}$ parameter.

$$S = \left[S_{j,j+1}\right]_{n\times n}, \; j = 1, 2, 3, \ldots n \quad (15)$$

$$S_{j,j+1} = \text{Correlation}[C_{ij}^{N} j_{th} \text{ parameter}, C_{ij}^{N} (j+1)_{th} \text{ parameter}] \quad (16)$$

Step-4: The measure of conflict (MC) based on Eq. (17) is created on j_{th} parameter that depends upon symmetric matrix. The greater the measureMC_j, the greater the information indicator for the parameter j.

$$MC_j = \sum_{j+1=1}^{n}(1 - S_{j,j+1}) \quad (17)$$

Step-5: Now, using Eq. (18), the measure of information (AI_j) is determined.

$$AI_j = \sigma_j \times MC_j \quad (18)$$

The standard deviation is used by the CRITIC approach to determine how important each criterion is. The correlation matrix is used to distribute weight among correlated criteria using $S_{j,j+1}$ in order to take into consideration on inter-criteria interactions. The amount of conflict that results from the jth criterion in relation to the other criteria is indicated by the value in Equation (18). Finally, using a multiplicative combination of measurements in accordance with Equation (18), the information content of the jth criterion is determined.

Step-6: Using Eq. (19) and normalisation of the AI_j values produce the final objective weights for each parameter (W_j), which will aid in prioritising the RA alternatives.

$$W_j = \frac{AI_j}{\sum_{j=1}^{n} AI_j}, \; j = 1,2,3 \ldots\ldots\ldots\ldots n \quad (19)$$

Where, AI_j represents the informational weighted average of all criteria. It could be argued that this approach gives more weight to criteria with high standard deviation and minimal correlation with other standards. In other words, a higher value of AI_j suggests that there may be more information gained from the given criterion, boosting the criterion's relevance in relation to other criteria for the issue with decision-making.

3.3. Additive ratio assessment (ARAS) MCDM method

A fairly standard MCDM challenge is to priorities a finite number of decision alternatives, each of which is clearly and unambiguously expressed in terms of various decision parameters that must be properly considered concurrently. Zavadskas and Turskis, introduced ARAS method as a new MCDM method [40]. The ARAS method states that a utility function value calculating the sophisticated relative performance of a viable solution is straightforwardly proportional to the relative outcome of the key parameter considerer's values and weights. The steps are outlined follows:

Step-1: The formation of a DM is the first stage to prioritized RA alternatives. Any design problem is depicted by the DM of choices for 'm' viable alternative (rows) rated on 'n' conflicting criteria (columns) in the MCDM of the multi-objective optimization issue based on Eq. (11) as depicted on section 3.2.

Step-2: Calculate the best score for the parameter under consideration using Eq. (20). If the value obtained of parameter j for decision-makers is unknown, then:

$$C_j^{p} = \max_i C_{ij}, \text{ if } \max_i C_{ij} \text{ is prominent}; \quad (20)$$

$$C_j^{p} = \min_i C_{ij}, \text{ if } \min_i C_{ij} \text{ is prominent};$$

Where, C_j^{p} is the optimal score of alternative 'i' with respect to j_{th} parameter.

Step-3: Following the creation of the DM, the performance outcomes must always be normalized in possible to correlate alternatives based on various assessment parameters. Eq. (21) and Eq. (22) can be used to calculate the normalized performance levels, which are as follows:

For the most favored score of the parameter:

$$\bar{C}_{ij} = \frac{C_{ij}}{\sum_{i=0}^{m} C_{ij}} \quad (21)$$

And the parameter with least favored score is normalized using a 2 different process:

$$C_{ij}^{*} = \frac{1}{C_{ij}}; \quad \bar{C}_{ij} = \frac{C_{ij}^{*}}{\sum_{i=0}^{m} C_{ij}^{*}} \quad (22)$$

Where, represents the normalized performance outcomes of i_{th} alternative with respect to j_{th}criterion, i = 0, 1, 2… m.

Step-4: The weighted normalized DM must be computed by stakeholders in this stage using Eq. (23).

$$C_{ij}^{W} = W_j \times \bar{C}_{ij} \quad (23)$$

Where, W_j expressed the weighted score of parameter 'j' and x_{ij} is the normalised score of parameter 'j'.

Step-5: Evaluate the optimality function scores of 'i' alternatives (S_i) using Eq. (24).

$$S_i = \sum_{j=1}^{n} C_{ij}^{W} \quad (24)$$

Where, represents the overall performance outcomes of i_{th} alternative, i = 0, 1, 2… m.

Step-6: Using Eq. (25), calculate the degree of alternative utility.

$$K_i = \frac{S_i}{S_0}; \; i = 0, 1, 2, 3, \ldots, m \quad (25)$$

Where, S_i and S_0 are indeed the formula-derived optimality parameters score. Because of the order of priorities, determined scores Ki range from 0 to 1, which can be designed in an increasing succession to determine the rank of Ra alternatives.

3.4. Complex Proportional Assessment (COPRAS) MCDM method

The COPRAS procedure has been used to solve a variety of problems involving multi-criteria evaluation processes. Zavadskas and Kaklauskas developed the COPRAS procedure, which has been used to assess the dominance of one alternative over the other and to rank the alternatives for decision makers [41]. The steps are outlined as follows:

Step-1: The formation of a DM is the first stage to prioritized RA alternatives. Any design problem is depicted by the DM of choices for 'm' viable alternative (rows) rated on 'n' conflicting criteria (columns) in the MCDM of the multi - objective optimization issue based on Eq. (11) as depicted on section 3.2.

Step-2: The DM is normalized using Eq. (26) which fulfil the intention to find multiple dimensionless scores to compare all parameter.

$$C_{ij}^{NC} = [C_{ij}]_{m\times n} = \frac{C_{ij}}{\sum_{i=1}^{m} C_{ij}}, i = 1,2,3\ldots\ldots m;\ j = 1,2,3\ldots\ldots n \quad (26)$$

Where, C_{ij}^{NC} represents the normalised DM of COPRAS method of j_{th} alternative relation to i_{th} parameter.

Step-3: The weighted Normalized DM (C_{ij}^{WNC}) is determined using Eq. (27) where W_j represents the weight vector from CRITIC method.

$$C_{ij}^{WNC} = W_j \times C_{ij}^{NC}, i = 1,2,3\ldots\ldots m;\ j = 1,2,3\ldots\ldots n \quad (27)$$

Step-4: For both the beneficial and non-beneficial parameter, the sums of the weighted normalized scores (L_{+j}, L_{-j}) were computed respectively. Eq. (28) and Eq. (29) were used to compute all such sums.

$$L_{+j} = \sum_{i=1}^{n} C_{+ij}^{WNC} \quad (28)$$

Here, C_{+ij}^{WNC} represents weighted normalised scores of beneficial parameters.

$$L_{-j} = \sum_{i=1}^{n} C_{-ij}^{WNC} \quad (29)$$

Here, C_{-ij}^{WNC} represents weighted normalised score of non-beneficial parameters.

So, L_{+j} and L_{-j} indicate the extent that each choice accomplishes its specific goals, the greater the L_{+j} score results in a better alternative and the lesser the L_{-j} score leads in a better alternative. Eqs. (30) and (31) are used to sum the L_{+j} and L_{-j} score.

$$\sum_{i=1}^{m} L_{+j} = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{+ij}^{WNC} \quad (30)$$

$$\sum_{i=1}^{m} L_{-j} = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{-ij}^{WNC} \quad (31)$$

Step-5: The relative significance (R_j) of every alternative can be determined by Eq. (32) and highest score of R_j indicate the top rank among the alternatives.

$$R_j = L_{+j} + \frac{L_{-min} \times \sum_{j=1}^{n} L_{-j}}{L_{-j} \times \sum_{j=1}^{n} \frac{L_{-min}}{L_{-j}}}, \quad (32)$$

$$L_{-min} = \min(L_{-j})$$

Step-6: The quantitative utility (Q_j) of every alternative is determined by Eq. (33).

$$Q_j = \left[\frac{R_j}{R_{max}}\right] \times 100 \quad (33)$$

The utility score (Q_j) of each alternative stretches through 1% to 100%. So, all alternative's priorities are resolved in regard to the most efficient and suitable alternative. The preferred alternative is considered as having the greatest quantitative utility score Q_j, and the evaluation is accomplished from largest to smallest in compliance with decreasing Q_j scores.

3.5. Evaluation based on distance from average solution (EDAS) MCDM method

The EDAS procedure is an MCDM technique that is extremely valuable in decision challenges with competing parameters. Keshavarz et al. were the first to recommend the EDAS procedure [42]. The steps are outlined as follows:

Step-1: The formation of a DM is the first stage to prioritized RA alternatives. Any design problem is depicted by the DM of choices for 'm' viable alternative (rows) rated on 'n' conflicting criteria (columns) in the MCDM of the multi-objective optimization issue based on Eq. (11) as depicted on section 3.2.

Step-2: Evaluation of the mean or average solution (AS) by determining the average value for each selection parameter using Eq. (34).

$$AS = [AS_j]_{m\times n} \ ; \text{where } AS_J = \frac{\sum_{i=1}^{n} C_{ij}}{n}, j=1,2,3,4\ldots\ldots m \quad (34)$$

Step-3: The positive distance from average (PDA_{ij}) and negative distance from average (NDA_{ij}) of i_{th} alternative from AS_j in contexts of j_{th} parameter is estimated using Eq. (35) and (36) based on benefit and cost parameters respectively.

$$PDA = [PDA_{ij}]_{m\times n} = \begin{cases} \frac{\max(0,\ (C_{ij}-AS_j))}{AS_j}; \text{ for benefit parameters} \\ \frac{\max(0,\ (AS_j-C_{ij}))}{AS_j}; \text{ for cost parameters} \end{cases} \quad (35)$$

$$NDA = [NDA_{ij}]_{m\times n} = \begin{cases} \frac{\max\left(0,\ (AS_j - C_{ij})\right)}{AS_j}; \text{ for benefit parameters} \\ \frac{\max\left(0,\ (C_{ij} - AS_j)\right)}{AS_j}; \text{ for cost parameters} \end{cases} \quad (36)$$

Step-4: The weighted sum of PDA_{ij}(WPsj) and NDA_{ij}(WNsj) for all alternatives are estimated by using Eq.(37) and (38) and W_j represents the weight value of each parameter derived from CRITIC method as follows:

$$WP_{sj} = \sum_{j=1}^{n} W_j \times PDA_{ij} \quad (37)$$

$$WN_{sj} = \sum_{j=1}^{n} W_j \times NDA_{ij} \quad (38)$$

Step-5: Eq. (39) and (40) are used to normalise WP_s (NWP_s) and WN_s (NWN_s) scores for all alternatives.

$$NWP_s = \frac{WP_{sj}}{\max(WP_{sj})} \quad (39)$$

$$NWN_s = 1 - \frac{WN_{sj}}{\max(WN_{sj})} \quad (40)$$

Step-6: Eq. (41) is used to estimate the appraisal score (ASj) for all alternatives to get the rank for stakeholders for decision assessment and the AS_j scores that varies in-between 0 to 1. Alternatives are ranked in lowest to highest based on the AS_jderived. Among all the other alternatives, the one with the maximum AS_j is the optimal solution.

$$AS_j = \frac{1}{2} \times (NWP_s + NWN_s) \quad (41)$$

3.6. . Grey relation analysis (GRA) MCDM method

Ju-Long established GRA for assessing the undefined connections among network entities [43]. This technique is applicable to MCDM challenges that can recognize all these qualitative and quantitative connections among intricate factors in a framework. The steps are outlined follows:

Step-1: The formation of a DM is the first stage to prioritized RA alternatives. Any design problem is depicted by the DM of choices for 'm' viable alternative (rows) rated on 'n' conflicting criteria (columns) in the MCDM of the multi - objective optimization issue based on Eq. (11) as depicted on section 3.2.

Step-2: A normalised DM (C_{ij}^N) is created using Eq. (42) based on the maximum condition or benefit parameter and the minimum condition or non-benefit or cost parameter.

$$C_{ij}^N = \begin{cases} \frac{C_{ij} - Min(C_{ij})}{Max(C_{ij}) - Min(C_{ij})}; \ i = 1,2,3,\dots m; \\ j = 1,2,3,\dots n; \text{ for } j \in \text{benefit parameter} \\ \frac{Max(C_{ij}) - C_{ij}}{Max(C_{ij}) - Min(C_{ij})}; \ i = 1,2,3,\dots m; \\ j = 1,2,3,\dots n; \text{ for } j \in \text{non-benefit parameter} \end{cases} \quad (42)$$

Step-3: Eq. (43) derives the deviation sequence (DS.

$$DS = [DS_{ij}]_{m\times n} = C_{maxj} - C_{currentj} \quad (43)$$

Where, DS is the deviation sequence matrix, $C_{maxj}$is the maximum score of j_{th} column and $C_{currentj}$ is the current score of that j_{th} column.

Step-4: Eq. (44) calculates the grey relation coefficient or degree (γ).

$$\gamma = [\gamma_{ij}]_{(C_{maxj},C_{ij})} = \frac{(\Delta_{ij})_{min} + \delta\times(\Delta_{ij})_{max}}{\Delta_{ij} + \delta\times(\Delta_{ij})_{max}}; \quad (44)$$

$\Delta_{ij} = |C_{maxj} - C_{ij}|$, i = 1,2, 3….m ; j=1,2,3…n

Where, δ is the fix coefficient score which varies between 0 and 1. In this case the δ value is taken as 0.5.

Step-5: Eq. (45) derives the grey relation rate (GRR).

$$GRR = [GRR]_{(C_{maxj},C_{ij})} = \sum_{j=1}^{n} W_j \times [\gamma_{ij}]_{(C_{maxj},C_{ij})} \quad (45)$$

Where, Wj indicates the weightage of parameter of CRITIC procedure. And ranking of the 10 RAs is based on grey relation rate score. Greater score value represents higher rank.

4. Results and discussion

The following illustrative instances are examined in this section to show the relevance and validity of the suggested methodology in resolving selection of RAs for SRPW prototype.

4.1. Application of power requirement of SRPW

The analysis of power requirement is carried out in 3 steps to understand the power requirement for SRPW prototype

Step-1: Force vs. Velocity Analysis: This analysis is based on table 3's assumptions and reference value. Different cases are involved with four degrees of slope or gradeability of the road (0, 6, 8, and 12 degrees), rolling resistance value (0.01), acceleration due to gravity (9.8m/s), three gross weights of the SRWP model (130, 180, and 230 kg), time to achieve the desired velocity in 3sec, and coefficient drag of the SRWP model (0.62). Figure 3 shows two graphs of force vs. velocity among the different cases that required for the SRWP model to run at a speed ranging from 0 to 20 kmph. To overcome aerodynamics resistance force, rolling resistance force, grading resistance force, and acceleration resistance force, the total tractive force is determined using Eq. (1), (3), (5), (7), and (9) for each case.The corresponding values of force are repesented in the from graph in figure 3.

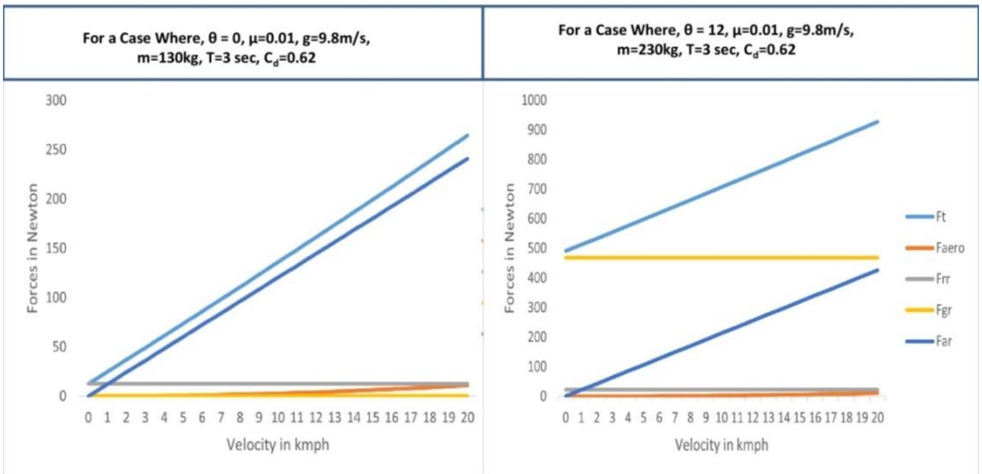

Figure 3. Case investigation and graphs of Force vs. Velocity.

Step-2: Power vs. Velocity Analysis: The assumptions and reference value for this study are taken from table 3. Different cases are also considered for this analysis, with four degrees of slope or gradeability of the road (0, 6, 8, and 12 degrees), rolling resistance value (0.01), acceleration due to gravity (9.8m/s), three gross weights of the SRWP model (130, 180, and 230 kg), time to achieve the desired velocity (3sec), and coefficient drag of the SRWP model (0.62). Figure 4 displays two graphs of power vs. velocity among the different cases that required power for the SRWP model for speeds ranging from 0 to 20 kmph. To overcome aerodynamics resistance power, rolling resistance power, grading resistance power, and acceleration resistance power, Eq. (2), (4), (6), (8), and (10) are used to calculate total power for each case. The corresponding values of power are repesented in the from graph in Figure 4.

Step-3: Recommendation setting for search of Rotary actuator based on power criteria: The following points describe two extreme examples as shown in figure 4, in order to gain knowledge of the minimum and maximum power required for the SRWP model, for which rotary actuator selection is dependent on power requirements.

- The total power necessary to overcome all resistance power in different speed conditions as shown in figure 4 (a) is 143 watt at 6 kmph, 378 watt at 10 kmph, 537 watt at 12 kmph, and 1460 watt at 20 kmph velocity. However, as described by Sahoo and Choudhury (2022), most ordinary electric wheelchairs travel at a speed of 6 to 12 km/h. As a result, the minimum power demand of an SRWP model to run at 6 kmph under wheelchair settings is 143 watt.
- As shown in figure 4 (b), the total power required to overcome all resistance power in different speed conditions are 1000 watt at 6 kmph, 1962 watt at 10 kmph, 2500 watt at 12 kmph, and 5152 watt at 20 kmph. However, when the SRWP model is run in a 12 degree gradebility scenario, the speed is reduced to 1/3rd to offer greater power and torque to the system under the conditions discussed in the focus group. So, for the SRWP model that wishes to run at 12 kmph, the suggested maximum power is reduced on 4 kmph condition, and the maximum power required to achieve the motion of the SRWP model is 520 watt at 4 kmph. If the user of SRWP model wants to acheive the velocity upto 7 kmph based on figure 4 (b), then the power requied is 1246 watt.
- As a result, the SRWP model's minimum and maximum power are 143 and 1246 watt, respectively. So, the total system movement ranges between 143 and 1246 watts while looking for a rotary actuator. Based on the differential driving situation, two rotary actuators are typically employed to get required wheelchair movement such as forward, backward, left turn, and right turn.
- For a single rotary actuator selection in the 71.5 watt to 623 watt range, 50% system power is required. RAs are sought in the internet market for design and development of an SRWP model based on this mathematical analysis, literature study, and focus group discussion, and 10 such RAs are selected for priority ranking of alternatives for the best possible evaluation, as shown in Table 2.

4.2. Application of CRITIC MCDM method on the Proposed Study

After the description of the criteria in literature review and methodology section, CRITIC method is applied to obtain the criteria weights. First the normalized decision matrix is determined using eq. (12), eq. (13), and eq. (14). Secondly, a symmetric matrix is constructed to show the inter criterion relationship between the criteria using eq. (15), eq. (16). The final objective weight (W_j) of selected criteria are determined using MC (eq. 17), AI_j (eq. 18), and normalization of AI_j(eq.19) and the corresponding values are shown in table 4.

4.3. Application of ARAS MCDM method on the Proposed Study

The ARAS method is applied to this study by converting the initial decision matrix to a normalize decision matrix utilizing eq. (21 & 22) and then converting the normalize matrix to weighted normalized matrix utilizing eq. 23. In table 5, this study calculates degree of alternative utility (Ki) that helps in ranking the different RAs.

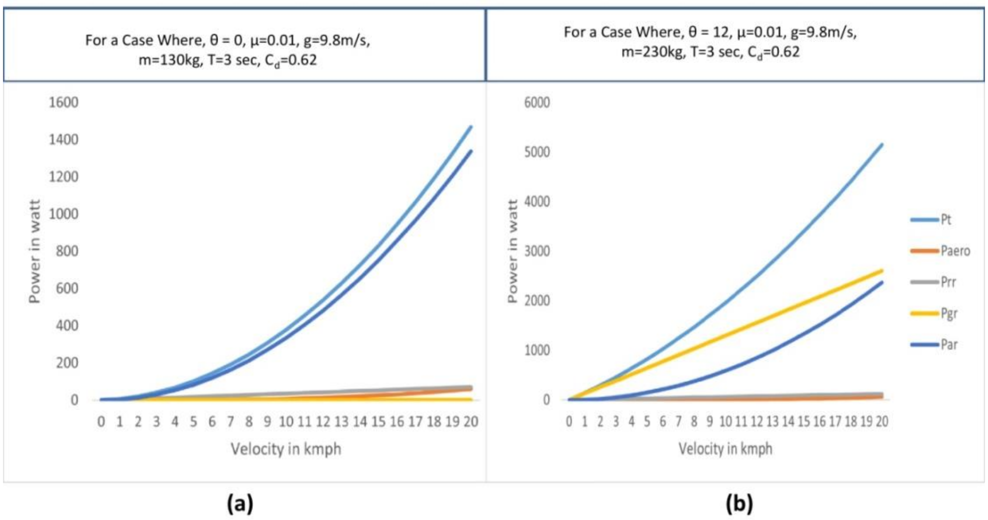

Figure 4. Case investigation and graphs of Power vs. Velocity.

Table 4. Objective Weights by CRITIC

	Co	W	V	RC	P	T	RS	Sum (MC_j)	σ_j	AI_j	W_j
Co	0	0.1776	1.2850	0.8220	1.0337	0.8529	1.2443	5.4157	0.3141	1.7012	0.1751
W	0.1776	0	1.1468	1.1172	1.2826	1.2309	1.6717	6.6271	0.2850	1.8892	0.1945
V	1.2850	1.1468	0	0.6453	0.3196	0.6158	0.8354	4.8482	0.3162	1.5331	0.1578
RC	0.8220	1.1172	0.6453	0	0.1370	0.1356	0.6862	3.5435	0.2754	0.9759	0.1004
P	1.0337	1.2826	0.3196	0.1370	0	0.1625	0.6615	3.5971	0.2677	0.9632	0.0991
T	0.8529	1.2309	0.6158	0.1356	0.1625	0	0.4568	3.4549	0.2881	0.9954	0.1024
RS	1.2443	1.6717	0.8354	0.6862	0.6615	0.4568	0	5.5562	0.2976	1.6538	0.1702

Table 5. Weighted Normalized Decision Matrix and Ranking of alternatives.

Alternatives	Co	W	V	RC	P	T	RS	Si	Ki	Rank
RA-1	0.0140	0.0377	0.0063	0.0031	0.0014	0.0022	0.0064	0.0714	0.4714	8
RA-2	0.0271	0.0238	0.0126	0.0058	0.0062	0.0073	0.0143	0.0973	0.6424	2
RA-3	0.0174	0.0163	0.0126	0.0078	0.0062	0.0110	0.0199	0.0914	0.6036	5
RA-4	0.0203	0.0176	0.0126	0.0101	0.0086	0.0081	0.0148	0.0925	0.6110	4
RA-5	0.0166	0.0110	0.0126	0.0145	0.0124	0.0145	0.0134	0.0952	0.6286	3
RA-6	0.0149	0.0083	0.0189	0.0113	0.0148	0.0135	0.0172	0.0991	0.6546	1
RA-7	0.0177	0.0151	0.0126	0.0101	0.0086	0.0081	0.0161	0.0886	0.5854	6
RA-8	0.0074	0.0100	0.0189	0.0079	0.0086	0.0073	0.0121	0.0725	0.4788	7
RA-9	0.0075	0.0137	0.0189	0.0074	0.0086	0.0066	0.0081	0.0709	0.4685	9
RA-10	0.0047	0.0030	0.0126	0.0076	0.0084	0.0088	0.0237	0.0691	0.4561	10

Bringing the degree of alternative utility (Ki) into account, the ranking of alternatives by CRITIC-ARAS method is as follows: RA-6 > RA-2 > RA-5 > RA-4 > RA-3 > RA-7 >RA-8 >RA-1 > RA-9 > RA-10

4.4. Application of COPRAS MCDM method on the Proposed Study

The COPRAS method is also applied to this study by converting the initial decision matrix to normalize decision matrix utilizing eq. (26) and then converting the normalize matrix to weighted normalized matrix utilizing eq. 27. This study calculates weighted normalize score (L_{+j}, L_{-j}) for both beneficial and non-beneficial criteria using eq. (28) and eq. (29) that helps in determine the relative significance(R_j) of each alternative. In table 6, it shows the quantitative utility (Q_j) of each alternative which helps in deciding the alternatives ranking.

The resulting Q_j vectors for each RA in order to meet the criteria for shortlisting of an optimum rotary actuator are acquired using Equations (26) to (33) again from weighted normalized matrix (C_{ij}^{WNC}). Eq. (32) is used to compute the priority scores or relative significance (R_j) for every alternative. Bringing Q_j into account, the ranking of alternatives of different RAs by CRITIC-COPRAS method is as follows: RA-2 > RA-6 > RA-5 > RA-4 > RA-3 > RA-7 > RA-8> RA-9> RA-10 > RA-1.

4.5. Application of EDAS MCDM method on the Proposed Study

To provide more comparison to the ranking of different RAs, EDAS method is also used. In this method, mean average solution is determined using eq. (34) which is needed to calculate the PDA_{ij} (eq. 35) and NDA_{ij} (eq. 36) for both benefit and cost criteria. The appraisal score for all alternatives is determined using eq. (41) that helps in determining the ranking of RAs as shown in table 7.

Table 6. Each alternative's Relative Significance (R_j), Quantitative Utility Scores (Q_j), and Ranking.

Alternatives	Rj	Qj	Qj in %	Rank
RA-1	0.0754	0.6346	63%	10
RA-2	0.1188	1.0000	100%	1
RA-3	0.1102	0.9270	93%	5
RA-4	0.1118	0.9409	94%	4
RA-5	0.1125	0.9469	95%	3
RA-6	0.1155	0.9717	97%	2
RA-7	0.1067	0.8977	90%	6
RA-8	0.0856	0.7205	72%	7
RA-9	0.0825	0.6940	69%	8
RA-10	0.0806	0.6781	68%	9

Alternatives are ranked in lowest to highest based on the AS_jderived. Among all the other alternatives, the one with the maximum AS_j is the optimal solution. Bringing AS_j into account, the ranking of alternatives by CRITIC-EDAS method is as follows: RA-6 > RA-5 > RA-3 > RA-2 > RA-4 > RA-7 > RA-9 > RA-1 > RA-8 > RA-10.

4.6. Application of GRA MCDM method on the Proposed Study

In GRA mcdm method, the initial decision matrix is converted to normalize decision matrix (C_{ij}^{N}) using eq. (42) considering both benefit and cost criteria and corresponding. Then a deviation sequence matrix is developed using eq. (43) and grey relation coefficient (γ) using eq. (44) that helps in determining the ranks of different RAs as shown in table 8.

4.7. Ranking Comparison and Copeland Voting Principle

Based on the weighted value of the CRITIC technique, all rotary actuators are evaluated by comparing using the ARAS, COPRAS, EDAS, and GRA procedures. For all 10 alternatives of RAs, the degree of alternatives utility score (k_i) for ARAS, the quantitative utility scores (Q_j) for COPRAS, appraisal scores (AS_j) for EDAS, and grey relation rate (GRR) for GRA methods are measured. To initiate, the four rankings given by four tools in Table 9 display that ARAS, EDAS, and GRA methods issue the first rank to RA-6 among all the alternatives or alternatives, but COPRAS provides RA-6 in second position. Nevertheless, it should be noted that in all three situations, the RA-6 has soared through first position. However, establishing the inferior alternative from the recommended ranking in response to negative influence is challenging, even though the four methods suggest RA-10 and RA-1 as among the worst.

The article suggests a final priority ranking for the potential choices in Table 9 by taking into account all four ranks and applying the Copeland voting principle to determine the particular alternative that is the worst out of the list. The Copeland technique is an extension of the Borda method that explicitly takes into account the losses in addition to how many victories an alternative has [44,45]. The victory score of each alternate is the sum of the ranks of various mcdm techniques, whereas the loss score is the total of the values subtracted from the win score with respect to each alternative's individual ranking. As indicated in table 9, the ranking of alternatives is determined based on the final score, which is the difference between the win and loss scores. This technique will aid users in labelling the 10 RA in the order shown below, from best to poorest effectiveness, based on notable attributes.

RA-6 > RA-5 > RA-2 > RA-3 > RA-4 > RA-7 > RA-8 > RA-9 > RA-1 > RA-10 based on Copeland voting principle.

Table 7. Appraisal Score and rank of alternatives.

Alternatives	WPsj	WNsj	NWPs	NWNs	ASj	Rank
RA-1	0.1742	0.4028	0.5967	0.4581	0.5274	8
RA-2	0.2117	0.0936	0.7251	0.8740	0.7996	4
RA-3	0.2201	0.0495	0.7538	0.9333	0.8435	3
RA-4	0.1812	0.0213	0.6207	0.9712	0.7960	5
RA-5	0.2499	0.0278	0.8560	0.9625	0.9093	2
RA-6	0.2919	0.0472	1	0.9364	0.9682	1
RA-7	0.1635	0.0222	0.5601	0.9701	0.7651	6
RA-8	0.0603	0.1532	0.2066	0.7938	0.5002	9
RA-9	0.1081	0.2060	0.3702	0.7229	0.5465	7
RA-10	0.1064	0.7434	0.3644	0	0.1822	10

Table 8. Grey Relation Coefficient and Rank of alternatives.

Alternatives	Co	W	V	RC	P	T	RS	GRR	Rank
RA-1	0.7168	1	0.3333	0.3333	0.3333	0.3333	0.3333	0.4833	10
RA-2	1	0.9078	0.5000	0.3948	0.4354	0.4626	0.4776	0.5969	6
RA-3	0.8081	0.8146	0.5000	0.4592	0.4354	0.6398	0.6956	0.6218	3
RA-4	0.8764	0.8353	0.5000	0.5661	0.5192	0.4926	0.4923	0.6117	4
RA-5	0.7887	0.7040	0.5000	1	0.7297	1	0.4571	0.7399	2
RA-6	0.7414	0.6195	1	0.6407	1	0.8608	0.5714	0.7762	1
RA-7	0.8159	0.7949	0.5000	0.5661	0.5192	0.4897	0.5333	0.6027	5
RA-8	0.4699	0.6764	1	0.4632	0.5192	0.4626	0.4266	0.5740	7
RA-9	0.4744	0.7666	1	0.4439	0.5192	0.4383	0.3555	0.5711	8
RA-10	0.3333	0.3333	0.5000	0.4533	0.5094	0.5202	1	0.5213	9

Greater score value represents higher rank. Bringing GRR into account, the ranking of various alternatives by CRITIC- GRA mcdm method is as follows: RA-6 > RA-5 > RA-3 > RA-4> RA-7> RA-2>RA-8 >RA-9> RA-10> RA-1.

4.8. Comparative Investigation of four MCDM methods

The observations of the article will be compared to indicate how reliable the effectiveness rankings of the various alternatives are. The goal of this study was to determine the degree of connotation rank created by various pairing operations. The Spearman's rank correlation coefficient Srcc is calculated using the eq. (46)

$$S_{rcc} = 1 - \frac{6 \times \sum D_r^2}{A_n \times (A_n^2 - 1)} \quad (46)$$

Where, $A_n$describes the number of RA alternatives and $D_r$indicates the deviation in rank with respect to pair wise analysis among CRITIC-ARAS, CRITIC-COPRAS, CRITIC-EDAS, and CRITIC-GRA. A statistical tool for evaluating the strength and direction of a monotonic link between two variables is the Spearman's rank correlation coefficient. The link between the rankings of the data points is the focus of Spearman's correlation. It is frequently employed when the assumption of uniformity is violated or when the data is ordinal. The coefficient is a number between -1 and 1, with +1 denoting a perfect positive monotonic association (i.e., as one variable rises in rank, the other rises as well). A perfect negative monotonic connection (one variable improves in rank while the other lowers in rank) is represented by a value of -1. In broad sense, a flawless correlation is recognized when the measured score of S is closest to 1, that is, from 0.8-1.0. The S_{rcc}value after using Eq. (46) and the data are listed in Table 10 is within the limit prescribed. The S_{rcc} value for CRITIC-ARAS and CRITIC –COPRAS is 0.9515, which signifies positive monotonic link between the ranks as it is very close to +1 value. Other comparative methods also have values ranging from 0.8060 to 0.9515, which is also very close to +1 representing the positive monotonic link between the ranks. As a result, it illustrates the consistency of the effectiveness rating. Therefore, the methodology studied in this article is equally effective identifying the appropriate RA selection algorithm.

4.9. Sensitivity Investigation

This section looks at the toughness and reliability of the four MCDM instruments that have been used so far. Sensitivity investigation is an algorithmic operation used to examine and confirm the uniformity of a technique. Under certain instances, the stake holders may be obligated to get their own views and suggestions refers to the knowledge and expertise. Even though there are various variables to examine when resolving a decision, stakeholders' preference for RA is majorly inspired by cost related parameter in the prototype development stages, as indicated with CRITIC method of this investigation, which illustrates the weight score of 0.17517.

Investigators such as Bhattacharya et al. [46] and Ghose et al. [47]commonly cite the ssensitivity investigation as a sensible scientific method for monitoring the efficacy of obtained results by varying cost attributes. Only one cost-based threshold, specifically "cost on RAs" was used in the screening process for every of the rotary actuator studied for the research design. The βscore in this research ranges from 0 to 1, with a 0.1 increment. As shown in Figs. (4), (5), (6), and (7), the mathematical Eq. (47) and (48) have been turned into to visualize data between selective index score and objective criterion choice weight. The program's main formulas are as follows:

$$SIS_j = [(\beta \times SFI_j) + (1 - \beta) \times OFI_j \quad (47)$$

$$OFI_j = \frac{1}{[OFC_j \times \sum_{j=1}^{n} OFC^{-1}]} \quad (48)$$

Where, SISj stands for selective index score, βindicates objective parameter choice weight, SFI stands for subjective factor indicator, OFI stands for objective factor indicator, OFC stands for objective factor cost parameter, and n represents for RA's list of alternatives. As shown in table 1, the OFCs are the cost for every rotary actuator. As display in Eq. (39), OFIs are built to generate a non-dimensional number of cost components from every RA. The SFI scores of every RA for each component are shown in Tables 10,12,15, and 18 and are focused primarily on CRITIC- ARAS normalised degree of alternatives's utility score, CRITIC-COPRAS relative significance column scores and CRITIC-EDAS normalised appraisal column scores, CRITIC-GRA normalised grey relation rate by RA candidates. Figures5, 6, 7 and 8 show the derived plot of the sensitivity investigation.

Table 9. Alternative's ranking and Copeland voting rule.

Ranking of RA Alternatives	ARAS Rank	COPRAS Rank	EDAS Rank	GRA Rank	Win score	Loss score	Final score	Copeland Voting Rule
RA-1	8	10	8	10	36	108	-72	9
RA-2	2	1	4	6	13	39	-26	3
RA-3	5	5	3	3	16	48	-32	4
RA-4	4	4	5	4	17	51	-34	5
RA-5	3	3	2	2	10	30	-20	2
RA-6	1	2	1	1	5	15	-10	1
RA-7	6	6	6	5	23	69	-46	6
RA-8	7	7	9	7	30	90	-60	7
RA-9	9	8	7	8	32	96	-64	8
RA-10	10	9	10	9	38	114	-76	10

Table 10. Spearman's rank correlation coefficient Matrix.

	ARAS	COPRAS	EDAS	GRA
ARAS	1	0.9515	0.8909	0.8303
COPRAS	0.9515	1	0.8424	0.8060
EDAS	0.8909	0.8424	1	0.9030
GRA	0.8303	0.8060	0.9030	1

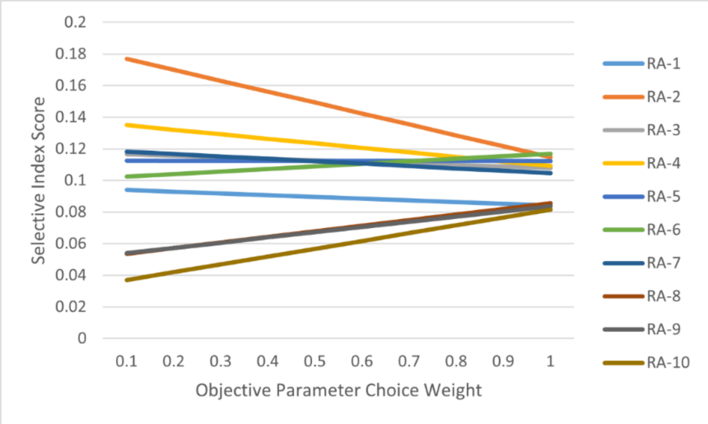

Figure 5. Sensitivity Investigation on CRITIC-ARAS Method.

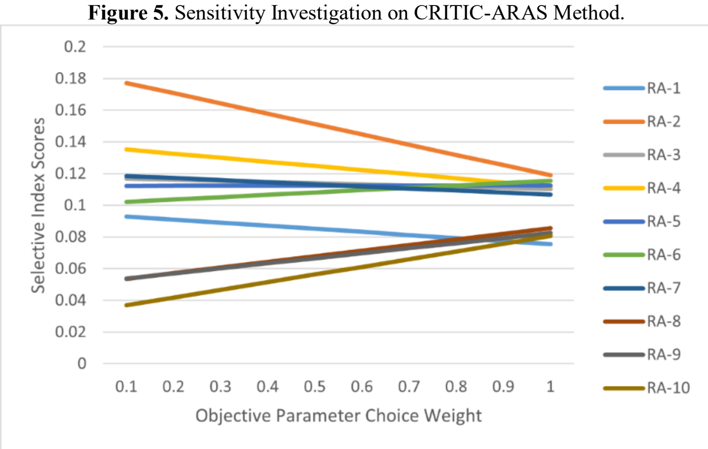

Figure 6. Sensitivity Investigation on CRITIC-COPRAS Method.

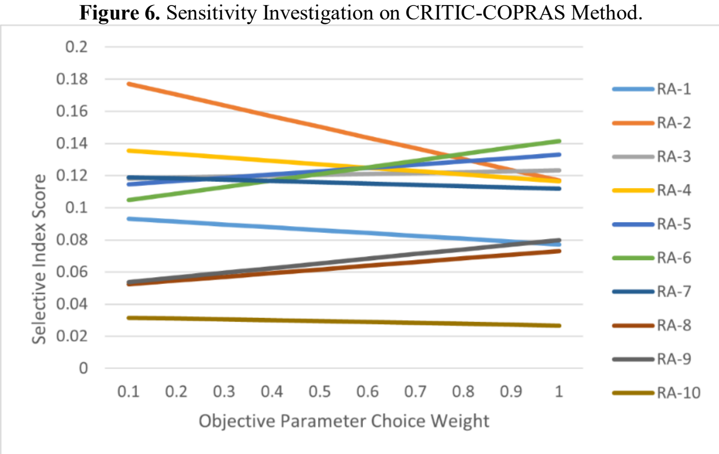

Figure 7. Sensitivity Investigation on CRITIC-EDAS Method.

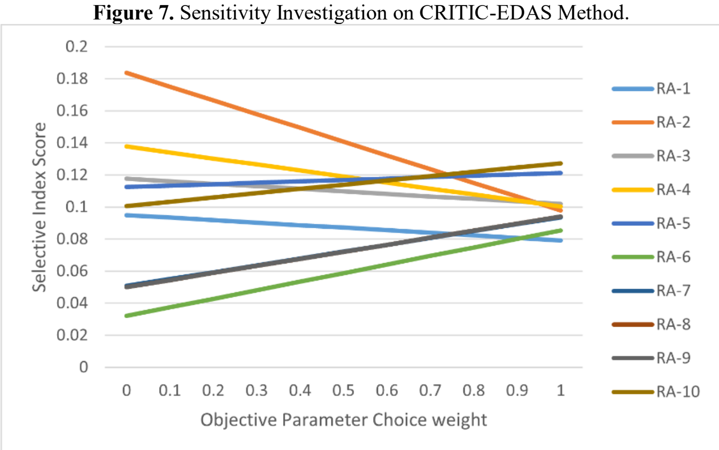

Figure 8. Sensitivity Investigations on CRITIC-GRA Method.

This sensitivity investigation plot is formed by altering the score of "beta," or the objective parameter alternative's weight in Eq. (47) in a 0–1 spectrum with an increment of 0.1. The associated SISi scores for the cost of RAs transformation when the score of "beta" shifts. The "beta" scores indicate how deviations in cost-related variables affect the research evidence from the CRITIC-ARAS, CRITIC-COPRAS, CRITIC-EDAS, CRITIC-GRA methods, illustrating the investigation findings' robustness. The presence of cost-related aspect in evaluation process over other variables could be linked to the instantaneous score of "beta," with a lesser score indicating a high prevalence for rotary actuators and a lower SFI score.

5. Conclusions

The CRITIC, ARAS, COPRAS, EDAS, and GRA methods are used in this article to determine the priority of rotary actuators or DC motors in the design and development of robotic wheelchairs using mathematical expression.Moreover, there are couple extra takeaways from this investigation, which are as described in the following:

- CRITIC is more precise and unbiased objective weighting tool than subjective weighing tools like ANP, AHP, BWM, as well as others because it is autonomous of the stakeholder's judgments and views.
- ARAS, EDAS, and GRA' output findings are superior to those of COPRASdue to their higher sensitivity to criteria weights, robustness in handling data variability, and comprehensive assessment capabilities. These methods provide a more nuanced evaluation by thoroughly considering multiple aspects of the alternatives, which ensures that critical factors significantly impact the ranking. Additionally, their flexibility in applying various criteria allows for a more tailored and reliable evaluation, making them more dependable for decision-making in dynamic environments. Although COPRAS also produces similar alternate preference orders and matches the final authorized ranking, the precision, robustness, and comprehensive nature of ARAS, EDAS, and GRA make them preferable for this study.
- According to this study, the RA-6 is the best, with the RA-5 and RA-2 coming in second and third, respectively in the final copeland voting ranking.
- If RA-6 is not available in the market owing to a shortage, he or she can choose RA-5 or RA-3 for design and development of a robotic wheelchair.
- Because there are so many alternative possibilities on the market, the last rank of RA-10 under the final ranking provided by copeland voting voting rule should be avoided.

5.1. Limitations

The entire study is based upon numerical calculations and assumptions. The final results cannot guarantee that it will meet all of the criteria in real life scenarios. This paper seeks to show some important information and make recommendations about rotary actuators and its alternatives. Moreover, the present analysis is based on seven competing factors and ten alternatives; however, other alternatives, such as comparability of rotary actuator with robotics application wheelchair, effectiveness of controlled path planning of wheelchair, rotary encoder attachment for positioning of robotic wheelchair, and so on, can be included to these seven elements. The ranking sequence may be altered in such a case.

5.2. Future work

IPV, CBA, COMET, DRAS, MAGIQ, MAUT technique, and other MCDM methodologies can be used to examine the same issue, and the results can be evaluated. Other measuring algorithms, such as ENTROPY, AHP, and ANP, can also be used to give variable weights. In addition to these applications, the CRITIC-ARAS, CRITIC-COPRAS, CRITIC-EDAS, and CRITIC-GRA methods could be used to select various micro controllers, motor drivers, and material selection for the design and development of robotic wheelchairs for people with disabilities.

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Conflicts of interest

There are no potential conflicts of concern in this research, according to the investigators.

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