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Prototype Design of Ergo-Flexibility Wheelchair Based on Stakeholder Technical Requirements, Zachman Framework Approach, and Nigel Cross Method Integration

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ABSTRACT

The increasing demand for ergonomic and flexible wheelchairs in Indonesia highlights the need for innovation that meets both user needs and national standards. Most wheelchairs circulating in the domestic market are low-cost imported products that do not comply with the ISO 7176 series SNI 09-4663-1998 medical device standard, leading to concerns over safety and quality assurance. This study aims to design an *ergo-flexibility wheelchair prototype* based on stakeholder technical requirements while identifying gaps in the existing standards to improve product competitiveness and user protection. The research integrates the Zachman Framework according to the FACTS stages with the Nigel Cross seven-step design method. Data were collected through observation, in-depth interviews, and participatory ergonomics focus group discussions. The data analysis employed the Inter-Rater Reliability (IRR) method to determine stakeholder agreement levels. The findings identified seven key technical parameters, stability, maneuverability, mobility, dimensions, strength, durability, and product information, that are essential for wheelchair standardization. The mapping analysis revealed that the current SNI standard primarily emphasizes product strength through drop testing, while other ergonomic and safety factors remain unaddressed. From the evaluation of three design alternatives, *Alternative 2* was selected, featuring aluminum material, dimensions of 1000 mm (L), 620 mm (W), and 910 mm (H), a foldable transport design, semi-manual manufacturing, and a weight of 12 kg with an 80 kg load capacity. Prototype testing using a roll machine and static load confirmed its structural reliability and ergonomic performance. The research contributes to advancing national wheelchair standards by integrating stakeholder-driven design parameters, promoting local innovation, and enhancing the competitiveness of Indonesian medical devices.

1. Introduction

The sector of accelerating the development of the pharmaceutical and medical device industry is a national priority in the independence of medical device production (Setiawan, 2023). Most of what is circulating and easier to find in the Indonesian market are foreign-made (imported) wheelchairs. While in Indonesia, wheelchairs circulating in the commercial market are dominated by imported products from China at affordable prices. On the other hand, health technology and technology products must meet standards. Sanctions if deliberately producing or distributing medical devices that do not meet standards and / or requirements for safety, efficacy or usefulness. There are no standards in the medical device sector issued by the National Standardization Agency that are mandatory and impose sanctions for violating them (Gestel & Lochem, 2020; Jiménez et al., 2021).

The parameters in ISO 7176 series SNI 09-4663-1998 are not considered to meet quality assurance, user compatibility, safety of use, and long-term productivity of use, so they have not been applied by manufacturers. In addition, the Ministry of Health as the regulator does not make ISO 7176 series SNI 09-4663-1998 as a reference for assessment and distribution permit requirements. The demand for wheelchairs in Palembang City has increased after the recovery period of the Covid-19 pandemic decreased (Irawan et al., 2020). From the results of interviews conducted by 3 people from PT SPU's customer service and medical device distributors, it was found that there was a special request from users who wanted a wheelchair that could help user flexibility ergonomically, especially when they wanted to move places (Haryanto et al., 2025; Rachmawati et al., 2021).

Although previous studies have discussed the ergonomic evaluation of wheelchair designs and user satisfaction levels, most of these investigations focus solely on usability or mechanical performance without linking them to standardized design frameworks or national standardization processes (Zhang et al., 2024; Zhen et al., 2024). Moreover, the existing ISO 7176 series SNI 09-4663-1998 has not been comprehensively aligned with the actual technical and ergonomic needs of users in Indonesia, leading to a significant gap between user-centered requirements and the current regulatory standards. This research addresses that gap by systematically mapping stakeholder expectations and comparing them against the national standard to identify areas requiring revision and improvement.

The novelty of this research lies in its integrative methodological approach that combines the Zachman Framework, FACTS method, and Nigel Cross's seven-step design process within a single research model for the first time in wheelchair design studies. This integration enables a structured and multidimensional analysis that simultaneously considers stakeholder technical needs, standard compliance, and product functionality. The proposed approach provides a more holistic pathway for developing ergonomic medical devices that are not only user-centered but also compliant with formal standardization requirements.

This study contributes both theoretically and practically to the field of ergonomic product design and standardization. From a theoretical perspective, it expands the application of integrative frameworks in the development of medical devices, offering a new model that bridges user-centered design and compliance with national standards. From a practical perspective, the findings provide valuable recommendations for policymakers and industry stakeholders regarding the revision of the ISO 7176 series SNI 09-4663-1998, facilitating the creation of competitive, safe, and ergonomically optimized wheelchair products within the Indonesian market.

The lack of user flexibility and ergonomic comfort is because the wheelchair design does not have multifunction components but fixed position components which have an impact on the user's difficulty in moving from the wheelchair (Setiawan, & Alfian, 2025). Users have difficulty moving due to the condition of their weak legs to rest or stand. At PT SPU, there are several wheelchair products but none of them meet the features that users need (Setiawan et al., 2023). Standardization of wheelchair prototypes is expected to protect producers and consumers and increase product competitiveness in the global market. Mapping and gap analysis of stakeholders' technical needs with ISO 7176 series SNI 09-4663-1998 is expected to increase the competitiveness of products circulating in the Indonesian market and protect consumers (Mokhtari et al., 2024; Win et al., 2024).

This study aims to determine the technical parameters required by stakeholders in the design of prototypes. Based on these problems, it is necessary to design a multi-functional wheelchair that has features that can facilitate user ergonomics in terms of wheelchair user flexibility easily and safely,

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for example, such as the use of components and also functions that can facilitate user flexibility. Flexibility an important yet compulsory feaures in wheelchair. Ergonomic wheelchairs reduce the risk of pressure ulcers by 45% compared to conventional wheelchairs. Flexibility in a wheelchair is essential for the user's adaptation to the environment (home, office, public roads). Adjustable wheelchairs cause up to 60% increase in back muscle fatigue (Setiawan, Susanto, Budiarto, Alfian, et al., 2025). The primary market for the designated wheelchair is elderly and disabled people with adjustable ergo-flexibility.

To meet the functional needs of the product in accordance with the wishes of the user, a series of product planning and development is needed starting from the discovery of problems or ideas, followed by product concept development, functional design, detailed system design, product prototyping, and evaluation.

2. Method

The data collection techniques used in this research were desk study, observation, in-depth interviews and focus group discussions (FGD) Participation Ergonomics (Setiawan, Susanto, Rinamurti, & Alfian, 2025). Primary data collection used a questionnaire instrument that contained a compilation of parameters from various references and then weighted stakeholder choices based on the technical needs of the product. Interviews were used to explore problems in the field that had not been contained in the questionnaire. The sampling technique used is proportional sampling. The consumer population of wheelchair users produced by PT SPU from distributors and sellers in Palembang City. Respondents of stakeholder technical needs are user stakeholders who are in technical contact with the product. Observations were made by interviewing marketing and also marketing managers in terms of looking for user customer desires related to wheelchairs.

This research is a collaborative research between PT SPU, the Standardization Society (Mastan) of South Sumatera Province, the Technical Service Office (KLT) of the National Standardization Agency (BSN) Palembang region and the Innovation System Center Laboratory of the Industrial Engineering Study Program, Faculty of Science and Technology, Musi Charitas Catholic University, starting with the same stakeholder analysis and questionnaire tools as those conducted by (Al-Haddad & Al-Abed, 2021; Ardiansyah et al., 2023; Oliveira et al., 2022; Zainuddin & Aulia, 2024). The difference in this study is the integration of the stakeholder technical needs analysis method approach, the Zachman framework and Nigel Cross. The data analysis used is inter rater reliability (IRR) using SPSS software. IRR aims to determine the level of agreement of raters or competent respondents through questionnaire data with a Likert scale. The principle of the IRR test is to compare the p value with the Kappa coefficient or Alpha Cronbach's (Hernawati et al., 2023). The minimum Alpha Cronbach's value is 0.7. To determine the high and low reliability using the reliability criteria as follows: very high (value 0.8 - 1.0), high (value 0.6 - 0.799), moderately high (value 0.4 - 0.599), low (value 0.2 - 0.399), and very low (value <0.2) (Ruslan Hadi et al., 2020).

2.1. Stakeholder Technical Requirements and Zachman Framework in FACT

The National Institute of Standards and Technology (NIST) has developed an approach method that covers the stages of standards development to standards implementation, namely the FACTS method (A Framework for Analysis, Standards Comparison, and Testing of Standards). The FACTS method itself has four stages Fig. 1, namely stakeholder analysis, technical analysis, standard comparison, and standard testing (Witherell et al., 2013). The FACTS method only guides an approach to standards development but does not prescribe methods for analysis or processing data. Stakeholder analysis is done by collecting many related parameters by collecting from related publications and standards into attributes and variables. The attributes and variables that have been operationalized are then grouped based on their dimensions and structured to become a questionnaire to technical stakeholders.

Stakeholder technical parameters are then processed with a method (not specified by NIST) that can show the parameters that are considered priority by stakeholders. The priority parameters are then mapped using the Zachman framework. Zachman framework is a conceptual framework for obtaining organisation-wide architecture mapped in 5W+1H, what, when, who, where, why, and how (Asefzadeh et al., 2016). It aims to identify the main objectives of the standard, the most important parameters, process levels, and the organizations and parties responsible for these activities.

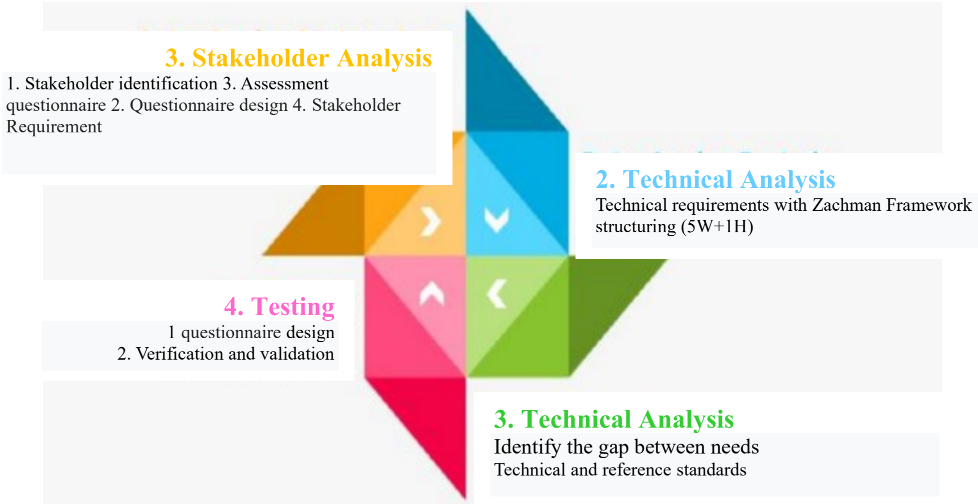

Fig. 1. Standards Development Framework with FACTS Method
Source: (Witherell et al., 2013).

2.2. Nigel Cross Method

The implementation of the Nigel Cross method includes; based on observations, and interview results about wheelchair parameters in ISO 7176 series SNI 09-4663-1998 (Ayundyahrini et al., 2019), user needs data and wheelchair standard size data will be obtained. Then the data is processed with 7 steps of Nigel Cross, namely; 1) classification of objectives, 2) determination of functions, 3) determination of specifications, 4) determination of characteristics, 5) generation of alternatives, 6) evaluation of alternatives, and 7) value engineering. Implementation of wheelchair testing through testing using a roll machine, testing using static loads, and testing on users.

3. Results and Discussion

Wheelchair product function data needed by users from interviews with prospective users are wheelchairs that have light weight, have dark color, have more than one function, can be folded, can withstand the weight of the user, use travel friendly wheels, and have a fordable armrest. So that the determination of the dimensions of the Ergo-Flexibility wheelchair must consider the results of the interview above and synchronous with the ISO 7176-5 standard (Nasional, 2020) with the following standard size restrictions: seat plane angle 4 degrees, effective seat dept 450 mm, effective seat width 450 mm, seat surface height at front edge 520 mm, back support angle 10 degrees, back support height 420 mm, handgrip height 950 mm, back support width 450 mm, footrest to seat 450 mm, but no less than: footrest clearance 40 mm, footrest length 250 mm, armrest height 200 mm, front of armrest to back support (front of armrest to backrests) 350 mm, hand rim diameter 530 mm, maneuvering wheel diameter (propelling wheel diameter) 610 mm, wheelbase 400 mm, camber 0 degrees, horizontal location of wheel axle 20 mm, vertical location of wheel axle 184 mm, castor wheel diameter 175 mm, castor trail 50 mm, track of drive wheel or maneuvering wheel (drive wheel track width) Mid-position, track of castor wheels or pivot wheel (castor wheel track width) Mid-position, movable wheel, horizontal position (castor stem housing position, horizontal) Mid-position, movable wheel, vertical position (castor stem housing position, vertical) Mid-position, movable wheel, vertical axle position (castor wheel axle position, vertical) Mid-position, castor rake (castor stem angle, fore-aft plane) vertical +1/-0 degrees, and castor cant (castor stem angle, lateral plane) vertical +-0,5 degrees (Naser & Bhattacharya, 2023; Rasmussen, 2023).

In the FACTS approach, stakeholder technical needs analysis is the output of the stakeholder analysis and technical analysis stages. To obtain stakeholder technical needs, parameters are needed that can be considered in developing standards. These parameters can be obtained from references that have innovations to show the level of product development. The standard formulation process must be able to accommodate stakeholder interests. Stakeholders in standard formulation according to Law Number 20 of 2014 are regulators, business actors, consumers, and experts or scholars. In order to obtain technical needs, the stakeholders needed are stakeholders who are in contact with technical specifications, namely six wheelchair manufacturers, three experts, wheelchair users with representatives from five hospitals, and 24 disabilities at the Center for Social Rehabilitation of the Physically Disabled (BBRSBD).

This aims to be able to capture the ideal parameters of a product. Mapping of parameters in the dimensions of parameters, sub-parameters, along with references is presented in Table 1. These parameters are stated in a questionnaire which then requires an assessment of approval from stakeholders if it becomes a wheelchair standard. The assessment is in the form of a Likert scale of 1-5 with representation representing Strongly Disagree for number 1 and Strongly Agree for number 5. The technical needs of stakeholders are carried out with an IRR analysis. This analysis aims to measure the level of respondent perception of competence so that priority parameters will be obtained (Heri Setiawan, Susanto, Rinamurti, & Alfian, 2025). In the process, data on the Likert scale will be processed and compared with Alpha Cronbach's produced at each execution.

The block diagram of the Ergo-Flexibility wheelchair product after classification using the objective trees method, function determination using the analysis function and black box methods, then the block diagram is obtained Fig. 2, and alternative generation is presented in Table 1. The questionnaire is said to be reliable if the Alpha Cronbach's value is > 0.7 (Sanaky, 2021). The parameters structured in the Zachman Framework are parameters that are considered a priority by respondents (value 1). At this stage, 28 sub-parameters were identified. The framework column consists of the people involved in doing the work (who), the purpose of the work (why), the work strategy (what), the working time (when), the sub-system doing the work (where), and the way to do the work (how). In addition, needs analysis is also used to restructure information so that there is no duplication of technical aspects due to information that looks different but has the same meaning. Each parameter is explained and viewed from six perspectives: the perspective of the planner, owner, designer, builder, sub-contractor and user (H Setiawan, Susanto, Rinamurti, Alfian, et al., 2025).

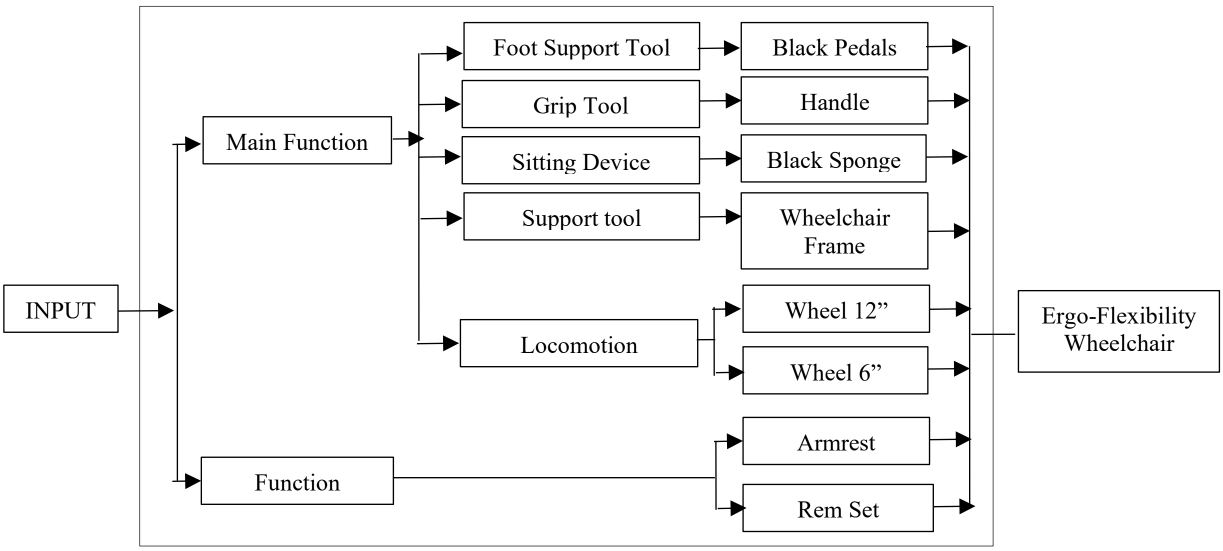

Fig. 2. Ergo-Flexibility Wheelchair Block Diagram

In this study, it is seen from the wheelchair manufacturer as a designer, builder, sub-contractor; experts as planners and designers; hospitals and people with disabilities as users. The output of the

Technical Needs Analysis using the Zachman Framework related to quality requirements and testing of wheelchair products is structured into seven parameters with twenty-eight sub-parameters. A summary of the output of the technical needs analysis is presented in Fig. 3. In the preparation of standardization, it is expected to be harmonious with international standards so that in its development it is necessary to pay attention to international rules, regulations and standards. In addition, standard comparison is used to find out the reference or reference in the preparation of the standard. The international standard for wheelchairs in the International Organization for Standardization (ISO) is in the ISO 7176 series, while the standard that applies in Indonesia is SNI 09-4663-1998. Table 2 shows that the sub-parameters of dynamic stability, energy efficiency, and maneuverability through obstacles are intended for electric wheelchairs.

Table 1. Morphological Chart of Wheelchair Ergo-Flexibility

No	Characteristics	Alternative		
		1	2	3
1.	Material	Steel	Alumunium	Stainless
2.	ISO-7176-5	1040 mm (L) x 625 mm (W) x 965 mm (H)	1000 mm (L) x 620 mm (W) x 910 mm (H)	1080 mm (L) x 650 mm (W) x 880 mm (H)
3.	Design	Homecare	Transport	Hospital
4.	Part Selection	Single Use	Multi Use	Single Use
5.	Mechanical System	Detachable	Foldable	Fixed
6.	Manufacturing Method	Manual	Semi Manual	Semi Manual
7.	Wheelchair Weight	15 kg	12 kg	16.5 kg
8.	Material Strength	90 kg	80 kg	80 kg

Generally, the standards in the ISO 7176 series contain dimensions and product testing to ensure the quality of the wheelchair product itself. Not all parameters in manual wheelchairs are required in electric wheelchairs. Conversely, not all parameters of electric wheelchairs are required in manual wheelchairs. So, the technical requirements of manual wheelchairs are seven parameters and 25 sub-parameters. The technical needs of stakeholders in wheelchair standards indicate that safety parameters must be present in the product. In Fig. 2. presents safety aspects including; stability, strength, and durability. Dynamic stability and static stability are needed so that wheelchairs can move safely on sloping, uphill, and downhill surfaces considering that wheelchair users rely on hand strength to move the wheelchair manually. Strength and durability contribute to the safety aspect of wheelchairs. This is because in Indonesia, many wheelchairs have failed fatigue tests, broken axles or hand rim axles and castors (Heri Setiawan, Susanto, Rinamurti, & Pratama, 2025). Several things to consider in creating a wheelchair are; (1) material used for the seating section, some materials could lead to allergy or inflammation for the users if being used in long time, (2) the size of the wheels set should be another consideration, because the center if the gravity of the users, is depend on the frame size, not proportionally built could lead to unavoidable accident in the future based on the alternative shown in Fig. 2 and Table 1.

According to ISO 7176-8, fatigue testing is carried out for 200,000 revolutions (International Organization for Standardization, 2014), while ANSI/RESNA stipulates 400,000 revolutions Ferretti et al., (2023) to experience fatigue test failure, broken axle or hand rim axle and castor. According to ISO 7176-8 fatigue testing (Setiawan, 2023) the high fatigue test requirements indicate that product durability is one of the critical parameters. In addition to fatigue testing, drop testing is also an important sub-parameter because it is related to the strength of the product frame material. In addition to being regulated in ISO 7176-8, SNI 09-4663-1998 has also regulated drop tests (National Standardization Agency, 1998). In its application in Indonesia, 1 (one) company with the main production of wheelchairs was identified as having difficulty in implementing drop tests (Putri Cahyani & Humaira Ramadhani, 2024). Meanwhile, wheelchair manufacturers who have been able to meet the ISO 7176 test requirements are exporters who have used ISO 7176 as a reference for their product standards.

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Table 2. Creating a Wheelchair Way Beyond the ISO or SNI Parameters with Zachman Framework Results

No.	Parameter	Sub Parameters	Standard Identification	Information
1.	Stability	Static Stability	ISO 7176-1;2014	Testing at rest, uphill, downhill and on inclined surfaces
		Dynamic Stability	ISO 7176-2;2017 ISO 7176-28;2012	For electric wheelchairs
2.	Maneuver	Maneuvering around obstacles (clear space)	ISO 7176-3;2012 ISO 7176-5;2008	Room corridor, room entry and exit access, u-shape, pivot width, door depth, turning room
		Maneuvering through obstacles	ISO 7176-10;2008 ISO 7176-28;2012	Ramp position testing and stair climbing for electric wheelchairs
3.	Mobility	Energy efficiency (small energy to move the wheelchair)	ISO 7176-4;2028	Efficiency of energy/power used or released for electronic wheelchairs
		Ease of transfer to and from a wheelchair	-	-
		Ease of transporting wheelchairs	-	-
4.	Dimensions	Wheelchair length	ISO 7176-5;2008	Wheelchair dimensions in cm
		Wheelchair width	ISO 7176-5;2008	Wheelchair dimensions in cm
		Total height of wheelchair	ISO 7176-5;2008	Wheelchair dimensions in cm
		Wheelchair height	ISO 7176-7;1998	Wheelchair dimensions in cm
		Seat height from the ground	-	-
		Armrest height from seat	ISO 7176-5;2008	Wheelchair dimensions in cm
		Seat length	ISO 7176-5;2008	Wheelchair dimensions in cm
		Seat width	ISO 7176-7;1998	Wheelchair dimensions in cm
		Maximum weight of wheelchair	ISO 7176-5;2008	Wheelchair weight without load
5.	Strength	Footrest/strong footrest	ISO 7176-5;2008	The strength of the footrest in supporting the foot load. Testing includes the strength to withstand the upward and downward load forces.
		Wheelchair is strong in normal use	ISO 7176-5;2008 ISO 7176-8;2014	Fatigue test using multi drum test
		Strong wheelchair in maximum load use	ISO 7176-5;2008 ISO 7176-8;2014	There are weight groupings for wheelchair users.
		Wheelchair is not damaged when it falls	ISO 7176-8;2014 SNI 09-4663-1998	Drop test
		No component cracks	ISO 7176-8;2014 SNI 09-4663-1998	Drop test
		Strong wheelchair frame	ISO 7176-8;2014 SNI 09-4663-1998	Drop test
		Push handle	ISO 7176-5;2008	Manual wheelchair with assistant. Testing includes the strength to withstand upward and downward load forces.
6.	Resilience	No plastic deformation of the surface	ISO 7176-13;1989 SNI 09-4663-1998 ISO 7176-8;2014	Drop test fatigue test tire friction coefficient
		Not flammable	ISO 7176-16;2012 ISO 7176-28; 2012	Horizontal and vertical ignition testing
7.	Addition	Wheelchairs have reflective stickers	ISO 7176-15;1996 EN 980; 1996	Permanent marking, tire marking
		Wheelchairs have a flat surface	ISO 7176-5;2008 SNI 09-4663-1998	Tire friction coefficient
		Ease of repair/obtaining components	ISO 7176-15;1996	Repair information, parts availability

In accordance with technological developments that demand high mobility, stakeholders feel the need for lightweight and compact wheelchairs. Ease of wheelchair mobility is related to the selection of product materials and manufacturer innovation (Hermawan et al., 2024). Meanwhile, dimensions should be ergonomic and adjusted to the anthropometry of the Indonesian people or facilitated by the addition of flexibility features so that they can be adjusted to the size of the user (Suryono et al., 2025). In Indonesia, additional parameters are considered important because they correlate with product traceability and product assurance in the event of product defects or damage (H Setiawan, Susanto, Budiarto, Alfian, et al., 2025). Users have difficulty in obtaining spare parts or product information, especially imported products that are widely found on the market. The results of mapping and gap analysis show that SNI 09-4663-1998 only covers the strength of the product frame through a drop test. Meanwhile, moving safety factors, dimensions, and product information that are considered important by stakeholders have not been facilitated in the standard (Sahu & Pandit, 2025; Vosoughi et al., 2024).

Table 3. Comparison of Non-Flexible vs Ergo-Flexible Wheelchairs

No	Aspect	Non-Flexible Wheelchairs	Ergo-Flexibility Wheelchair
1.	Design & structure	Stiff, non-foldable, fixed size	Fordable, adjustable in height/backrest & lightweight
2.	Ease of mobility	Difficult to maneuver in narrow spaces/sidewalks	Easy to maneuver, small turning radius
3.	Sitting comfort	Not ergonomic, high pressure on the back and buttocks	Soft seat, adjustable sitting position
4.	Pressure injury risk	Height – cannot change sitting position	Low – can change position or backrest
5.	Medical adjustments	Does not support additional buffering	Can install headrests, feet, even pressure sensors
6.	Portability	Heavy, difficult to carry around	Lightweight, fordable, easy to carry in public transportation
7.	User independence	Depend on others	Users can operate it themselves (by hand/motorcycle)
8.	Aesthetics & psychology	Looks old, can reduce self-confidence	Modern design, enhance user self-image
9.	Maintenance costs	Often worn out because it cannot be removed	Modules are replaceable, easy to clean
10.	Terrain resistance	Unstable on uneven roads	There is suspension, special wheels for outdoor use

From the calculation results obtained, it shows that alternative 2 has the largest value, which is 214, which is the best choice. The second-best choice is alternative 1, which is 175, and alternative 3, which is 111. Therefore, alternative 2 was selected design will be created. The results of making the Ergo-Flexibility wheelchair prototype are presented in Fig. 3 (Esmaeili et al., 2023; Hasanain, 2024; Rodríguez et al., 2022). Aside from standardization given by ISO or SNI this research considering to ask the disabled or special needs people as one of their respondents in this section. The disabled/special needs persons as one of the potential users in this section. In essence, a normal person who is experiencing an injury so that in their recovery process they have special needs which are the same as a disabled person/person with special needs Table 3. Comparison of Non-Flexible vs Ergo-Flexible Wheelchairs presents a comparison of several aspects as follows; design & structure, ease of mobility, sitting comfort, pressure injury risk, medical adjustments, portability, user independence, aesthetics & psychology, maintenance costs, and terrain resistance.

Recommended types of ergonomic seat cover materials include: memory foam, gel cushion, gel+foam combination, high density PU foam, air cushion, natural latex, and porous, antimicrobial cover. Ideal recommendation (practical combination). Core: memory foam or gel + PU foam combination. Upper surface: breathable lining (e.g., mesh or antimicrobial fabric). Bottom layer: anti-slip protector or waterproof material. Additional: anatomical contour design (hip and thigh support), can be removed for washing. The decision to select ergonomic wheelchair base materials can be based on the target market segment of user needs (e.g.: elderly, disabled/special needs person, paraplegics, active users).

Fig. 3. Alternative Design 2 Ergo-Flexibility Wheelchair Prototype

4. Conclusion

This study demonstrated that the current SNI 09-4663-1998 standard primarily focuses on product frame strength through drop testing, while essential ergonomic and functional aspects, such as motion safety, dimensional accuracy, and comprehensive product information, remain unaddressed. The findings underscore the urgent need to revise the SNI standard to better reflect the technical and ergonomic requirements of stakeholders. Stakeholder analysis identified seven main technical parameters with twenty-five sub-parameters that must be considered in future wheelchair standardization: stability, maneuverability, mobility, dimensions, strength, durability, and product information. Among the three design alternatives evaluated, Alternative 2 was selected as the optimal solution, characterized by an aluminum frame, dimensions of 1000 mm (L) × 620 mm (W) × 910 mm (H), black epoxy powder-coated steel finishing, solid tires (6″ front and 12″ rear), black leather upholstery, foldable transport design, semi-manual manufacturing method, and a total weight of 12 kg. Prototype testing using roll and static load assessments confirmed the design's capability to withstand an 80 kg load, validating its ergonomic flexibility and functional reliability.

The comparative analysis between non-flexible and ergo-flexible wheelchairs revealed that the proposed design provides superior advantages in terms of user comfort, safety, mobility, independence, and maintenance efficiency. Material selection for ergonomic wheelchair bases can therefore be guided by user segments, such as the elderly, individuals with disabilities, or active users, to enhance personalization and market fit. Future research should expand prototype testing to include long-term durability and fatigue resistance under real-life usage scenarios, while also integrating biomechanical modeling and digital simulation to optimize ergonomic parameters. Additionally, collaborative efforts with regulatory institutions are recommended to support the development of a revised, stakeholder-oriented SNI framework that aligns with international wheelchair standards (ISO 7176 series) and promotes innovation within Indonesia's medical device industry.

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