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Designing an Assistive Devices for Transferring a Wheelchair Users with Comparative Study using AHP Method and Delphi Method

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Abstract. Persons with disabilities in Indonesia increase significantly every year. The average increase of the number disabilities from 2012 to 2017 was 4.8%. Increasing the number of disabilities is not followed by an increase in accessibility and mobility for people with disabilities. This causes dependency and barriers for persons with disabilities to have similarity opportunities for decent living. There are 33% of people with disabilities have difficulties in walking and needing access to mobility. In addition, the availability of mobility devices in Indonesia is minimal. So in this study trying to design a mobility devices for entering a car for wheelchair users with comparative study from previous studies using the AHP method and the Delphi method. The purpose of the design is to solve dependencies and barriers in accessibility and mobility of wheelchair users. The output obtained is visualization design concept of wheelchair user transfer for entering and leaving a car according to the specified design requirement criteria.

1. Introduction

Person with disabiities are person who has a physical or mental disorder that is disturbing or is an barrier for them to carry out daily activities properly or normally [1]. In law No. 8 of 2016 stated that similarity opportunity is a condition that provides access to people with disabilities to distribute all aspects that potential of state and society administration. But in reality there are 414,222 people with disabilities are unemployed. Economic opportunities for disability can be pursued by increasing accessibility and adequate mobility [2]. Conditions that severely limit the space for wheelchair users is the lack of mobility devices from one place to another, and the lack of public transportation that can be accessed by wheelchair users. Therefore it is necessary to design mobility devices in order to increase access for wheelchair users, including assistive devices fr wheelchair users to entering and leaving the car.

At present in some developed countries a tool for wheelchair users has been developed to entering and leaving the vehicle so as to facilitate the mobility of wheelchair users. Considering the high demand and high price of mobility devices abroad and to reduce import dependence, it is necessary to develop technology designs in the form of devices to mo ve people with disabilities in wheelchairs to entering and leaving a car as well as moving devices from one place to another. Research on previous comparative studies has been conducted Arief (2014) regarding the Development of Urban Bicycle Concepts by Considering Ergonomic Criteria. The study uses the Analytical Hierarchy Process method by considering ergonomic criteria. In the initial study 74 criteria were found on urban bicycles. After confirmation to the expert, 13 criteria will be used as assessment material. Alternative objectives used in the study were 17 alternatives.

The development of a design concept generally requires references or preliminary designs that are selected based on certain considerations. There are 16 mobility devices in several countries [3]. However, only 11 research reference mobility devices that relevant for this study. Of the 11 studies, each of them has advantages and disadvantages of each research. The research reference will be an alternative goal in the assesment. In this study try to do a systematic comparative study of the 11 studies by determining the criteria obtained from the initial study involving several experts and persons with disabilities in wheelchair users.

Determination of criteria is done by consensus using the Delphi Method because it requires exploration of opinions from various expert [7]. Then an assessment is done using Analytical Hierarchy Proccess (AHP) to generate the score of each criterion and priority of the goal alternatives [4][5][6]. From the results of the comparison, it is expected to obtain design requirements for the development of design wheelchair users to entering and leaving a car. The purpose of designing mobility devices for wheelchair user is to reduce wheelchair user dependence, reduce mobility and accessibility barriers for wheelchair users, and design safe also stable devices.

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2. Research Method

A. Identification Problem

The background of the problem is an idea from the emergence of a problem to an explanation of the problem in the current condition and threats that will arise if the problem is not immediately resolved. There is a gab between the rules that have been made with the current conditions.

B. Determination of Criteria

The collection of criteria is obtained through three aspects, namely aspects of assistive technology [8-12], biomedical devices [13-17], and universal design [18]. The results of the agreed criteria collection are then in the form of a hierarchy of criteria for pair assessment with the Analytical Hierarchy Process.

C. Determination of Alternatives

Selection of reference alternatives is adjusted to the performance criteria that have been previously set. The results of alternative reference selection are then paired for assessment and get the highest rating. The reference alternative with the highest weighting value will be a reference for the development of car in and out tools for wheelchair users.

D. Determination of Design Requirement

From the paired assessment, we also find the weight of each criterion that will be used as a design requirement in the design. The design of the design concept is adjusted to the design requirements that have been obtained and then the design results are returned to the respondent whether it is appropriate, if appropriate, then the analysis phase is carried out, whereas if it is not appropriate then go back to determining the design requirements and re-design.

E. Design Visualisation

Design visualization is obtained from the design requirements and alternative concepts that get the highest value.

F. Analysis using Finite Element

To find out the level of strength of the tool, the analysis is done using Finite Element Analysis in Autodesk Inventor. From Finite Element Analysis the results of stress analysis, displacement analysis and safety factor can be known. Then a mass analysis is carried out to determine the mass of the aid.

Table 1. Criteria Hierarchy

Goal	Criteria	Sub Criteria	Sub sub Criteria
Criteria compiler for mobility devices wheelchair users to entering and leaving a car	Criteria for assistive devices are adapted to adaptive design	Accessibility	The properly of the devices function in use.
			Using an automatic control system
			Simple use
			Flexible tools for use
		Effectiveness	The length of time used to use the devices
			Movements of the user are not complicated
		Easy to Handle	Easy installation of devices
			Easy to saving
			Can be applied to all types of cars
			Can be installed in various parts of the car body
		Independence	Independence of the use of devices
		Ergonomic	Body work position is right
			Low physical effort
			Low physical workload
			Light arm load
			Does not cause shoulder pain
			Does not cause spinal cord injury
			Body Fit

Table 1. Criteria Hierarchy (Continued)

Goal	Criteria	Sub Criteria	Sub Sub Criteria
Criteria compiler for mobility devices wheelchair users to entering and leaving a car	Criteria assistive devices are adjusted with usability design	Performance	A tough frame formation
			Strength of the devices when supporting the user body
		Safety	Condition of the body when transfer is safe
			Devices not damage the car parts
		Proper Material	Lightly Material
			Tough material
			Durable material
	Criteria assistive devices are adjusted with universal design	Design	Does not need large space
			Simple design
			Appearance
		Cost Effectiveness	Effective production cost
			Effective maintenance cost
		Sustainability	Adaptability over the lifespan
			Friendly materials
			Maintenance is easy

3. Result and Analysis

Pairwise comparison calculation starts from the criteria level then sub criteria, subsub criteria, and finally the alternative goal. The first calculation is at criteria level there are 3 criteria, adaptive design, usability design, universal design. From the results of assessment among 7 respondents, geometric calculations were calculated to get a combination of criteria assessment.

Table 2. Combined Criteria Level Assessment

	Criteria	Respondent							A
		1	2	3	4	5	6	7	
Level 1	x-y	5	7	7	3	5	5	3	4.76
	y-z	3	3	3	1	5	3	3	2.76
	z-x	1/5	1/7	1/7	1/5	1/7	1/5	1/3	0.19

Description :
x : Adaptive design
y : Usability design
z : Universal design

This is an example of a calculation with a geometric mean in the comparison of xy pair : respondent 1= 5, respondent 2 = 7, respondent 3 = 7, respondent 4 = 3, respondent 5 = 5, respondent 6 = 5, respondent 7 = 7. From seven data, the geometric mean is used using the equation :

$Aij = (z_1 \times z_2 \times z_3 \times .... \times z_n)^{1/n}$

$A = (z_1 \times z_2 \times z_3 \times .... \times z_n)^{1/n}$

$A = (5 \times 7 \times 7 \times 3 \times 5 \times 5 \times 5 \times 7)^{1/7}$

$A = 4.76$

The same calculation used for other paired comparisons and the following results are obtained :

Table 3. Total *Geometric mean* at Criteria Level

Goal	x	y	z
x	1	4.76	5.38
y	0.21	1	2.76
z	0.19	0.36	1
Total	1.40	6.13	9.14

Then, next calculation is normalization of assessment score.

Table 4. Normalization of assessment score at level criteria

Goal	x	y	z	Total	X score
x	0.72	0.78	0.59	2.08	0.69
y	0.15	0.16	0.30	0.62	0.21
z	0.13	0.06	0.11	0.30	0.10
Total	1	1.00	1.00	3.00	1.00

Then calculate the consistency ratio (CR). If consistency ratio (CR) is smaller or equal to 10%, the matrix fulfill the requirements for consistency. The results of the calculation are as follows :

$$\underbrace{\begin{vmatrix} 1.00 & 4.76 & 5.38 \\ 0.21 & 1.00 & 2.76 \\ 0.19 & 0.36 & 1.00 \end{vmatrix}}_{\text{Matrix}} \; X \; \underbrace{\begin{vmatrix} 0.69 \\ 0.21 \\ 0.10 \end{vmatrix}}_{\text{Score}} = \underbrace{\begin{vmatrix} 2.21 \\ 0.63 \\ 0.30 \end{vmatrix}}_{[a]}$$

From the results of the calculation, each row in column [a] is divided by the average value (score) for price determination (D), the division is as follow :

$$D = \begin{vmatrix} \frac{2.21}{0.69} & \frac{0.63}{0.21} & \frac{0.30}{0.10} \end{vmatrix} = \begin{vmatrix} 3.19 & 3.06 & 3.02 \end{vmatrix}$$

Then, the average value of the calculation above is calculated to obtain value of λmax :

$$\lambda max = \frac{\text{The number of elements in the criteria score matrix}}{\text{N}} = \frac{9.27}{3} = 3.09$$

Next step is to find the consistency index (CI) value that calculated using the formula :

$$CI = \frac{\lambda \max - N}{N-1} = \frac{3{,}09-3}{3-1} = 0{,}046$$

Consistency ratio (CR) is obtained from the result of the consistency index (CI) with Random Index (RI) as in table 2, then for the matrix 3x3 or N=3, which is 0.58.

$$CR = \frac{CI}{RI} = \frac{0.048}{0.58} = 0.079$$

A consistency value of 0.079 or equal to 7.9% is acceptable because it is smaller than 10% an it is accordance with the term of consistency.

The same calculation is used for sub criteria level and sub sub criteria. At level of sub criteria adaptive design obtained consistency ratio of 4.7%, sub criteria usability design obtained consistency ratio of 1.6%, sub criteria universal design obtained consistency ratio of 1.4%. Then the next calculation is sub sub criteria level. Consistency ratio value on sub criteria accessibility is 3.3%, 0% effectiveness, 4.5% easy to handle, 4.3% ergonomic, 0% performance, 0% safety, 0.5% proper material, 0.5% design, 0% cost effectiveness, and 2.8% sustainability.

In pairwise comparison calculation between subsub criteria and alternative goal used expert choice software. Because in normally humans can only compare stimuli in a limited range and their perception is sensitive enough to make difference, the comparison range should not be too wide or will be inconsistency. The output obtained is priority level for each alternative goals.

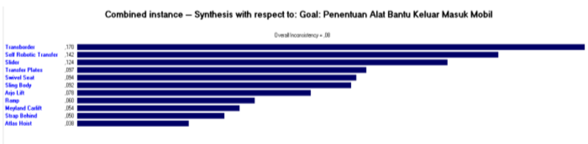

Figure 2. Priority Graph of Alternative Goal

The overall consistency of the alternative goal assessment is 0.8% and it is within the limits of consistency. The first rangking is transborder alternative with a score value of 0.170 then followed by self robotic transfer alternative with a score of 0.142. The most criteria that dominates and prioritize is independently use.

Variations in priority criteria and their effects on alternative prioritize can be obtained with sensitivity analysis using experts choice software. The following is a performance sensitivity shown in figure 3:

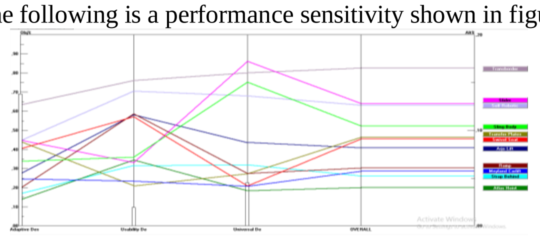

Figure 3. Performance Sensitivity Graph of Alternative Goals

The selected alternative is an alternative that has the highest total scoreing value from the previous calculation. Alternative transborder obtained with a score of 0.170 and self robotic transfer 0.142. The highest two were chosen from alternatives because of the two alternatives dominating the independence criteria which was an important aspect in designing a devices for disability. From these two alternatives, a development analysis was carried out and then reassessed to 7 experts.

Table 5. Potential Development Criteria

Subsub Criteria	Transborder	Self Robotic Transfer
Easy to saving	0.375	0.342
Lightly Material	0.511	0.312
Does not need large space	0.678	0.349
Does not cause spinal cord injury	1	0.398
Low physical effort	0.777	0.474
Low physical workload	1	0.498
Does not cause shoulder pain	1	0.404

Then the criteria that have low value are carried out development analysis for each alternative. If it can be developed, the value of the criteria will increase and if it cannot be developed the value is fixed. Value of the result of the analysis between two alternative transborder and self robotic transfer devices is compared again. An alternative that has the highest value will be used as the best concept. At table 6 showing the result of improvement value.

Table 6. Improvement Assessment Result

Subsub Criteria	Transborder	Self Robotic Transfer
Easy to saving	0.550	0.487
Lightly Material	0.607	0.419
Does not need large space	0.599	0.582
Does not cause spinal cord injury	1	0.687
Low physical effort	0.691	0.831
Low physical workload	1	0.729
Does not cause shoulder pain	1	0.727

Then the alternative goal that have the highest score after development analysis is transborder alternatives. Transborder alternative value is 0.174 and self robotic transfers value is 0.143. The next step is to develop concept of transborder devices to obtain the optimal design result.

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The results of the evaluation will be the main development improvement. And the main criteria that form the basic of design are independence in use, safety, comfort, and convenience. The following is a design visualization design that is adapted to the previous criteria.

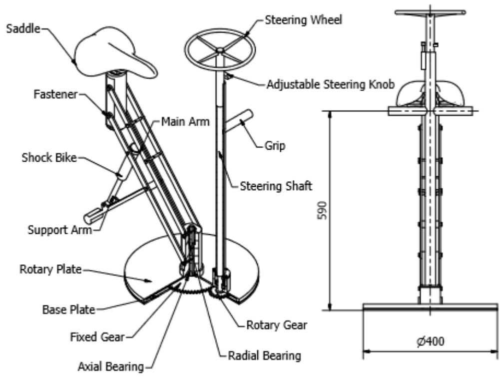

Figure 4. Mechanism of Design Concept

How to use the transfer devices is by lowering the sadle to same level as wheelchair seat. Then the user move from a wheelchair to devices. User can adjust the height of the devices by adjusting the shocks bike's that used remote control. Devices can be rotate by rotating using steering wheel that controlled by planetary gear at base plat. Then after the rotation, user adjust the height level of the tool and move to other place. Following is the process of using an transfer devices.

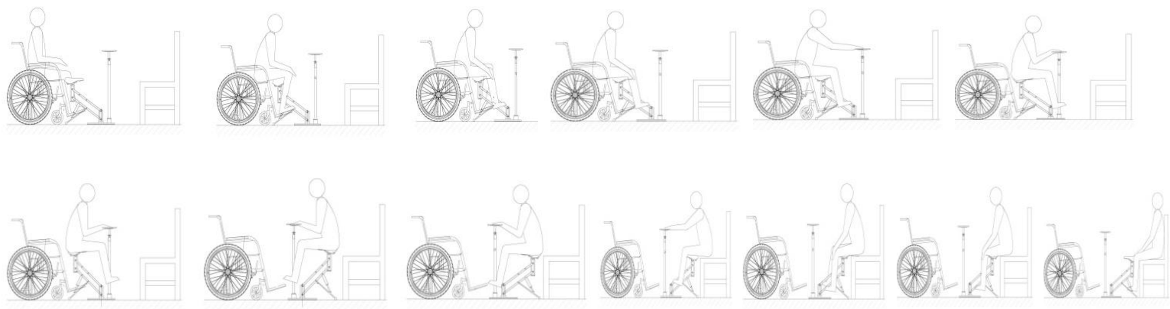

Figure 5. Step to Use Devices

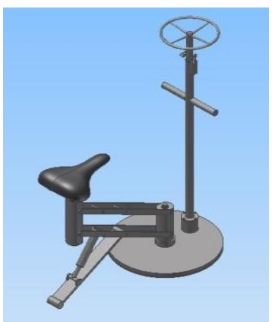

Figure 6. 3D Design Visualization

So the design of assitive devices for wheelchair users to entering and leaving a car can used independently and improving the safety in using assisive device. The limitation is ability of the upper extremity body is good and the maximum user load of 125 kg. Then do analysis from the design using Finite Element Analysis. Material that used is steel st 37.

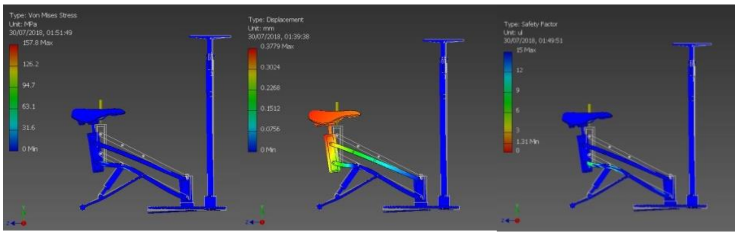

Figure 7. Von Misses Stress Analysis, Displacement Analysis, Safety Factor

The level of safety of the tools to move wheelchair users to get in and out of the car with st 37 steel material is at least 3 ul and a maximum of 15 ul, maximum stress analysis is 157.8 Mpa, and maximum displacement analysis is 0.3024 mm

4. Conclusion

Based on the data, there are 3 criteria, 11 sub criteria, and 32 sub sub criteria in assistive devices for wheelchair user to entering and leaving a car. There are 11 alternative goal references for this devices and transborder alternative is the highest ranking. Transborder alternative used for reference in developing the device design. Design of devices for wheelchair user to entering and leaving a car using leveling sistem and rotation system. System that used for leveling is shock bikes that controlled by remote and can be controlled slowly. For rotation system using a planetary gear at base plate and controlled by steering wheel. Maximum load that can be received by this devices is 125 kg. The design of assistive devices for wheelchair user to entering and leaving a car can increases independence, overcome the mobility barriers, and can move to another place safely and stably. The level of safety of the tools to move wheelchair users to get in and out of the car with st 37 steel material is at least 3 ul and a maximum of 15 ul, maximum stress analysis is 157.8 Mpa, and maximum displacement analysis is 0.3024 mm.

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