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Optimization Of Handcycle Design And Engineering Using The VDI 2221 Method Through An Anthropometric Approach For The Disabled

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ABSTRACT
People with disabilities are people who experience physical limitations either due to birth or accidents and so on, causing difficulty in walking and other activities. One of the obstacles for them is the existence of transportation to do work or just for daily mobility. And one solution to help people with disabilities in doing daily activities is a handcycle. Handcycle is driven by the arms, not the legs. Handcycle is generally used by people with disabilities who have limitations in using their legs. The research activity aims to produce a handcycle product that is friendly to people with disabilities with an anthropometric aspect approach where the bicycle can be moved either manually or electrically. The position of the seat and steering system can be adjusted according to needs. The seat arrangement (adjustable chair) and steering wheel arrangement (adjustable steering wheel) need to be planned in order to provide a sense of security and comfort to the user. The creation of this bicycle product design begins with identifying customer needs, designing a design concept, designing a shape, designing details and making the product. Where Product Design using the VDI 2221 method. A design method that uses a systematic approach to designing products and engineering systems. Through testing of handcycle products carried out by 2 people (users) with disabilities, it shows that users can adjust the distance of the body with the electric steering system and manual steering by adjusting the distance between the seat and steering wheel. The distance between the seat and the electric steering wheel is 726 - 838 (mm), the distance between the seat and manual steering wheel is 675 - 785 (mm), the height of the seat from the floor is 550 - 700 (mm) with a vehicle speed of 25 km/h if using an electric motor.

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INTRODUCTION

Disability is a term that includes disorders, activity limitations, and participation restrictions (1). Based on the definition set by WHO, disability is a condition that causes disruption to a person's relationship with their environment (2) (3). Physical imperfections are often an obstacle for someone to carry out various daily activities. One form of physical imperfection is the presence of disorders or damage to bones and muscles which are more often referred to as Physical Disability (2) (4). As a result of the disabilities they have, individuals with physical disabilities face various problems, both in terms of emotions, social and work (5).

*Hand cycle*is a combination of a wheelchair and a bicycle that began to be developed since 1900. It has become an alternative transportation for those with lower limb disabilities (6). Handcycle is a bicycle whose rider is in front of it, driving it using an arm chain and crank transmission. Most bicycles are tricycle-shaped, with two rear wheels sliding and one front wheel powered and controllable. Although they usually have three wheels, they are also known as handbikes (7) (8).

Figure 1. Handcycle for the disabled

*Hand cycle*generally have seats that are often too low and create a risk of accidents due to collisions with the road. This is actually understandable considering the difficulty for users when they want to ride it. And in Indonesia itself, there is no product/manufacturer that produces handcycle bicycles that can position users as if riding a normal bicycle. And Indonesia has never produced a handcycle product (6). This study designs a handcycle and makes a prototype based on the frame design, seat design that can be adjusted according to anthropometry.

Planning as a process of transforming ideas or market needs into detailed information where a product can be made. Design by type: Original design is a new design and has never existed before. Additive design, aims to obtain a design plan to be better in terms of quality, both technical and non-technical through technical improvements/methods/working principles, Variant design is a design process where the scale of dimensions or details of the designed tool is changed without changing the function or working method of the tool (9). The benefits of the design stage that make it easier for designers to get good results, namely: The time set for a job can be realized, The budget plan can be controlled well and the goods/products produced have the appropriate technical and functional value (10).

The purpose of this study is to obtain the best design variant using the VDI 2221 design method through an anthropometric approach to the final product in the form of a prototype. The results of this study are expected to provide more benefits for users by increasing comfort when boarding, driving and getting off the vehicle. Based on the research objectives above, the following problem formulation is carried out in this study:

1. How to implement the VDI 2221 method in the handcycle design optimization process through an anthropometric approach?
2. How to realize the handcycle design that has been obtained to become a product (pro-totype)?

Through the formulation of the problem that has been determined, it is expected that the results of the research can produce a handcycle product as a design result by implementing the VDI 2221 method where the chair can be adjusted according to anthropometry.

METHODS

Design Method

The method used in this study uses a flow diagram as in Figure 2. To facilitate getting the best results in the design that suits the needs, a design method is used to make it more measurable and focused. The method used is the VDI 2221 method.

The VDI 2221 Design Method is a design method created by the German Engineers Association Verein Deutscher Ingenieure/VDI which is described by Gerhard Pahl and Wolfgang Beitz. The method is a "Systematic Approach to the Design of Technical Systems and Products". The specialty of the VDI 2221 design method lies in the conceptual design stage, namely the steps for creating a functional structure that identifies the elements that make up the technical system to be created and the functions that must be performed by each element so that the system as a whole can carry out its tasks. (11)

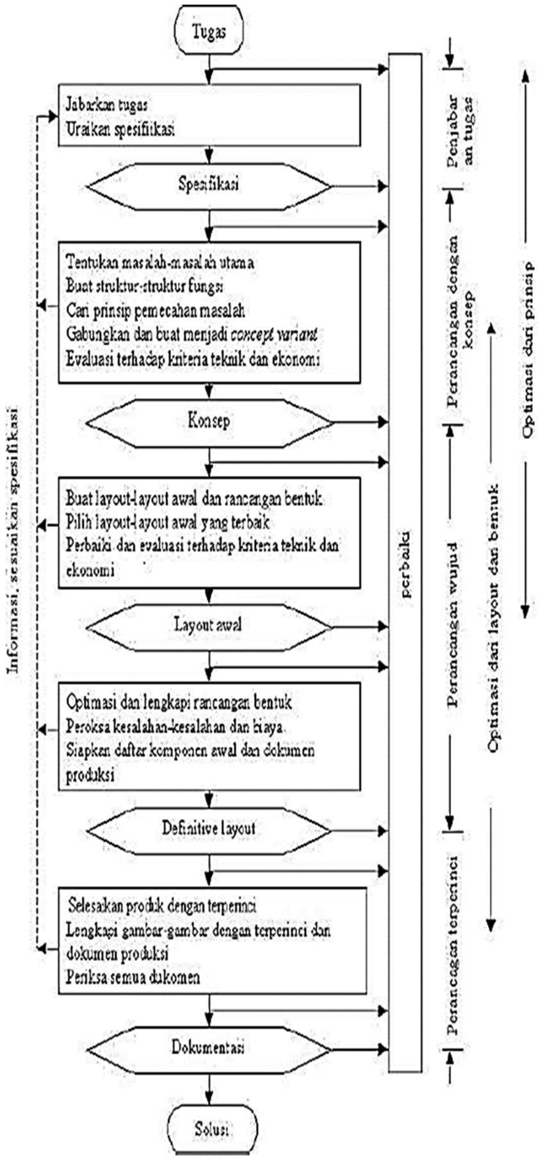

Figure 2. VDI 2221 Method Diagram

In terms of product design with VDI 2221, there are at least 4 main processes that must be carried out, namely: (11)

1. *Clarifying the tasks and planning*(Determine needs).
   The description of this task includes information about the problems and obstacles faced. Then a list of requirements is prepared regarding the design that will be made as a result of this stage in the form of conditions or specifications.
2. *Conceptual design*(Concept design).
   Includes information on search function structures, suitable problem solving principles and combines them into variant concepts. The result of this stage is basic problem solving or concepts. In determining this design concept, there are three work steps, namely:

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a. Determine its function and structure
b. Finding the solution principle and its structure
c. Breaking down into variants that can be realized

3. *Embossment design*(Designing form)
The combination sketch of the solution principles that have been made is a form of initial layout, then selected which meets the requirements that are in accordance with the specifications and are good according to technical and economic criteria. The initial layout that is selected and developed into a definitive layout which is a form of design that is in accordance with needs and expectations. The definitive layout includes several things that are the results of this stage, including:
a. The form of a product element
b. Engineering calculations
c. Selection of shape and size

4. *Design details*(Detail image).
In this stage, the design results are made into a product document, so that it can be produced continuously and product development is better, this product document can include:
a. Drawings
b. Image Details
c. Operating System

Anthropometry (Human Body Dimension Calibration)

Anthropometry is a collection of numerical data related to human physical characteristics that will be used in the design/planning process (12). To support the anthropometric approach, it is necessary to determine the following design:

Handcycle seat design includes:
1. Seat height setting
2. Seat length determination
3. Seat width determination

Handcycle Steering Bar Design
1. Determining the distance between the handlebars and the driver
2. Steering wheel height adjustment
3. Steering wheel width setting

Design of handle, front brake, rear brake and gear transmission of handcycle
1. Design of the paddle handle
2. Determining the distance between the rotary handle and the rider
3. Determining the length of the manual steering handle
4. Determining the distance from the front brake lever to the handlebar grip

Based on the VDI 2221 Design method and the anthropometric approach, a problem-solving flow diagram is determined as in Figure 3.

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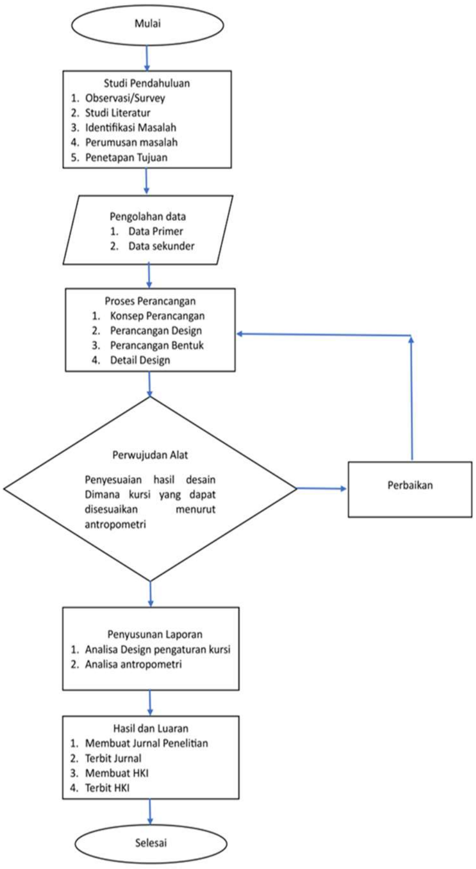

Figure 3. Flowchart of Research Implementation Stages

Primary data collection

Primary Data, is data obtained directly from related sources, either through interviews, questionnaires, or collecting documentation images. The main data taken in this study include:

1. Bicycle frame design
2. Electrical Components
3. Construction and transmission
4. *Assembling*component

Secondary Data Collection

Secondary Data, is data obtained from libraries and the internet such as articles about handicapped tricycles, manual books, tribike manufacturing journals, and other supporting data. Supporting data taken in this study include:

1. Handycycle pictures
2. Bicycle Material Reliability
3. Electrical Component Technical Data

After the data is obtained, the next step is to carry out an alternative design process to find the best variant that will be made into a prototype product.

RESULTS AND DISCUSSION

Clarify the Task and Planning

With the VDI 2221 design method, to fulfill the design concept and design, a list of requirements consisting of several design aspects can be identified. The assessment aspect consists of things that must be met, namely Demand (D) or still limited to desires or what is called wishes (W) and can be seen in table 1.

Table 1 Design Concept Analysis

No	Analisa Konsep Perancangan	D/W	Spesifikasi
1	Ergonomi	D D D W	Dimensi Kursi nyaman bagi pengguna Posisi kursi dapat diatur sehingga nyaman bagi pengguna Posisi kemudi dapat diatur sehingga nyaman bagi pengguna Posisi Kaki lebih leluasa
2	Rekayasan a. Sistem Gerak b. Struktur c. Engineering	 D D D D D D	 Sistem gerak manual dan Elektrik Roda BLDC dan Konvensional Rangka simple dan kuat Konstruksi rigit Kelistrikan Pengereman
3	Estetika	W W	Warna menarik Bentuk sederhana
4	Ekonomi	W W	Biaya Produksi terjangkau Biaya beli terjangkau
5	Sosial	D	Mendukung mobilitas secara lebih luas
6	Kebutuhan a. Handcycle b. Barang bawaan	 D D D W	 Nyaman di gunakan Kuat secara konstruksi Adjustable Lampu, GPS, Klakson, Rak

Information :
D = Demand
W = Wishes

Anthropoetric Analysis

In designing a hand crank bicycle (Handcycle), the first thing that can be done is to measure the body dimensions of the disabled person in a stationary position and take them linearly (straight) on the surface of the body as in the following image:

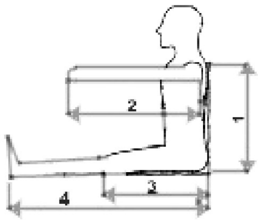

Figure 4 Anthropometry of people with disabilities (Source: Jarosz. 1996, edited)

In determining the design of a bicycle that is in accordance with the ergonomics of Indonesian men and women, it is necessary to know the anthropometric percentile of the user. There are 3 types of Riding Position used on tricycles, namely classic, dynamic, and sport. On this type of bicycle, the classic position is applied so that the user does not get tired easily and the foot position is more relaxed. from the research of Rela Adi Himarosa and Sunardi from their journal entitled "Design, Frame Analysis and Manufacture of Handcycle Prototype" revealed that the Handcycle was designed based on anthropometric data.

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Characteristics of anthropometric data from the Indonesian National Standard for People with Disabilities in Indonesia (6)

Table 2 Anthropometric Data of People with Disabilities

No	Pengukuran	Laki-laki			Perempuan		
		Avg.	5%	95%	Avg.	5%	95%
1	Posisi tinggi bahu duduk	569.0	563.1	575.0	506.9	499.4	514.3
2	Tinggi siku posisi duduk	216.7	214.3	225.1	131.8	124.9	138.7
3	Kedalaman poplitea	485.5	481.5	489.5	459.5	452.4	466.6
4	Tinggi poplitea	430.3	425.9	434.7	339.2	331.3	347.0
5	Lebar bahu	460.6	455.9	465.2	416.8	410.0	423.6
6	Luas pinggul	328.9	324.0	333.9	320.9	313.2	328.5
7	Keluasan siku	455.5	451.9	459.1	446.7	442.8	450.5

Information :
5% : 5th percentile value (indicates the population small body)
95% : 95th percentile value (indicates the population large body)
(note: the anthropometry of Indonesian people with disabilities is generally obtained from interpolation of European anthropometric data to determine the anthropometric data of people with disabilities in Indonesia)

From the dimensions that have been set, several alternatives are then carried out which aim to obtain the dimensions of the bicycle and are related to the riding position. The position used greatly affects the comfort of the user, in this case a person with disabilities in an urban area. The following is a table explaining the riding position and style quoted through (ergotec, 2019) and a review from (Albar, 2018).

Table 3 Sitting Positions When Riding a Bicycle

Ilustrasi	Keterangan	Kelebihan	Kekurangan
 Classic (Dutch) Ride Position	Posisi ini cocok untuk berkendara berkecepatan sedang. Pada sepeda klasik Anda duduk dengan nyaman. Postur tubuh Anda tegak, hampir vertikal (sudut 90 ° ke tanah). Setang dan pegangan sangat dekat dengan tubuh.	Tekanan pada lengan dan tangan sangat rendah. posisi yang optimal untuk berkendara santai.	Semua beban keseluruhan bertumpu di pantat sehingga tidak cocok untuk menempuh jarak yang jauh dengan waktu yang lama
 City Ride Position	Posisi ini cocok untuk berkendara jarak pendek dan memungkinkan pengendara untuk dapat menikmati lalu lintas. posisi duduk dengan batang tubuh yang agak condong (sekitar 60 ° hingga 70 ° ke tanah). Semua sepeda kota memiliki setang tinggi.	Postur tegak memberikan pandangan yang baik untuk berkendara di lalu lintas kota, Beban dipindahkan (dibagi) pada pijakan kaki	Tingginya seat menjadikan tulang punggung condong ke depan, Lengan sering pada posisi lurus untuk menggenggam setang yang tinggi. Hal ini menyebabkan bahu dan rasa sakit.
 Sporty Ride Position	Posisi sporty cocok untuk berkendara dengan kecepatan tinggi. Posisi duduk dengan batang tubuh yang sangat miring (sudut 15 ° hingga 30 ° ke tanah). Saddle lebih tinggi dari setang.	Transmisi beban yang optimal karena beban di bagi pada 3 tumpuan, Aerodinamis, dam resistansi udara rendah.	Tidak cocok untuk bersepeda dalam lalu lintas sehari-hari. Tubuh tegang seiring dengan tingkat kinerjanya. Menuntut area otot yang sangat terlatih (punggung, kaki, bahu, perut).

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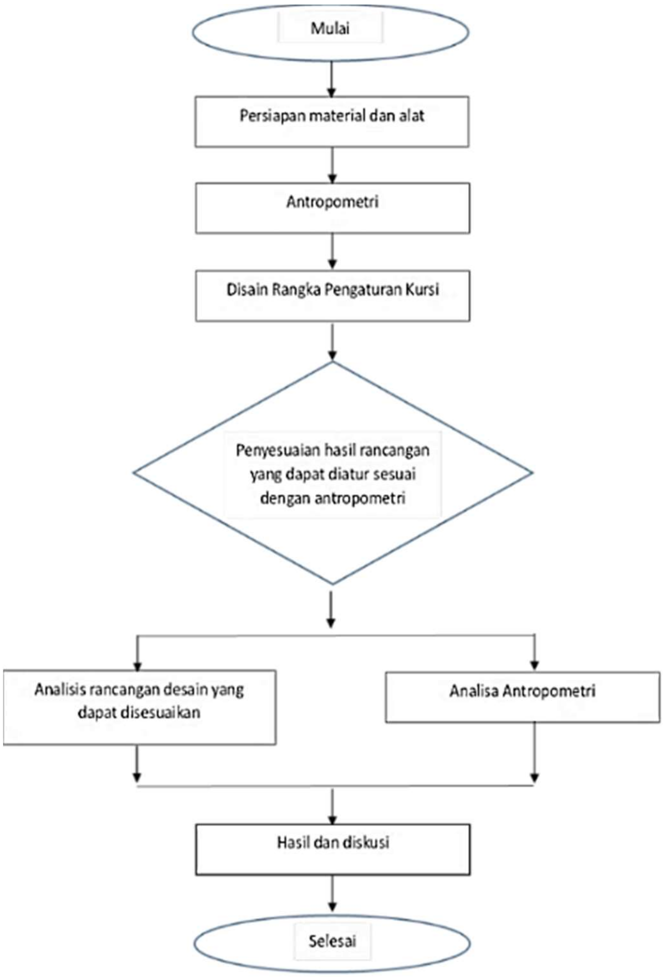

Figure 5. Flow diagram of an adjustable seat on a hand bike

Conceptual design (Concept design)

At this stage, the function division of the tool that will be designed as a means to find alternatives for each of these functions is carried out. To facilitate the division of functions, you can create a function chart in the form of a Black Box Concept as in Figure 6.

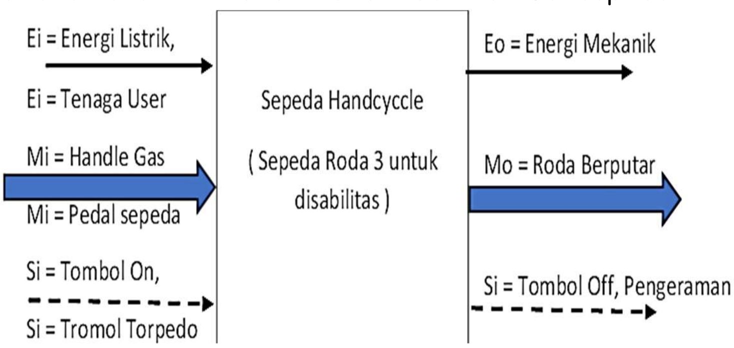

Figure 6. Tool Function Block

Function structure is the input and output of an engineering system to perform a specific task. The function structure of this handcycle consists of 2 elements, namely the overall function and the overall sub-function created in a module system as seen in Figure 7.

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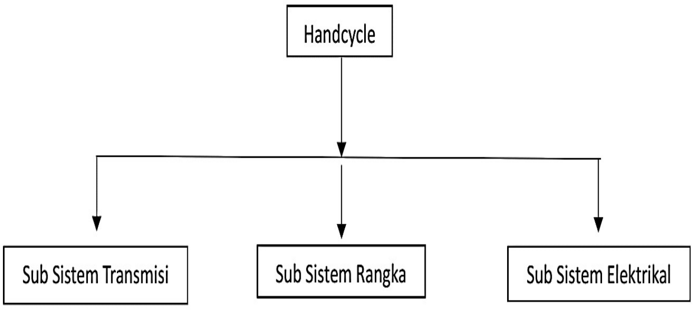


Figure 7. Module System

Based on the black box concept development module system above, an alternative design and design scheme was created which can be seen in Figure 8. And to further serve as a guide in selecting alternative subsystems.

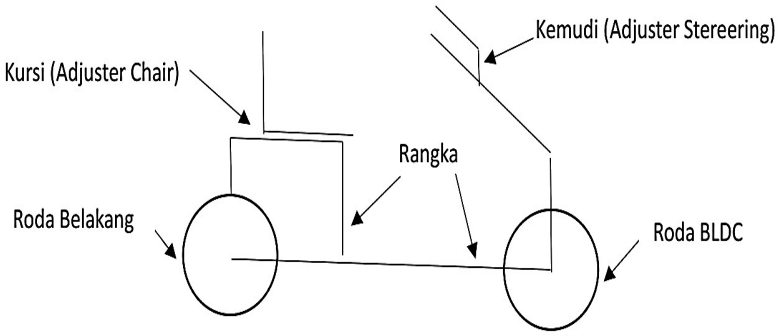
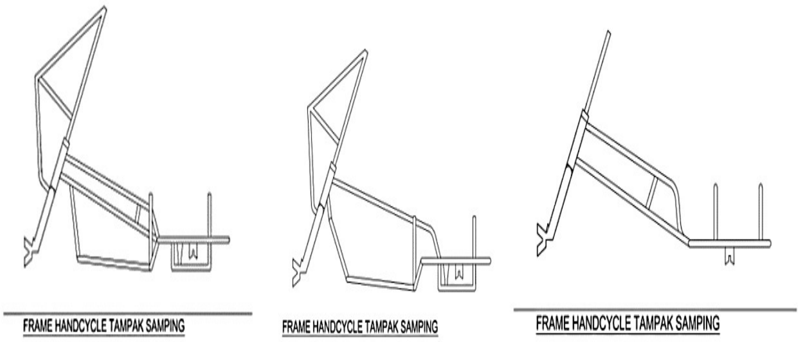


Figure 8. Design Schematic

Handcycle Design Concept

At this stage, it is done by making several product designs as an alternative process or material determination. The following is a picture of 9 Handcycle frame design.



Variant 1 Variant 2 Variant 3

Figure 9. Frame Design Variants

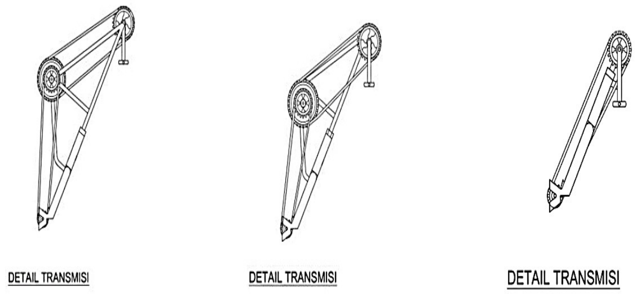
Conceptually, the difference between each variant of this tool is in the design of the middle frame, namely:

1. Variant 1 does not use bottom reinforcement and the battery mount is placed at the back. Frame construction using MS ST37 pipe with a diameter of ¾"

2. Variant 2 uses floor reinforcement and the battery is placed under the seat frame. Frame construction using MS ST37 pipe with a diameter of ¾"
3. Variant 3 uses the bottom bone and the battery is placed in the middle of the floor. Frame construction using MS ST37 pipe with a diameter of ¾"

Transmission System Design Concept

Next, a supporting design for the handcycle is made, namely a transmission system for bicycle operations. Alternative transmission designs can be seen in Figure 10.



Variant 1 Variant 2 Variant 3

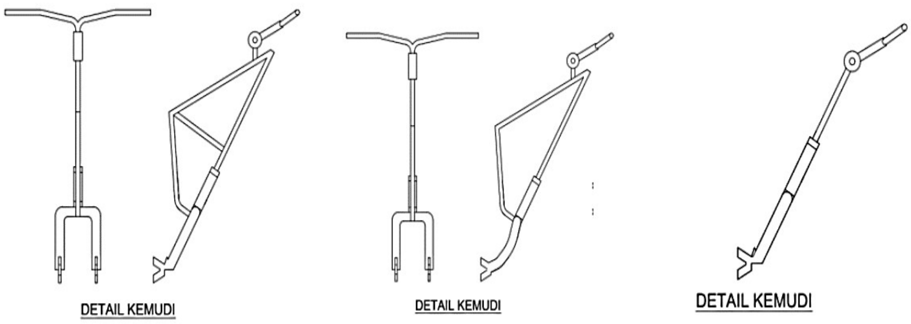
Figure 10. Transmission Design Variants

Conceptually, the difference between each variant of this tool is the placement and number of sprockets used, namely:

1. Variant 1 uses 2 times rotation shift and placement on the left side of the BLDC wheel. Using 4 sprockets
2. Variant 2 uses 2 times rotation shift and placement on the right side of the BLDC wheel. Using 4 sprockets
3. Variant 3 uses direct transmission from the driver (handling driver) to the BLDC wheel. Using 2 sprockets.

Steering Design Concept

The next design is the steering system. Variants can be seen in Figure 11.



Variant 1 Variant 2 Variant 3

Figure 11. Steering System Design Variants

Conceptually, the differences between each variant of this tool are:

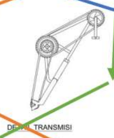
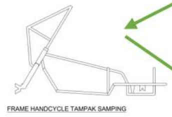
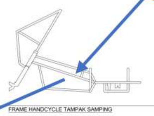
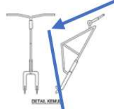
1. Variant 1 is prepared for 2 transmission system shifts with center reinforcement in the center sprocket mount.
2. Variant 2 is prepared for 2 shifts of the transmission system without center

reinforcement in the center sprocket mount.
3. Variant 3 is not prepared for the construction of placing the middle transmission system.

Selected Concept Results

Based on the technical specifications, several alternative handcycle concepts were created that could meet the requirements in the desired specifications. Table 4 shows the solution principles of the tricycle (handcycle) that will be determined in the concept design.

Table 4. Matrix Solution

No	Matrik Solusi	Varian 1	Varian 2	Varian 3
1	Sumber Penggerak / Energi			
2	Penerus daya / Transmisi			
3	Rangka Kendaraan			
4	Sistem Kemudi			
5	Pengaturan kursi			

In this stage, a work organ arrangement is carried out to obtain alternative combinations which are then selected to obtain the right results.

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Table 5. Model structure

No	Matrik Solusi	Varian 1	Varian 2	Varian 3
1	Sumber Penggerak / Energi			
2	Penerus daya / Transmisi			
3	Rangka Kendaraan			
4	Sistem Kemudi			
5	Pengaturan kursi			

Alternative Combinations With these principles, several combinations will be obtained, including:

Variant 1 : 1-1, 2-3, 3-2, 4-2, 5-3
Variant 2 : 1-2, 2-2, 3-1, 4-2, 5-3
Variant 3 : 1-3, 2-1, 3-3, 4-3, 5-2

Each alternative is then entered into a scoring matrix table based on its suitability to the design concept and objectives. The scoring matrix uses a scale of 1-5. The higher the value, the higher the level of suitability to the existing parameters.

Table 6. Variance Research Matrix

No	Parameter	Varian 1	Varian 2	Varian 3
1	Kemudahan Pengoperasian	5	4	3
2	Kebutuhan energi manual	4	4	2
3	Rangka Kuat dan Rigit	4	3	3
4	Kendali Gerak Ringan	3	3	3
5	Kenyamanan Berkendara	4	2	2
	Total	20	16	13

By using Table 6 to determine the selected variant, the product concept with the highest score is product concept/variant 1.

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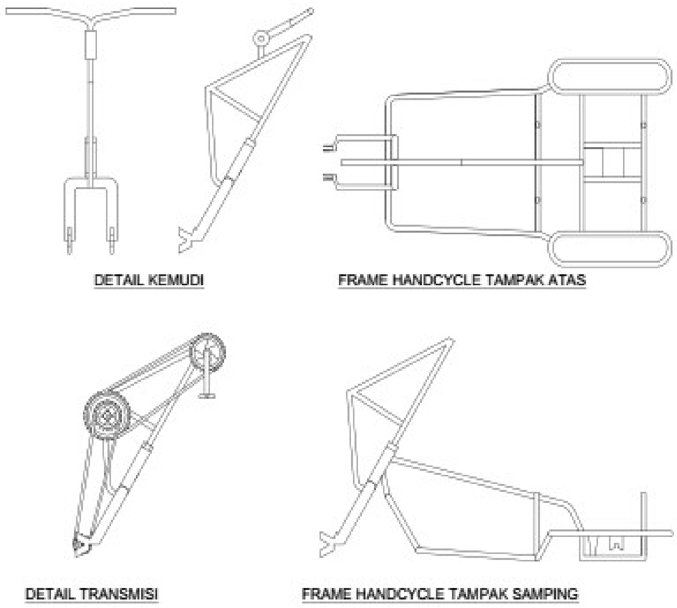

Figure 12. Selected variant (variant 1)

For the next product concept will be developed in product development. Next will be done the step of giving shape.

Shape Design (Embodiment Design)

Design here is a product concept that is "formed", namely a product concept designed in the form of a sketch or schematic diagram made into a product in a form that can be made using components that are planned in advance. Figure 12 shows the product layout.

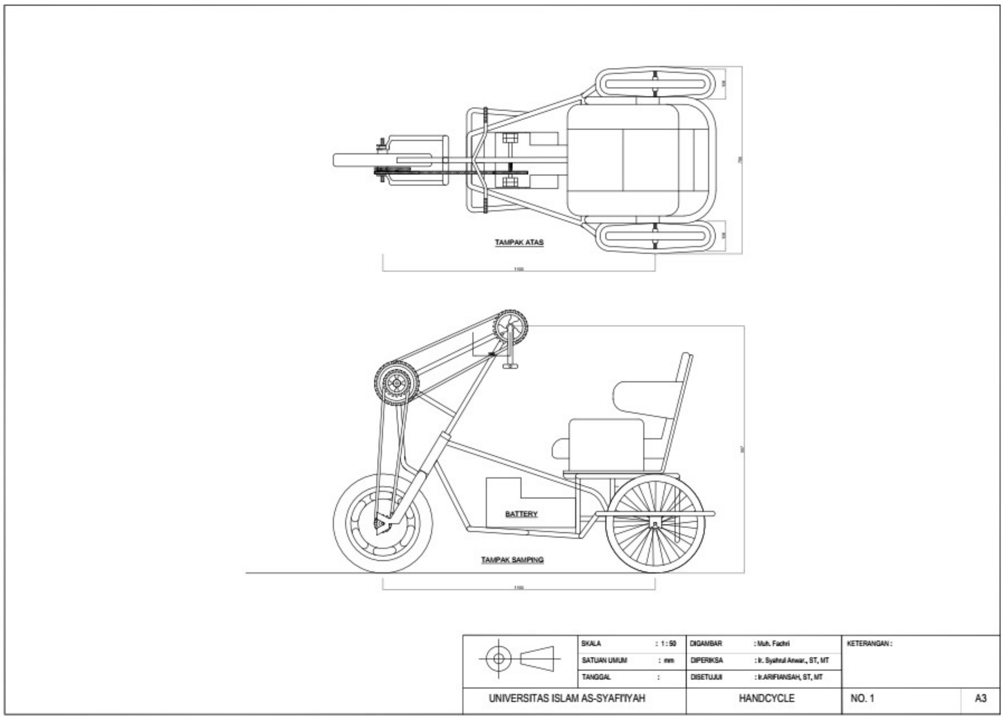

Figure 13. Handcycle Layout

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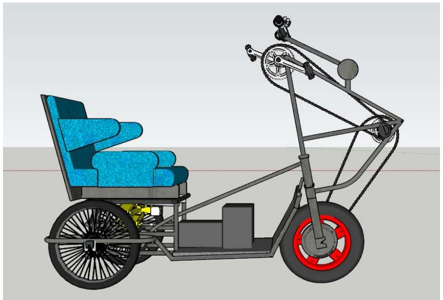
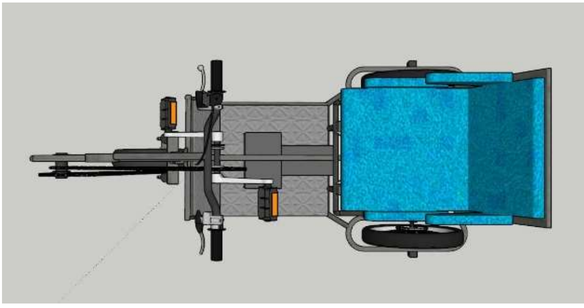

Figure 13. Handcycle variant 1

Handcycle Load Capacity Calculation

The vehicle load that must be borne by the handcycle is the user's weight, which is 70 kg. By calculating the maximum user load set, which is 100 kg, the calculation of the lorry load capacity is obtained:

F = 100 kgf

$$F = mg \quad (1)$$

= 70 kgf x 9.807 m/s2
= 686.7 kgf.m/s2
= 686.7 Newton (N)

Factor of Safety

*Factor of Safety*or what we more often know as the Safety Factor is a safety factor used to provide design assurance. (14) In machine construction design, the Safety Factor must be greater than 1 (one). The safety factor is given so that the construction design and machine components have resistance to the loads received. (14). The Safety Factor figures based on the type of load are as follows:

1. Static Loading : 1.25 – 2
2. Dynamic Loading : 2 – 3
3. Shock Loading : 3 – 5

Material Strength Calculation

The frame is made of materials that are widely available on the market, safe, reliable, low cost, and have good weldability. Low carbon steel (St 37 = AISI 1006) has a carbon content of less than 0.3% with a tensile strength of 37-45 Kg/mm2. (14)

Table 5. Material Properties

Mechanical Properties

Elongation %	22
Tensile Strength MPa	370
Yield Strength MPa	300
Shear Strength MPa	230
Hardness Brinell	100

By calculating the load borne by each frame as can be seen in Figure 14.

Jurnal Info Sains : Informatika dan Sains
Volume 14, Number 04, 2024, DOI 10.54209/infosains.v14i04
ESSN 2797-7889 (Online)
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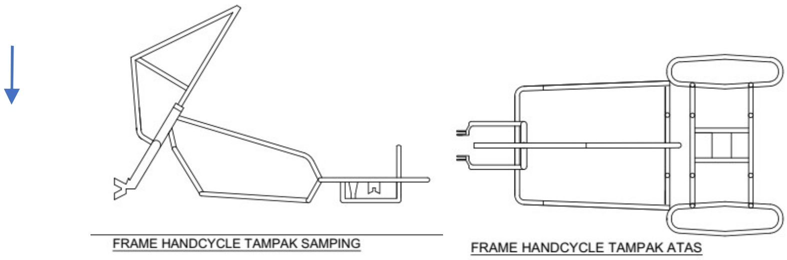

Figure 14. Bicycle Frame to be Analyzed

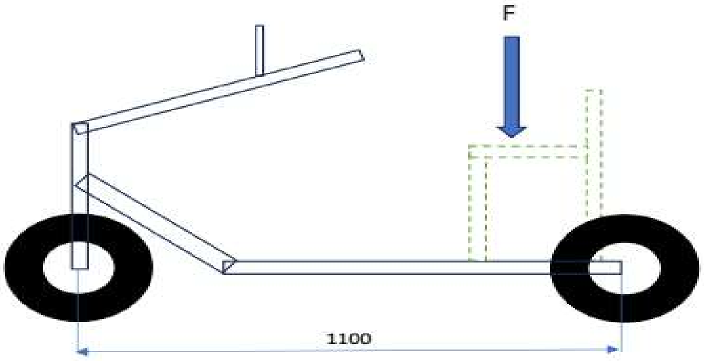

Figure 15. Handcycle Loading Layout

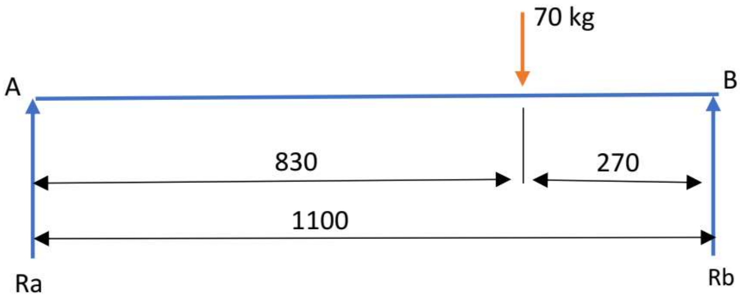

Figure 11. Free Body Diagram

∑ Ma = ∑ Mb = 0
∑ Ma = F x L
=(70x830) -Rb.1100 mm
1100Rb =58.100 kg.mm
Rb =52.8 kg

∑ Mb = F x L
= (70x270)-Ra.1100
1100Ra =18,900 kg.mm
Ra =17.2 kg
Ra + Rb = F
17.2 + 52.8 = 70

70 kg = 70 kg

So the maximum moment value that occurs at points RA and RB is ∑MFmax = 58,100 kg.mm

Maximum Bending Stress

$$\sigma_{max} = \frac{M_{max}}{W_{max}} \quad (6)$$

$$\sigma_{max} = \frac{1 \text{ x } b^2 \text{x h}}{(6)}$$

b2 = Width of cross-section / most critical support point
h =Cross-sectional height / diameter of iron pipe

$$\sigma_{max} = \frac{1\ x\ 270^2 x\ 19}{(6)}$$

= 0.252 kg /mm²
=2.2 N/mm2

Actual Voltage

$$\sigma_{aet} = \frac{\sigma_{max}}{Sf} \quad (7)$$

Based on the calculation above, where the design bending stress (**σ_{max}**) that occurs is 2.2 N/mm² with static loading (Sf = 4), the yield strength of the ST 37 material can be calculated:

$$\sigma_{aet} = \frac{370 \text{ N/mm}^2}{4}$$

= 92.5 N/mm²

Because $\sigma_{max} \leq \sigma_a c_t$ (2.2 N/mm2 ≤ 92.5 N/mm2), the pipe profile using ST 37 material is safe.

Detail Design

In this stage, the detailing step is carried out for the selected variant by providing complete specifications as in Figure 12.

Volume 14, Number 04, 2024, DOI 10.54209/infosains.v14i04
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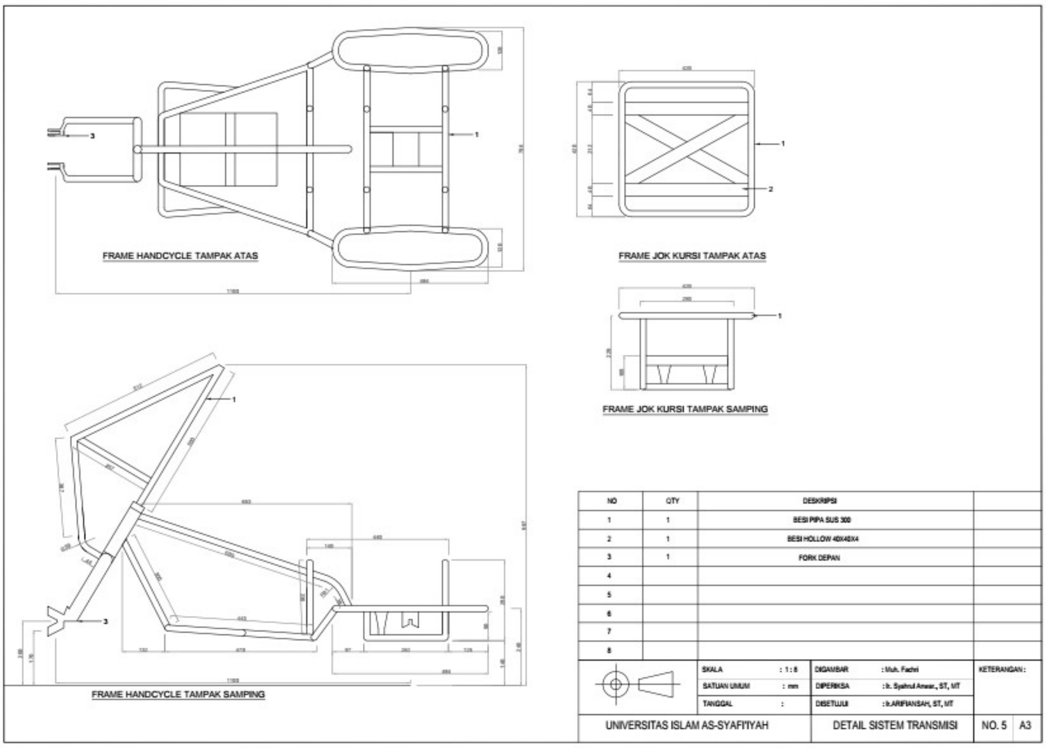

Figure 13. Frame Detail Drawing

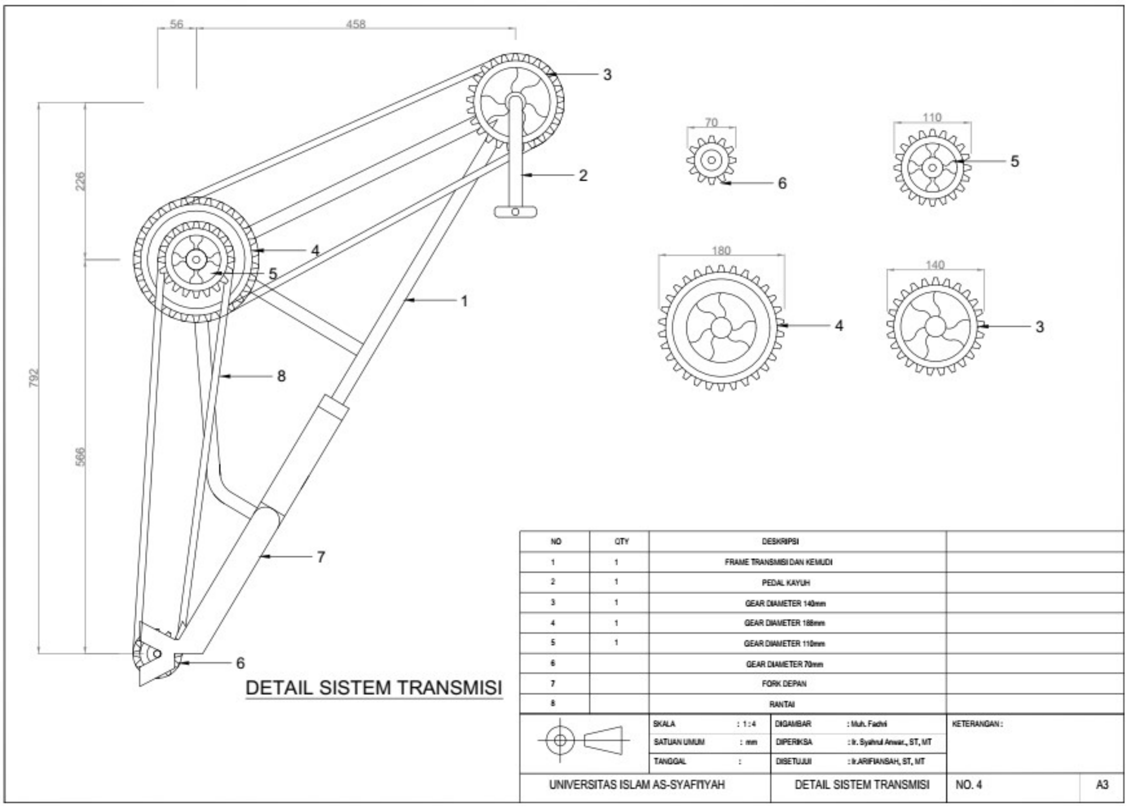

Figure 12 Transmission Details

Jurnal Info Sains : Informatika dan Sains
Volume 14, Number 04, 2024, DOI 10.54209/infosains.v14i04
ESSN 2797-7889 (Online)
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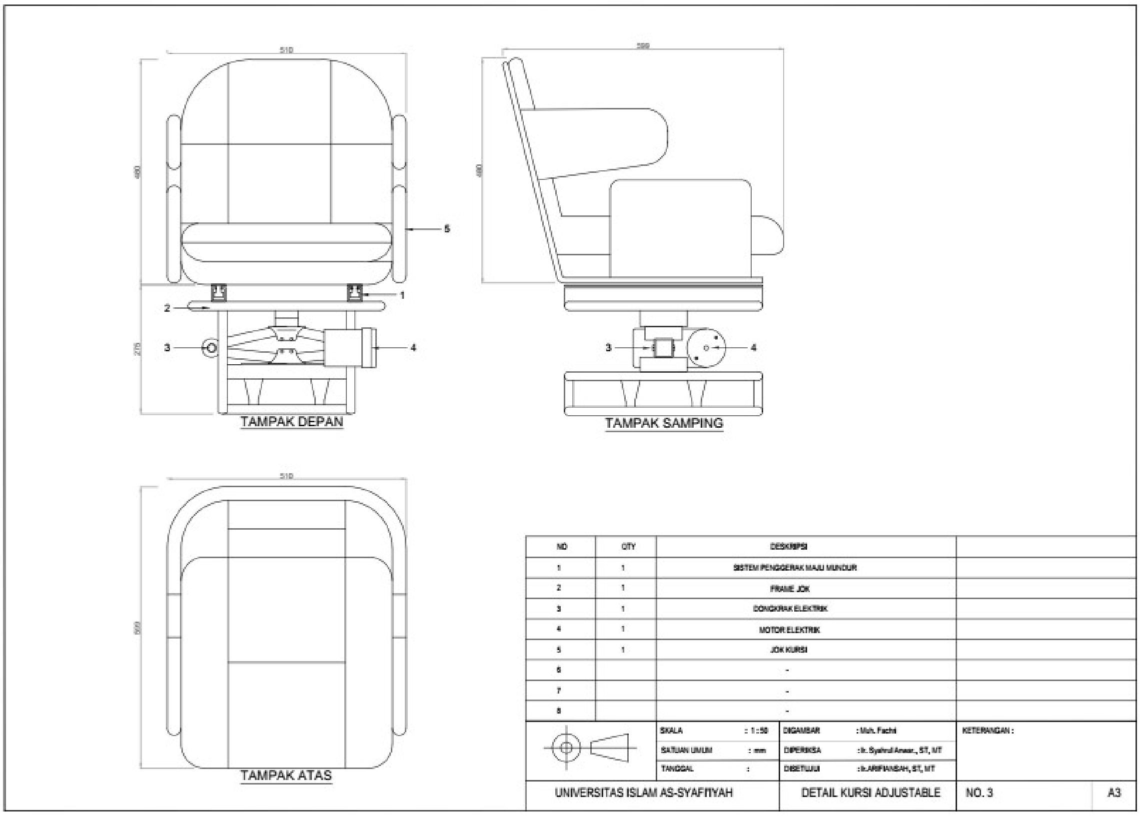

Figure 13 Detail Adjustable chair

CONCLUSION

The design and development of a handcycle optimized for individuals with disabilities demonstrate a significant advancement in accessible mobility solutions. By employing the VDI 2221 method and incorporating anthropometric considerations, this research successfully created a prototype that accommodates users' diverse physical needs. The adjustable features of the handcycle, including the seat height and steering system, enhance user comfort and safety, allowing for both manual and electric operation. Testing with users confirmed the effectiveness of these adjustments, showing that the design meets the ergonomic requirements essential for a positive user experience. Overall, this study highlights the importance of integrating user-centered design principles in engineering projects aimed at improving the quality of life for people with disabilities. Future work should focus on further refining the design based on user feedback and exploring additional functionalities that can enhance mobility and independence for users.

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