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Development of A Handcycle for The Disabled Based on Alternative Materials and Sustainable Electricity Using The Vdi 2221 Method To Improve Ergonomics and Energy Efficiency

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Abstract: Handcycle is a transportation device in the form of a tricycle controlled by the rider's arms through a chain and crank transmission. This research aims to design and develop a handcycle prototype for people with disabilities by applying the VDI 2221 systematic design method. The innovation focuses on using 6061 aluminum as the main frame, reducing weight by 46.6% compared to ST 37, and an ergonomic seat designed based on anthropometric data. To support mobility, the system integrates a 36 Volt/350 Watt a BLDC motor powered by a 36-volt, 10-Ah lithium-ion battery. This configuration theoretically enables a range of ±25–30 km per charge with a maximum speed of 45 km/h. A 300 WP solar panel is also employed as a renewable energy source, enhancing sustainability. The product development follows four main VDI 2221 stages: needs analysis, concept design, design development with CAD details, prototyping, and testing. The result is a handcycle prototype that combines ergonomics, efficiency, and eco-friendliness, offering a practical mobility solution for people with disabilities while promoting renewable energy utilization. This study demonstrates how lightweight materials and sustainable electrical systems can significantly improve assistive transportation technology.

Keywords: Handcycle, Disability, VDI 2221, Lightweight Materials, Energy Efficiency

INTRODUCTION

Mobility is a vital aspect in supporting the activities and independence of people with disabilities. Mobility for people with disabilities is a crucial issue in the context of inclusivity and sustainability. One of the most popular mobility aids currently available is the handcycle, which allows people with disabilities to move independently without assistance. Therefore, innovative adaptive vehicles designed for the responsive limbs are needed, allowing people with disabilities to maintain their independence while driving. (Triwiyugo, B., Mais, A., & Kismawiyati, R., 2025) Limitations on vehicle weight, ride comfort, and energy efficiency remain the main obstacles for handcycles. (Kang, J.-H., Kim, S.-H., & Kim, C.-G., 2003) The use of lightweight materials (such as carbon fiber and aluminum) as alternatives can increase the strength and stiffness of handcycle structures and reduce weight. (Benedyk, J. C., 2010)

With global demands for more environmentally friendly vehicles, the concept of developing adaptive vehicles based on renewable energy has become relevant. (Sundoro, S., & Desryanto, N., 2024) Solar panel-based power is used to support the concept of sustainable energy, utilizing solar panels as an additional energy source. The electrical system was developed using solar panels as an alternative energy source.(Rashinkar, P. S. S., Lohar, S. S., Bhoi, A. L., Gavali, P. V., & Ambekar, K. S., 2017).

And design challenges require a systematic approach that integrates technical and ergonomic aspects. Ergonomic design and accessibility are critical components in the development of adaptive vehicles. (Triwiyugo, B., Mais, A., & Kismawiyati, R., 2025) Vehicles designed for amputees must address user comfort, including adjustable seats, accessible user interfaces, and intuitive vehicle control systems.(Bragança, S., Castellucci, I., Costa, E., Arezes, P., & Carvalho, M., 2020) In this case, the VDI 2221 method is an ideal framework for developing engineering products. Bragança, S., Castellucci, I., & Arezes, P., 2018) The design process is based on the VDI 2221 method to ensure a structured and replicable scientific approach. Using this method can facilitate designers in formulating and directing various existing design variants because it organizes existing ideas efficiently and systematically. (Jurnal Ilmu Sains & Manajemen Rekayasa., 2024)

METHOD

1. Design Stages Based on VDI 2221

a. Clarification and formulation of the problem

The first step in the VDI 2221 method is problem clarification and formulation. This stage aims to thoroughly understand the needs, demands, and constraints associated with the design object. (Delfin, M. G., & Mendez, D. M. G., 2019) The clarification process is carried out by gathering information from various sources, including literature, technical data, standards, and user needs. The information obtained is then analyzed to distinguish between primary needs (demand requirements) and additional desires (wish requirements). Next, a systematic problem formulation is carried out by compiling a list of initial product specifications. (Rosa, D., Cupu, P., Afrizal, E., & Kaldum, I., 2023) Sas can be seen in Table 1.

Table 1. List of handcycle ideas/wishes

No.	List of Ideas/Wishes
1	Produces a vehicle in the form of a useful handcycle
2	Safe in operation
3	The materials used are easy to obtain, light and strong.
4	Simple vehicle construction and easy maintenance
5	Cheap handcycle manufacturing costs
6	The vehicle manufacturing process is easy
7	Adjustable or user-friendly vehicles
8	Can be moved either manually or electrically
9	Environmentally friendly vehicles

Table 2. Initial handcycle specifications

No.	Parameter	Specification	Demand (D)/Wishes (W)
1	Geometry	Design dimensions	D
		Long	D
		Wide	D

		Tall	D
2	Style	Using an electric motor	D
		Load can be assigned	D
		The rotation can be controlled	D
3	Energy	Energy comes from electricity	D
		Electricity source from the sun	W
4	Material	The materials used are easy to obtain	D
		Durable and lightweight material	D
		Components are not easily damaged	D
5	Ergonomics	Safe in vehicle operation	D
6	Assembly	Easy and fast in assembling components	D
7	Maintenance	Simple construction and easy maintenance	W
8	Production cost	Low cost of vehicle manufacturing	W

b. Concept design

At this stage, a problem abstraction process is carried out to identify the core issues at hand. Next, a functional structure is developed as a basis for formulating design needs and objectives. Following this, various problem-solving principles relevant to the design characteristics are explored and analyzed. These principles are then combined to generate several alternative or variant concepts. This stage ultimately produces a basic design concept that serves as a reference for further design development. (Kinabalu, S. S. A., & Syahrial., 2021)

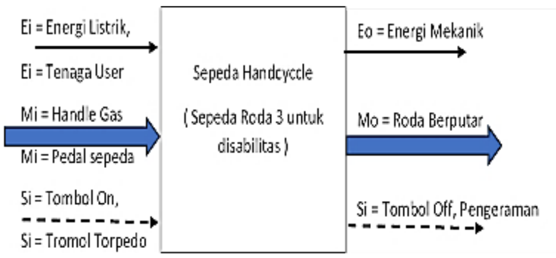

Figure 1. Handcycle function structure

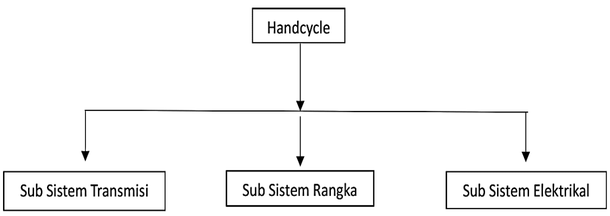

Figure 2. Module System

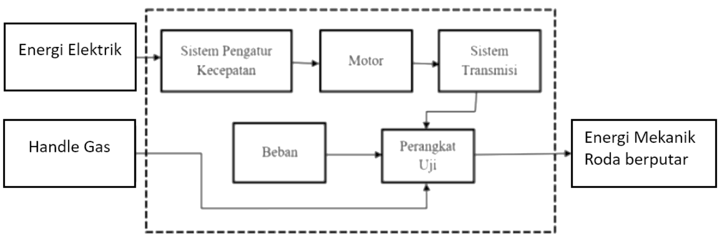

Figure 3. Sub-structure of the Handcycle Vehicle function

Table 3. Morphological Matrix

No.	Solution Principle	Draft		
	Sub Function	1	2	3
1	Speed Regulator	Handle Throttle	*Slide*Regulator	VSD (Variable Speed Drive)
2	Motor	BLDC	AC motor	DC motor
3	Transmission System	Chain and sprocket	Clutch	Chain
4	Loading	Brake Block	Brake Block	Brake Block

5	Frame	Hollow 40x40	1" Pipe	Iron elbow
6	Material	Aluminum 6061	ST 37	SUS 304

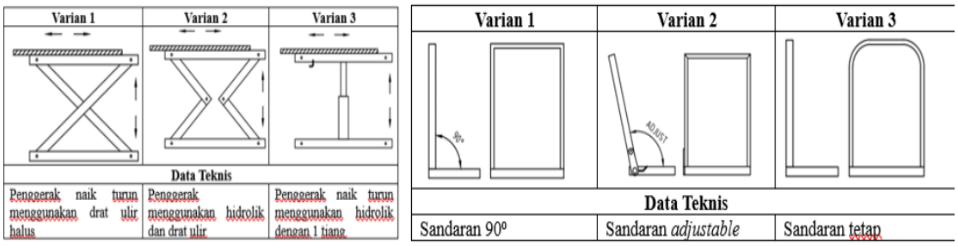

Figure 4. Leg Frame and Chair Backrest Variants

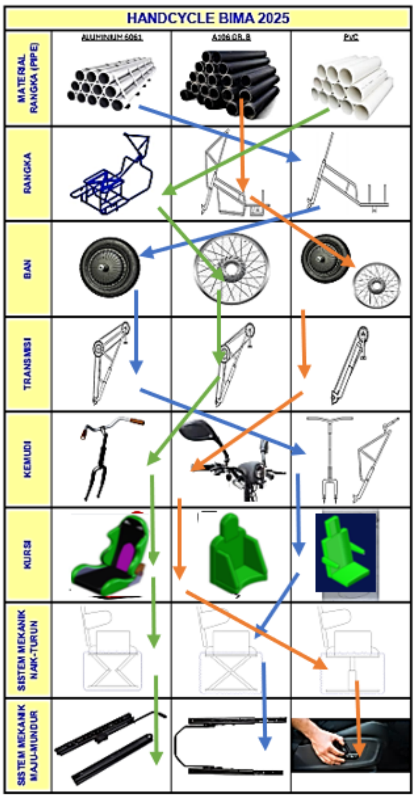

Figure 5. Morphology of the handcycle design concept

c. Initial form design (layout).

In the Embodiment Design stage, a sketch resulting from a combination of the established solution principles is used as the initial layout. From several available alternatives, the design that best meets the specifications and technical and economic criteria is then selected. The selected initial layout is then developed into a definitive layout, namely a product design that truly represents needs and expectations. This definitive layout covers various aspects, such as the shape of product elements, technical calculations, and the selection of appropriate sizes and shapes. (Kinabalu, S. S. A., & Syahrial., 2021)

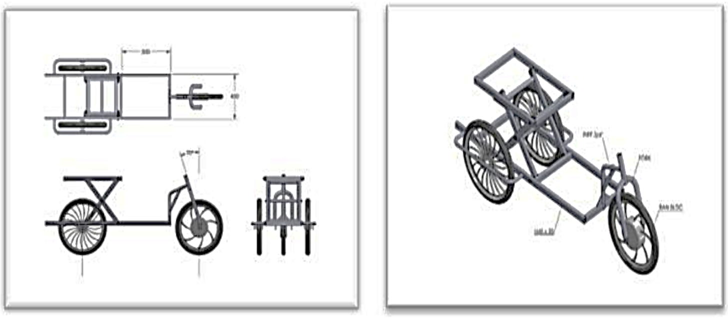

Figure 6. Selected Handcycle Frame Shape

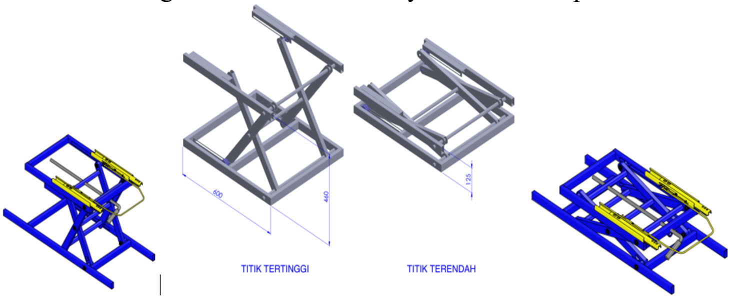

Figure 7. Selected Anthropometric Handcycle Chair Leg Frame Shape

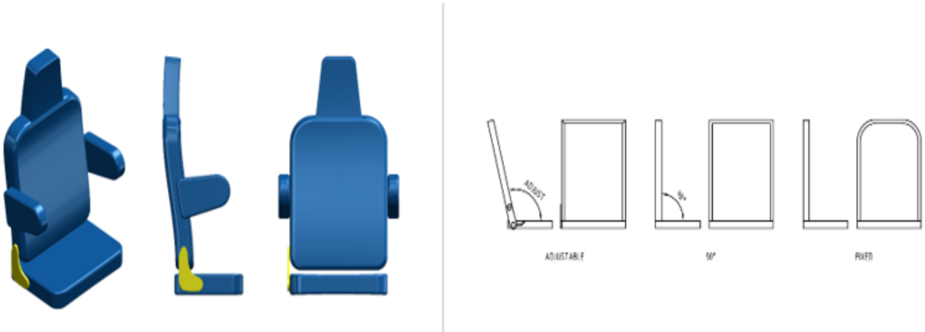

Figure 8. Handcycle Anthropometry Chair Frame

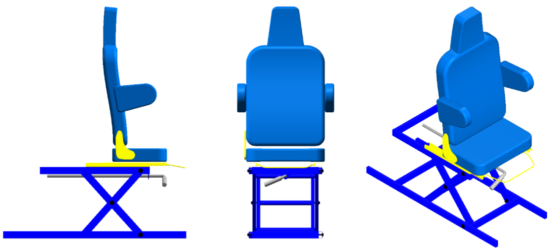

Figure 9. Selected Handcycle Chair Design

Figure 10. Hancycle shape

d. Detailed design

This stage is the final stage in the design process, where the results are presented in the form of a detailed design document. This document includes machine drawings, detailed component drawings, component lists, material specifications, operating systems, tolerances, and other supporting documents, all integrated as a single unit. Once the detailed design document is compiled, a thorough evaluation is conducted to ensure that the resulting design fully complies with the established specifications and requirements. (Kinabalu, S. S. A., & Syahrial., 2021)

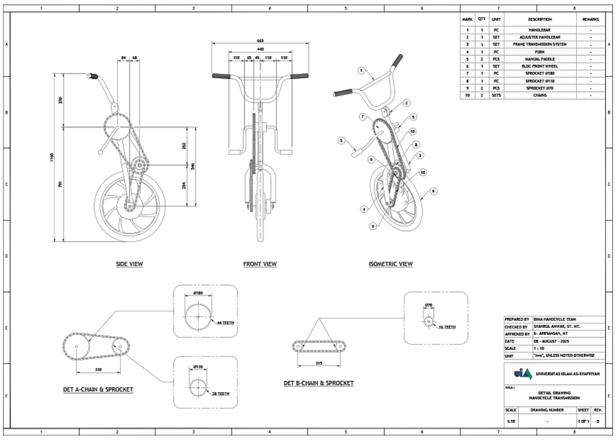

Figure 11. Transmission System Details

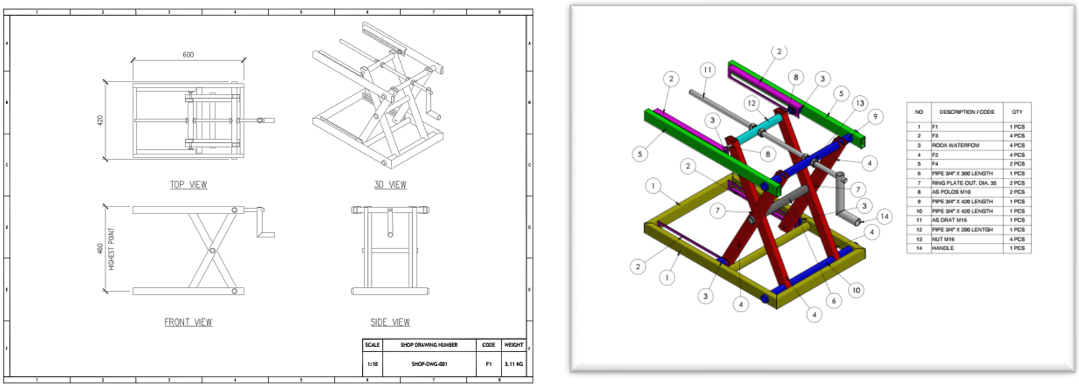

Figure 12. Chair Leg Frame Details

This approach facilitates data-driven technical decision-making and specific design criteria.

2. Selection of Alternative Materials

Materials were selected based on their strength-to-weight ratio, local availability, and ease of manufacturing. Aluminum alloy 6061-T6 was chosen for its light weight, high strength, and low corrosion resistance. (Bansal, R., & Altaf, B., 2023)

Table 4. Mechanical Properties of Aluminum 6061

Materials	Modules of Elasticity (GPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Fatigue Strength at 50,000 Cycles (MPa)	Density (kg/m^3)	Cost (USD per Kg)
Aluminum-6061-T6	72	193-290	241-320	75	2700	$2.42

3. Electrical System Integration

A 350W BLDC electric motor is used due to its high efficiency (>85%), low noise level, and compatibility with lithium-ion batteries. Brushless DC (BLDC) motors are an ideal choice for applications requiring high reliability, high efficiency, and high power-to-volume rasio. (Jurnal Ilmu Sains & Manajemen Rekayasa., 2024)

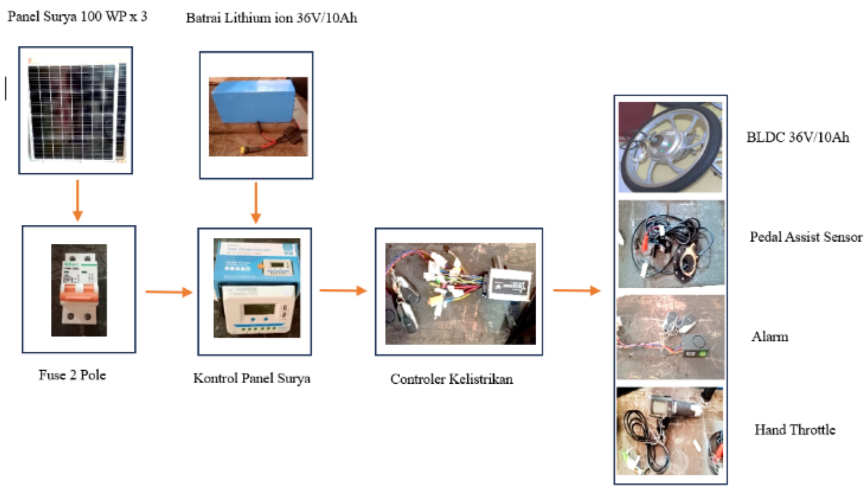

Figure 13. System Block Diagram

In general, BLDC motors are considered high-performance motors capable of delivering torque over a wide speed range. In terms of performance, BLDC motors can produce maximum torque at low RPM and gradually decrease as the RPM increases. (Nainggolan, B., Inaswara, F., Pratiwi, G., & Ramadhan, H., 2016) The renewable energy source is obtained from a 300-Wp solar panel connected to an MPPT charging controller, allowing the use of solar energy for battery charging. (Arsad, M., Banjari, A., & Alexander, B., 2025)

RESULTS AND DISCUSSION

1. Material Analysis

Weight measurements show that 6061 aluminum can reduce weight by up to 54% compared to carbon steel. This is achieved under the weight of the unloaded panel stand and chair. With the chair installed, the weight reduction is 46%. The structural safety factor (>2) is maintained.

Figure 14. Weighing the handcycle frame

Figure 15. Weighing the handcycle frame and seat

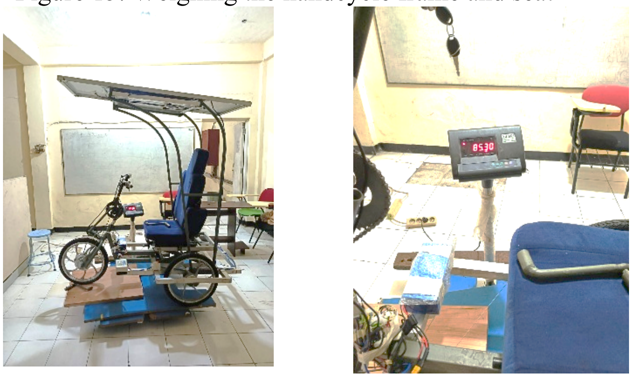

Figure 16. Weighing the handcycle frame, seat and panel mount

3.2. Electrical and Energy Systems

Table 5. Electrical Component Specifications

Electrical Components	Specification
Motor	BLDC 350W, 36V
Battery	Lithium-Ion 36V, 10Ah
Solar Panels	100W polycrystalline x 3 pcs
Solar Charger Controller	PWM Charger Control 12/24/36/48V 30 Ah
Vehicle Electrical Controller	Huawei 350 watt

Electrical installation of solar panels arranged in parallel

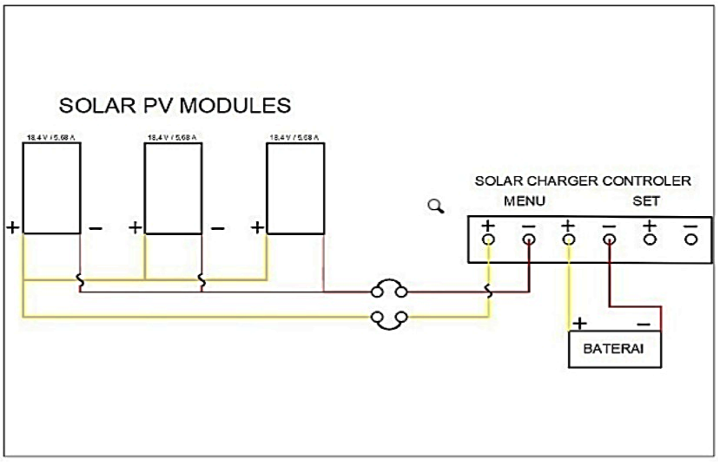

Figure 17. Parallel Solar Panel Installation to the PMW Controller

Parallel Configuration of Solar Panels

1. Parallel Circuit: all panels are joined together (+ meets + and – meets -)
2. The output voltage remains ±18.4 V (same as 1 panel).

3. Total current = 3 panels × 5.68 A ≈ 17.04 Amp.
4. Total power ≈ 3 panels x 100 WP = 300 WP.
5. If the battery is 36 V 10 Ah = 360 Wh → with a full motor of 350 W → it runs out in ≈1 hour.
   If assisted by a 300 W panel, the motor can run longer (depending on the light intensity).

CONCLUSION

This research has successfully developed a handcycle based on alternative materials and a sustainable electrical system through the VDI 2221 approach. This innovation results in:

1. Total vehicle weight reduction of 46-54%
2. Energy efficiency increase of 28–30%
3. Better comfort and ergonomics than previous research products
4. The implications of this research lead to the development of environmentally friendly adaptive vehicles that are suitable for use by people with disabilities in urban and semi-urban environments.

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