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Design of Tools for Loading and Unloading Wheelchairs into/from Avanza Hatchback Cars Using an Ergonomics Approach

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Abstract
Wheelchairs are necessary mobility aids for people with lower-limb disabilities. However, transporting a heavy electric wheelchair in a car presents challenges and can result in injuries to caregivers who assist with loading and unloading. The goal of this study was to create an ergonomic transfer assist that would make it easier and safer to transport wheelchairs into cars. The Avanza Hatchback and electric wheelchair were measured for width, length, base height, and weight. Using this information, a transfer assist with a slanted base was built using ergonomic principles to alleviate physical strain during loading and unloading. The design was also based on the REBA (Rapid Entire Body Assessment) score to determine the optimal posture. This study makes a unique addition because it focuses on specific aids for safe wheelchair transfers into and out of automobiles, where there is currently insufficient research.

Keywords: design, ergonomics, transfer-aids, wheelchairs

1. Introduction

Not everyone in the world is lucky to have complete body organs and perfect body functions. There are people who have leg disabilities. What is meant by people with leg disabilities here are people who are paralyzed, have legs that cannot move, have weak legs (only able to move minimally), or legs that cannot be used to stand/walk. People with leg disabilities need walking and moving aids, namely wheelchairs to support their activities and mobility.

Wheelchairs are used for relatively short trips or inside buildings. Usually used in homes, schools, offices, or other places. However, to go to other places that are far away, they need a car to take people with lower limb disabilities and their wheelchairs to their destination. The car used needs to have enough space to store the wheelchair. A suitable car for this is one with a spacious trunk or rear compartment, and doors that open fully, making it easy to fit a wheelchair. This type of car is commonly called a hatchback.

To transfer into the car, the wheelchair put into the car by the person helping (helper/caregiver). The cars used are usually vans, which have doors that can be fully opened upwards (hatchback type) at the back of the car. Cars like this that are common in Indonesia include the Avanza, Zenia, Wuling Confero, Wuling Cortez, and the like. In this study, the Avanza was chosen because this car has the highest sales in Indonesia (source: Association of Indonesian Automotive Industries https://oto.detik.com/mobil/d-6482945/20-mobil-terlaris-sepanjang-2022-toyota-avanza-masih-jadi-raja).

When loading and unloading a wheelchair to/from the car, the helper often finds it difficult. This difficulty can be caused by the high enough hatchback base of the vehicle, the large dimensions of the wheelchair, or because the wheelchair is heavy for the helper. Moreover, if the wheelchair being loaded or unloaded is an electric wheelchair equipped with a motor and battery as its power source, the task becomes even more challenging. In addition to causing difficulties, this can cause injury to the helper. Therefore, this study designs the ergonomic tools needed to load and unload the wheelchair to/from the

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car. People with disabilities, especially leg disabilities that cause sufferers to have limitations in moving and changing places easily have been widely studied and observed by experts. This is indicated by the increasing number and sophistication of wheelchairs. Another thing that also shows a lot of attention is the many assistive devices made for wheelchair users, such as train boarding and alighting aids (Hosaka, Imamura and Nagata, 2020; Kim *et al.*, 2022), mobility aids (Choukou *et al.*, 2021; Borden, Jacene and Steriti, 2024), even utilizing various electronic devices, even artificial intelligence (Cui *et al.*, 2022; Sadi *et al.*, 2022; Shashidhar *et al.*, 2023; Balamurugan *et al.*, 2024). However, it is still very rare to find research on assistive devices for loading and unloading wheelchairs into and from cars. Thus, this study has novelty, namely examining assistive devices for loading and unloading electric wheelchairs.

Many researchers and experts have studied the use of wheelchairs and related matters. Several researchers have studied assistive devices related to wheelchair user mobility. Researchers have also studied the mobility difficulties of wheelchair users (Koontz, Bass and Kulich, 2021; Goldberg *et al.*, 2024) and then designed assistance for using trains (Hosaka, Imamura and Nagata, 2020; Kim *et al.*, 2022). Furthermore Klinich *et al.* (2022) studied literature reviews of wheelchair transportation. Several researchers have also adopted internet technology and artificial intelligence in designing wheelchairs. Cui *et al.* (2022) and Sadi *et al.* (2022) designed wheelchairs that were moved based on user gestures, Sanshidar (2023) controlled the movement of the wheelchair using eye-blink using Arduino, and Balamurugan *et al.* (2024) designed a smart wheelchair using artificial intelligence and intelligent sensors assets. Next, Balamurugan *et al.* (2024) and (Zhou *et al.*, 2023) also designed a multifunctional smart wheelchair.

Regarding ramp design, there are several researchers who have designed it, such as Kumtepe *et al.*, (2021), Pratama and Sutriaadi (2024) designed ramp driver while wheelchair in open position, Tedja *et al.* (2025) designed ramp for disable to enter Hercules C-130 aircraft, while Luthfiyah and Susetyardo (2023) and Ikechukwu *et al.* (2015) designed disability aids for climbing stairs, while still using a wheelchair. In addition, there are still many experts who have conducted research. However, no one has studied assistive devices for transporting wheelchairs by car. This research is designed to make it easier for disabled people to move from one place to another and to help the helper load and unload the wheelchair into and out of the car.

This study is aimed at designing a tool to help load/unload wheelchairs to/from cars, especially Avanza hatchback type cars (namely a car with full-width doors at the back that open upwards to provide easy access to load objects/goods) easily and safely (reducing the risk of injury to the person transporting the wheelchair). Avanza was also chosen because it is a car with a high sales rate and is widely used by people in Indonesia. Ergonomics is a scientific discipline that studies human limitations, strengths, and characteristics, then uses this information to design products, machines, facilities, environments, and even work systems to achieve the best work quality while still paying attention to aspects of human health, safety, and comfort (Iridiastadi and Yassierli, 2014). Ergonomics aims to improve workspaces and environments to minimize the risk of injury or harm. Meanwhile, REBA is a series of postural analysis tools, particularly with sensitivity to the types of changeable work positions found in healthcare (e.g., handling live loads) and other service industries (Hignett and McAtamney, 2000). In this study, REBA was used to analyze the posture of people loading and unloading wheelchairs from and into cars.

2. Research Method

Design consists of the stages of finding ideas, analyzing problems, creating product designs, making designs and completing designs (Yusra, 2017). The design and development of a product is based on 4 types (Ulrich and Eppinger, 2001), namely New product platforms; Derivatives of existing product platforms; Improvements to existing product improvements; Product development, which means designing very different products (Ulrich and Eppinger, 2001). Product design is a process that designers use to combine user needs with business goals to help maintain a consistently successful product brand. Product designers work to optimize the user experience in the solutions they create for their users—and help their brands by creating sustainable products for long-term business needs (Interaction Design Foundation - IxDF, 2019).

The stages carried out in this research are as shown in Figure 1. This figure illustrates that the first stage is preliminary observation, namely observation of the practice of loading and unloading wheelchairs to and from cars. From this observation, it was captured that there were difficulty and discomfort for people doing the lifting, due to the weight. The next stage was preliminary interviews. At this stage, interviews were conducted with several people who usually load and unload wheelchairs to and from cars. From the interviews, it was found that they felt heaviness and discomfort in the lower back and knees because the weight was supported there. Another complaint reported was difficulty due to the high position of the car door.

Based on the two previous stages, the next step is to define the problem. The problem here is the need for a device to help lift a wheelchair into a car, making it easier, safer, and with less weight. Therefore, fourth step was this research was aimed at designing a tool to load and unload wheelchairs from and to cars. For that, it is necessary to collect data as fifth step. In this step, first we examine the characteristics of the car that will be used and the characteristics of 2 types of wheelchairs, namely standard wheelchairs and electric wheelchairs. Standard wheelchairs are compact wheelchairs and are cheaper than other wheelchairs, so this wheelchair is widely used by the public. While electric wheelchairs have a motor and battery to supply electricity to the motor.

Meanwhile, the cars used here are the Toyota Avanza and Daihatsu Xenia which have the same shape and dimensions, have a hatchback shape, and are types of cars with medium prices and are widely used by people in Indonesia. Wheelchairs have a folding mechanism to make them easy, compact, and do not take up space in storage. Therefore, the folding mechanism of the chair is also studied. The folding mechanism of standard wheelchairs is sideways. While electric wheelchairs have 2 types, namely electric wheelchairs with a sideways folding mechanism (Type A) and wheelchairs with a forward folding mechanism (Type B). This folding mechanism affects the dimensions of the storage area in the car and the characteristics of the tool to be designed.

The next stage is to design a tool to help move the wheelchair to and from the car. Sixth stage was analyzing the activity of loading and unloading wheelchairs into and out of cars using REBA (Rapid Entire Body Assessment). Figure 2 shows a helper loading a wheelchair into an Avanza car. Using REBA in Figure 2, the helper's posture can be depicted. It can be seen that his posture is disturbed. Using REBA analysis, as in Figure 3, the score is calculated as 12, which is included in the Very High Risk category. This score indicates a high risk of injury in this job. Therefore, it is necessary to design it to reduce this risk.

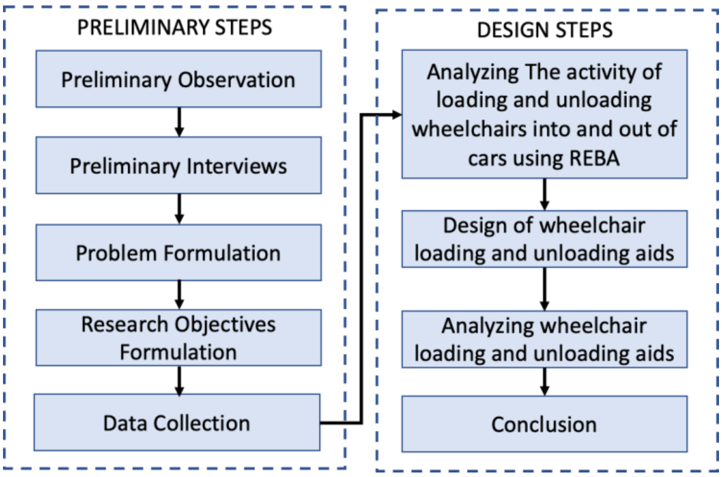


Figure 1. Research stages to design tool aid

Figure 2. Helper posture for loading and unloading a wheelchair without assistive device

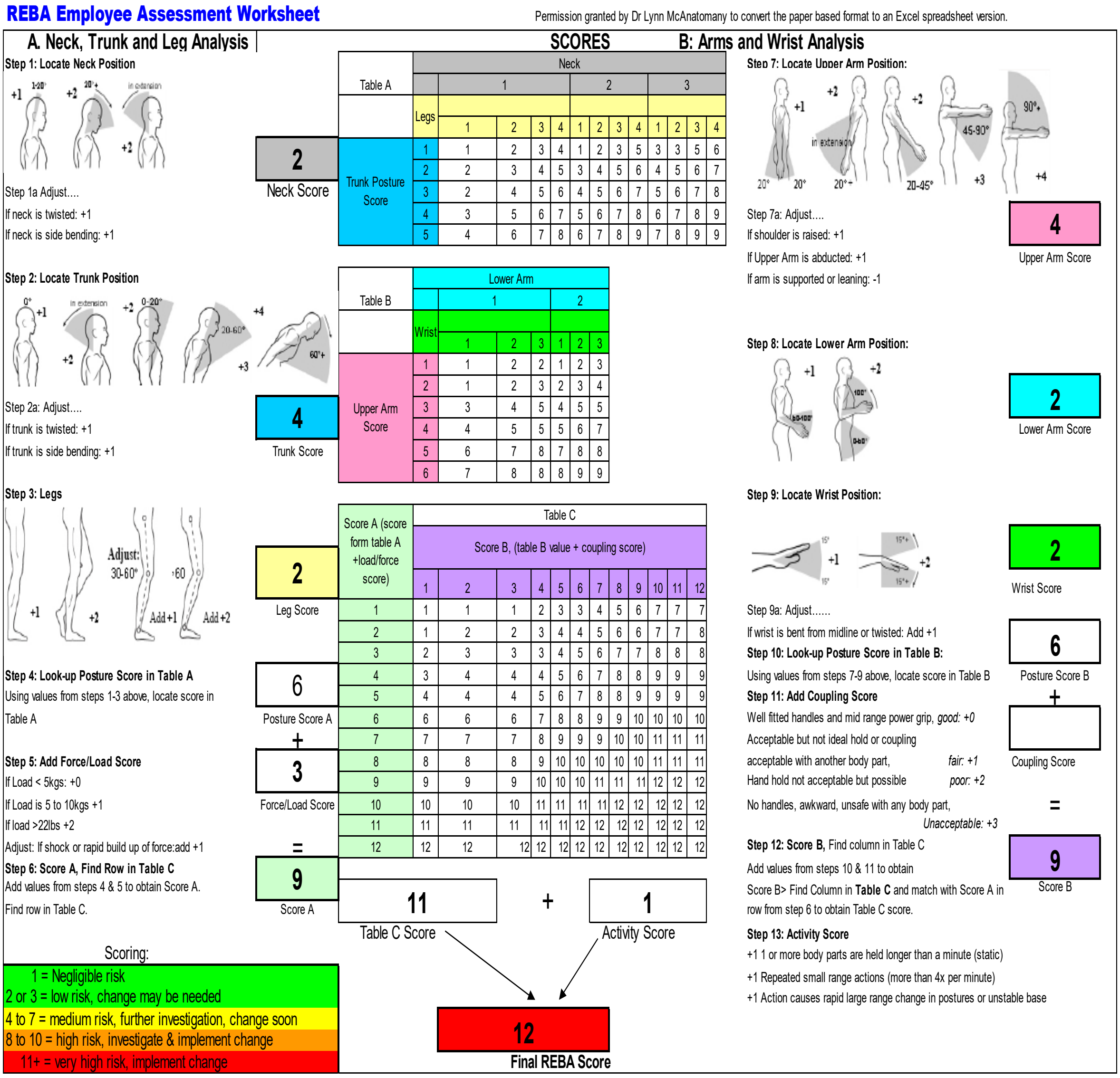


Figure 3. Calculation of REBA scores for loading and unloading a wheelchair without assistive device

Next, we needed to design a device to load and unload the wheelchair into and out of the car. The seventh stage is to design the device. The device is designed to be done manually using an inclined plane from the floor to the side of the car's door surface. In addition to considering the strength of the material of the inclined plane base, the angle of the inclined plane also needs to be considered, because it will affect the weight or lightness of the helper when pushing the wheelchair onto the car or pulling the wheelchair when it is unloaded from the car. If the angle is larger, although the area of the inclined plane base on the floor is smaller, it will require more power to push the wheelchair into the car. Conversely, if the angle is smaller/gentler, reduce the power to push the wheelchair into the car, but enlarge the area of the inclined plane base on the floor. While not all vehicle parking spaces have a large area behind the car. We design several dimensions of the plane aid device, and we analyze the effect to weight and posture. We do this at eighth stage. The last stage is conclusion, the final design proposed.

3. Results and Discussion

As previously described, preliminary observations and interviews revealed that helpers had trouble and discomfort when moving wheelchairs into and out of cars. This situation necessitates the use of assistive devices to facilitate and reduce the risks of this task. Furthermore, data on cars and wheelchairs was collected for analysis. In this study, we examined 3 types of wheelchairs, namely standard wheelchairs and two types of electric wheelchairs.

Standard wheelchairs are wheelchairs that are commonly used by the public because they are compact and cheaper than other wheelchairs. In wheelchair shops/places selling wheelchairs, they are known as standard wheelchairs. These wheelchairs are always used in Hospitals, Health Centers, Rehabilitation Centers, Disabled Children's Education Foundations, Medical Centers, Lodging/Hotels and in recreational areas. The wheelchairs in question are as shown in Figures 4 and 5 below.

In addition to standard wheelchairs, two (2) types of electric wheelchairs were also studied, namely electric wheelchair A and electric wheelchair B. Electric wheelchairs A and B differ in shape, dimensions and shape when folded. When folded, electric wheelchair A is folded from the front, while electric wheelchair B is folded from the side, as can be seen in Figures 6 and 7 for type A wheelchairs, and Figures 8 and 9 for type B electric wheelchairs. Next, the research was continued by measuring the dimensions and weight of each wheelchair.The dimensions of the three wheelchairs discussed are as in Table 1. The battery of type A electric wheelchair is non-removable, while the battery of type B electric wheelchair must be removed when folded. The weight of type B electric wheelchair battery is 8.5 kg, shown in Figure 10 below. In addition to the dimensions and weight of the wheelchair, the dimensions of the car trunk are also measured to ensure the wheelchair can fit and to determine the inclination of the assistive device. The trunk of an Avanza car is used to store wheelchair as shown in Figure 11 and the dimensions are in Table 2.

Considering the difficulty and non-ergonomic nature of the helper's posture when loading and unloading, it is necessary to design an assistive device that can facilitate and improve the helper's posture when loading and unloading wheelchairs. The proposed aid is a sloping platform that placed at the rear door of the car and connect it to the floor. With this tool, the helper doesn't need to lift the wheelchair; they can simply push it when loading and unloading it to and from the car. We designed the inclined plane to be made of metal so that it can be used for a long time, as shown in Figure 12.

Because the inclined plane base is too long to fit in the limited area of the car, and to be more compact, a tilt plane base is designed that can be folded into 2, without reducing its strength as can be seen at Figure 13 and 14. The specifications of the inclined plane base aid are: for the frame made of hollow iron, size 2 x 2 cm, for the base material above the frame made of iron plate with a size of 140 x 20 cm, 3 mm thick. Folding using hinges. So that the two parts of the folded base are sturdy when used, a locking slot is installed on the frame under the base. The top of this aid is fitted with L iron as a hook to lock this aid in the car.


a. Top view


b. Back view

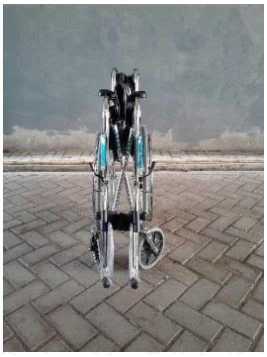

c. Side view


d. Front view


e. Isometric view

Figure 4. Standard wheelchair in open position (ready to use)


a. Top view


b. Back view


c. Side view


d. Front view


e. Isometric view

Figure 5. Standard wheelchair in folded position



a. Top view b. Back view c. Side view


d. Front view e. Isometric view

Figure 6. Electric wheelchair type A in open position (ready to use)



a. Top view b. Back view c. Side view


d. Front view e. Isometric view

Figure 7. Electric wheelchair type A in folded position

a. Top view

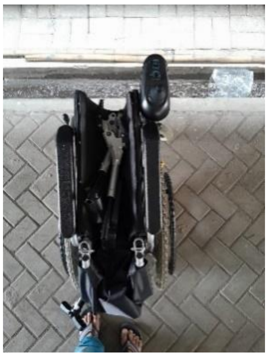
b. Back view

c. Side view

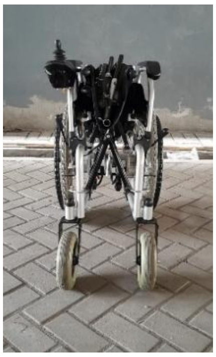
d. Front view

e. Isometric view

Figure 8. Electric wheelchair type B in open position (ready to use)



a. Top view



b. Back view

c. Side view

d. Front view

e. Isometric view

Figure 9. Electric wheelchair type B in folded position

Table 1. Dimensions and weight of each type of wheelchair

No.	Dimension	Wheelchairs dimensions (cm) and weight (kg)					
		Standard wheelchair		Electric Wheelchair type A		Electric Wheelchair type B	
		Folded	Opened	Folded	Opened	Folded	Opened
1	Wheelchair length	105	105	35	90	90	113
2	Wheelchair width	26	66	60	55	55	70
3	Wheelchair height	87	87	80	90	80	94
4	Distance between front tires	17	57	52	102	26	50
5	Distance between rear tires	21	60	59	52	34	56
6	Front tire width	2,5	2,5	4,5	4,5	5	5
7	Rear tire width	2,5	2,5	5,5	5,5	4	4
8	Weight (complete)	17	17	28	28	27	35,5
9	Weight (without battery)					27	27

Figure 10. Electric wheelchair type B battery weight measurement

a. Rear of the Avanza car b. The back door is open c. Inside the rear door

Figure 11. Avanza car hatchback trunk

Table 2. Dimensions of the Avanza car trunk

Types of trunk dimensions		Dimensions (cm)
Height of the trunk base from the ground surface		56
Height of trunk from trunk floor		100
Trunk width		109
Trunk depth from trunk door to inner limit when	Rear seats fold down	64
	No back seat	75
	Rear seats do not fold	26
Hook on the trunk floor	Length	6
	Width	9
	Distance from the trunk door	38
	Distance from the left side	50

a. Inclined plane top view

b. Inclined plane bottom view

c. Inclined plane isometric view

Figure 12. Base of inclined plane

Figure 13. Foldable inclined plane base

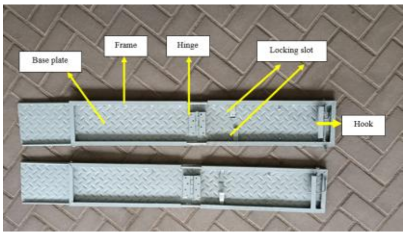


Figure 14. Rear view of the inclined plane base

Figure 15. Simulation of the measurement of the tilt angle of assistive device for all types of wheelchair

In designing aid, it is necessary to measure and test the angle of inclination to allow the wheelchair to be raised and lowered easily. In this case, a method of testing the angles that are possible is carried out with field research using the simulation method. This can be seen in Figure 15, while the dimensions and elevation angles related to the Avanza car can be seen in Figure 16. With y is the height of the car trunk from the floor to the trunk mouth, 56 cm high. So according to the Pythagorean formula, then with a slope angle of 25 degrees, the length of the inclined plane base facility is needed along 140 cm as can be seen at Figure 14. The auxiliary tools installed on the Avanza car can be seen in Figure 17.

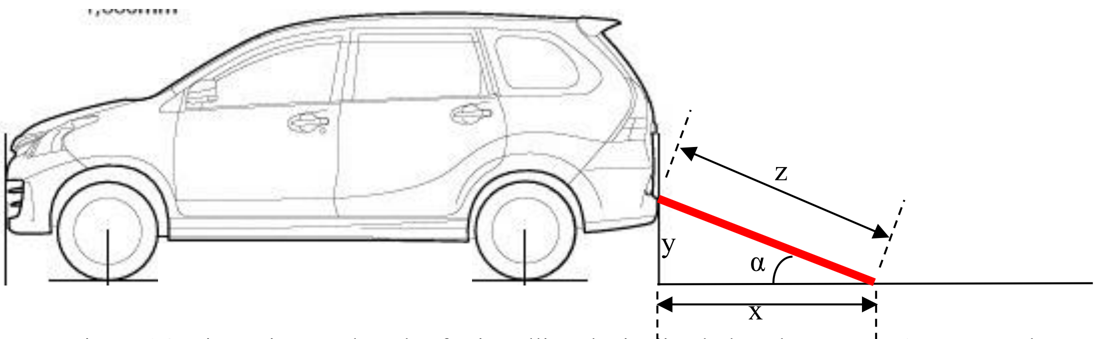


Figure 16. Dimensions and angles for installing the inclined plane base on an Avanza trunk

Figure 17. Installation of inclined plane base on the car

The next step is to take measurements and tests to determine the most optimal tilt angle. For this test, a test was conducted by 4 helper. Each person tried to load the wheelchair using various tilt angles of the assistive device. The four people are as shown in Figure 16. The first person is a tall and thin man, the second person is a short and thin man, the third person is a tall and fat man, and the fourth person is a short and fat woman as can be seen in Figure 18. The measurement results are as shown in Table 3. From the test on 4 helpers, it was found that the most optimal angle and produces the effort or power needed to raise the wheelchair is a maximum of 25 degrees. If it is below 25 degrees it will be easier, but it will result in the area of placing the inclined plane becoming wider because the inclined plane becomes long. This is not practical and sometimes there is no adequate place to place the inclined plane as minimally as possible. Thus, a slope of 25 degrees was chosen. Next, another posture analysis was conducted using REBA regarding four people trying to load a wheelchair into a car. For the first to fourth helper, REBA analysis was carried out, as can be seen in Figure 18 to Figure 25.

Table 3. Testing the angle of inclination (inclined plane base) for each type of wheelchair

Elevation angle (α)	Standard wheelchair difficulty level				Type A electric wheelchair difficulty level				Type B electric wheelchair difficulty level			
	1st person	2nd person	3rd person	4th person	1st person	2nd person	3rd person	4th person	1st person	2nd person	3rd person	4th person
10	S	S	S	S	S	S	S	S	S	S	S	S
15	S	S	S	S	S	S	S	S	S	S	S	S
20	S	S	S	S	S	S	S	S	S	S	S	S
25	S	S	S	S	S	S	S	S	S	S	S	S
30	S	S	S	M	S	M	M	L	M	M	M	M
35	M	M	M	L	M	L	L	L	M	M	L	L
40	L	M	M	L	L	L	L	L	L	L	L	L
45	L	L	L	L	L	L	L	L	L	L	L	L

Table description: S = light power; M = medium power; L = heavy power

Figure 18. First helper posture for loading and unloading a wheelchair with assistive device

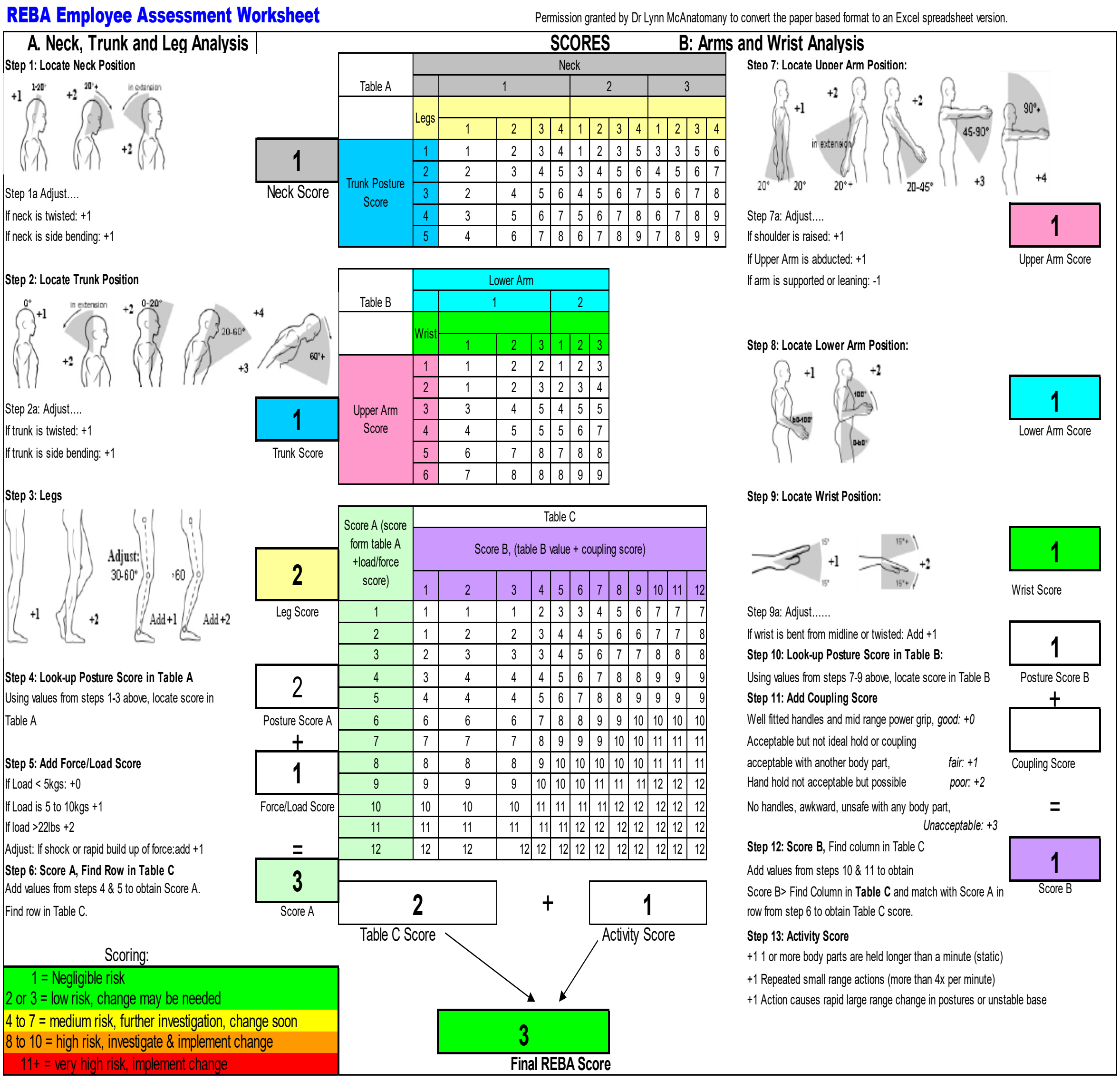


Figure 19. Calculation of REBA scores of first person for loading and unloading a wheelchair

Figure 20. Second helper posture for loading and unloading a wheelchair with assistive device

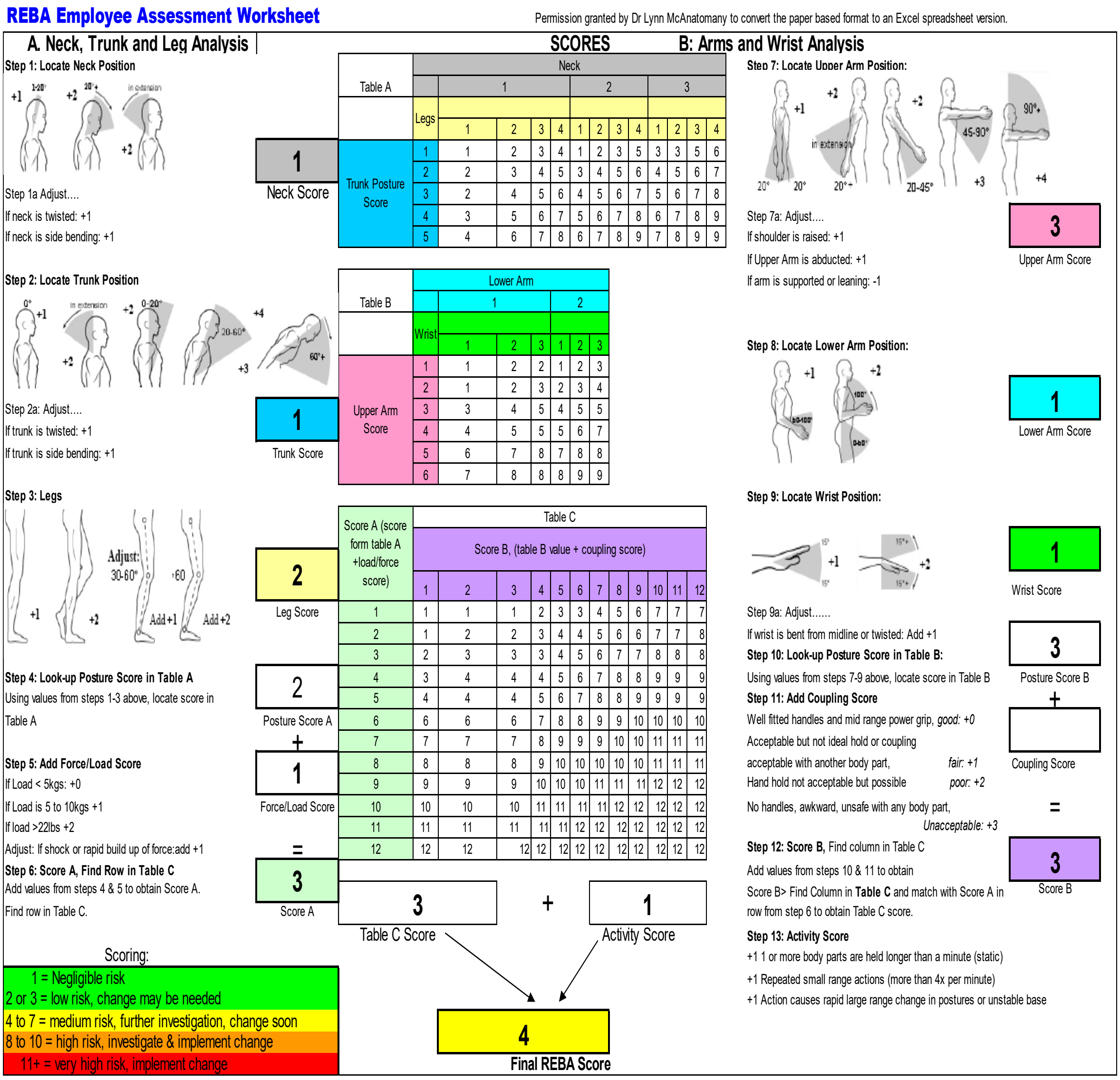


Figure 21. Calculation of REBA scores of second person for loading and unloading a wheelchair

Figure 22. Third helper posture for loading and unloading a wheelchair with assistive device

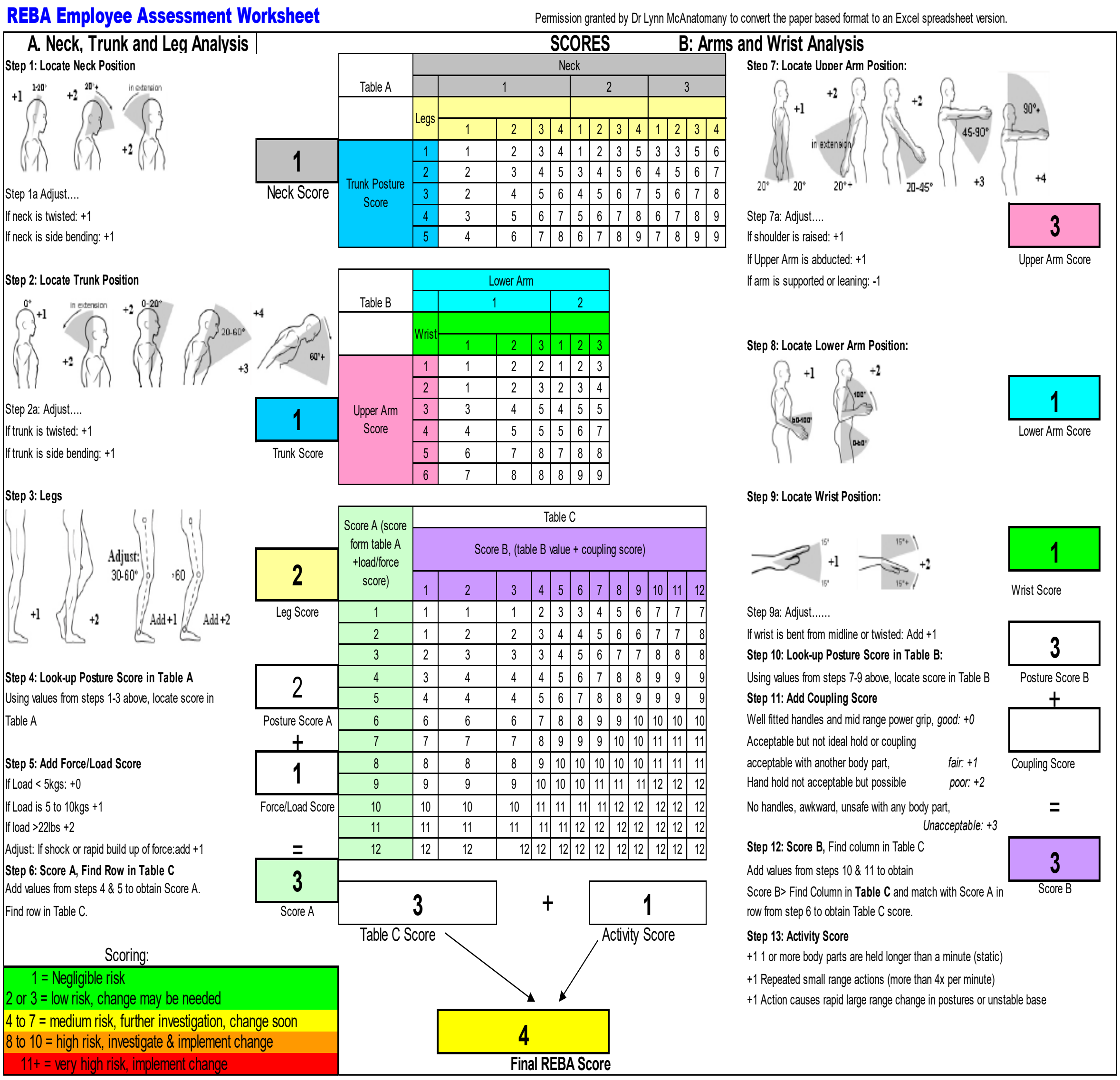


Figure 23. Calculation of REBA scores of third person for loading and unloading a wheelchair

Figure 24. Fourth helper posture for loading and unloading a wheelchair with assistive device

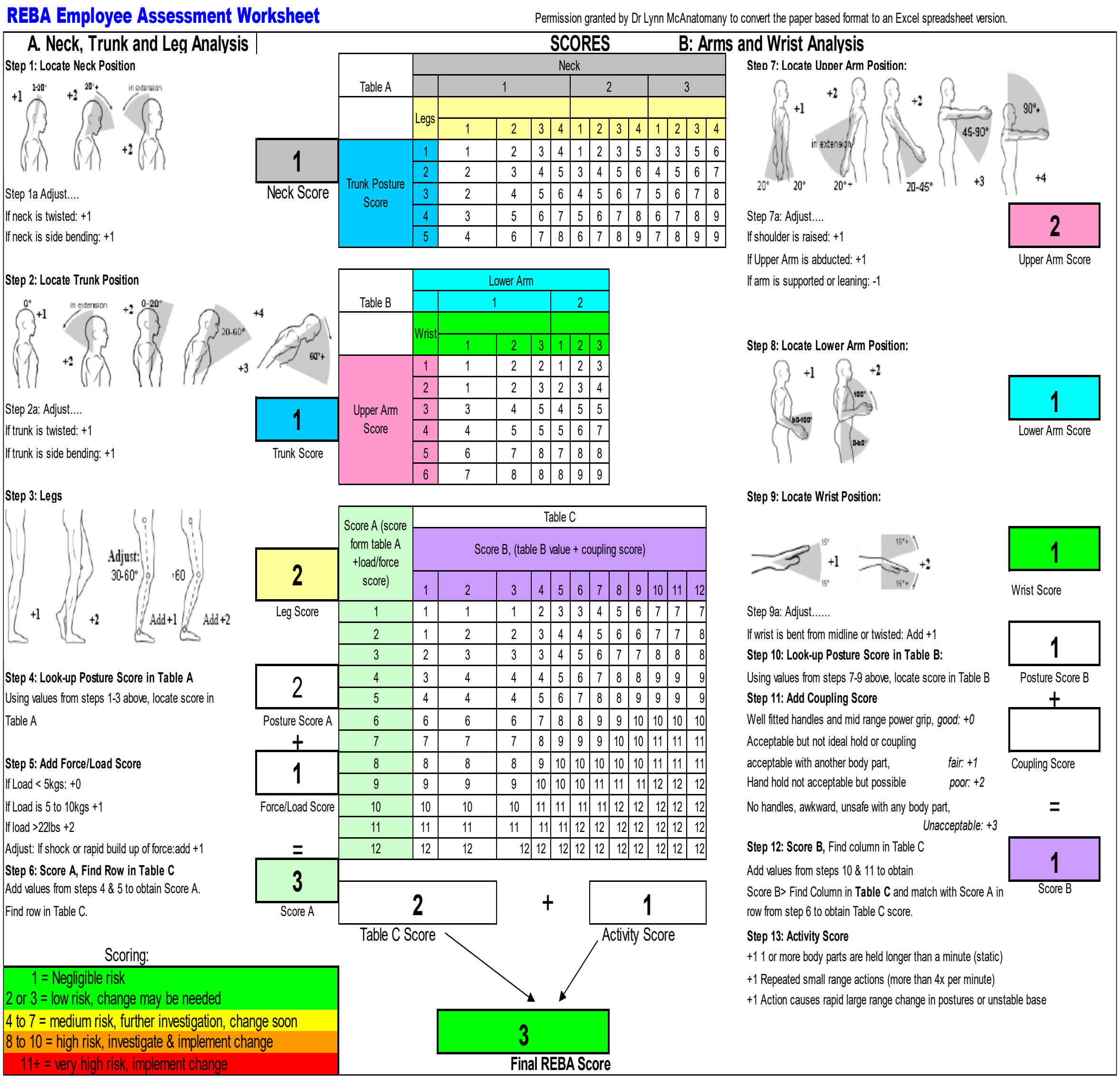


Table A	Neck	1				2				3			
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	5	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B	Lower Arm	1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Score A (score form table A +load/force score)	Table C: Score B, (table B value + coupling score) 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	11	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Figure 25. Calculation of REBA scores of fourth person for loading and unloading a wheelchair

By using an inclined plane as an assistive device, objects are not lifted but moved by pushing them along the plane. This is in accordance with research conducted by Pratama and Sutriaadi (2024) and Tedja *et al.* (2025) although in their research, they put the wheelchair in an open position and the wheelchair user sat on it. The angle of the incline indicates the pushing load; the higher the angle (elevation), the greater the load. Through posture analysis using REBA, it was found that using an inclined plane resulted in the REBA scores of all wheelchairs falling into the Low-Medium Risk category. This is significantly better than the REBA analysis when the helper did not use an assistive device. This finding is in line with findings regarding improvements in forklift worker posture with redesign of forklift components (Umyati, Mariawati and Peti, 2023). Therefore, using an inclined plane can reduce the risk of injury from the highest category to a low risk. Furthermore, using an inclined plane eliminates the need for lifting the wheelchair; instead, it is simply pushed, thus reducing the load. This aligns with ergonomic principles, which emphasize designing work systems with low loads and safe postures.

4. Conclusion

To help mobility of people with disabilities, sometimes wheelchairs need to be transported using a car. For that, the wheelchair needs to be lifted to load and unload into and out of the car. For that, this study designed a foldable assistive device to help helpers to load and unload wheelchairs. Using the foldable assistive incline device, helpers can carry out their work more easily, comfortably and safely. This study revealed that the assistive device is a platform connecting the floor to the car door at a 25-degree angle. The platform is made of metal and is designed to be foldable for easy portability. This platform also improves the posture of helpers by loading and unloading wheelchairs into and out of cars, thereby reducing occupational safety risks. This research also concludes that appropriately designed assistive devices can help and reduce risks to humans. Therefore, proper design of assistive devices is crucial.

However, this study still has limitations. These limitations become further research directions. The first limitation is that this study only designed 1 type of assistive device. In subsequent studies, other types can be designed, for example different shapes or using machines. The second limitation is that this study only used 1 type of material, namely iron. In further studies, it can be considered to compare with other materials and find the most optimal material both in terms of function and cost. The third limitation is that this study did not consider the cost of making assistive devices. Furthermore, this can be an area for research. The fourth limitation is that the most optimal wheelchair to be carried by car has not been selected, in addition to the most optimal car to be used has not been carefully selected. Further research can conduct wheelchair selection, in addition to car selection. Further research can also be conducted using other methodologies.

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References

Balamurugan, R. *et al.* (2024) 'A smart electronic wheelchair design using artificial intelligence and intelligent sensors association', in *Proceedings of the 2nd International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics, IITCEE 2024*. Available at: https://doi.org/10.1109/IITCEE59897.2024.10467609.

Borden, A., Jacene, M. and Steriti, S. (2024) *Design and evaluation of a propulsion aid device for folding wheelchairs*. Worcester Polytechnic Institute.

Choukou, M.-A. *et al.* (2021) 'Scoping review of propelling aids for manual wheelchairs', *Assistive Technology*, 33(2), pp. 72–86. Available at: https://doi.org/10.1080/10400435.2019.1595789.

Cui, J. *et al.* (2022) 'IoT wheelchair control system based on multi-mode sensing and human-machine interaction', *Micromachines*, 13(7), p. 1108. Available at: https://doi.org/10.3390/mi13071108.

Goldberg, M. *et al.* (2024) 'Wheelchair service provision content in professional rehabilitation organisations' standards documents and contemporary initiatives: a rapid review', *Disability and Rehabilitation: Assistive Technology*, 19(1), pp. 78–89. Available at: https://doi.org/10.1080/17483107.2022.2063421.

Hignett, S. and McAtamney, L. (2000) 'Rapid entire body assessment (REBA)', *Applied Ergonomics*, 31(2), pp. 201–205. Available at: https://doi.org/10.1016/S0003-6870(99)00039-3.

Hosaka, T., Imamura, T. and Nagata, K. (2020) 'Development of the support system for wheelchair use at boarding and alighting trains', in *Proceedings of the 2020 IEEE/SICE International Symposium on System Integration, SII 2020*. IEEE, pp. 790–795. Available at: https://doi.org/10.1109/SII46433.2020.9025988.

Ikechukwu, A. A. *et al.* (2015) 'An assessment of ramp designs as barrier-free accesses in public buildings in Abuja, Nigeria', *Humanities and Social Sciences*, 3(2), pp. 75–82. Available at: https://doi.org/10.11648/j.hss.20150302.12.

Interaction Design Foundation - IxDF (2019) *What is product design?* Available at: https://www.interaction-design.org/literature/topics/product-design (Accessed: 10 October 2023).

Iridiastadi, H. and Yassierli (2014) *Ergonomi suatu pengantar (ergonomics an introduction)*. Bandung: PT Remaja Rosdakarya.

Kim, K. *et al.* (2022) 'Development of train-boarding assistance device for wheelchair', *Journal of Robotics and Mechatronics*, 34(1), pp. 167–176. Available at: https://doi.org/10.20965/jrm.2022.p0167.

Klinich, K. D. *et al.* (2022) 'A literature review of wheelchair transportation safety relevant to automated vehicles', *International Journal of Environmental Research and Public Health*, 19, p. 1633. Available at: https://doi.org/10.3390/ijerph19031633.

Koontz, A. M., Bass, S. R. and Kulich, H. R. (2021) 'Accessibility facilitators and barriers affecting independent wheelchair transfers in the community', *Disability and Rehabilitation: Assistive Technology*, 16(7), pp. 741–748. Available at: https://doi.org/10.1080/17483107.2019.1710771.

Kumtepe, E. D. *et al.* (2021) 'Design based exploration of medical system adoption: case of wheelchair ramps', *Technology in Society*, 66, p. 101620. Available at: https://doi.org/10.1016/j.techsoc.2021.101620.

Luthfiyah, A. and Susetyardo, M. . (2023) 'Vertical accessibility transportation study for physical disabilities in hospitals (studi transportasi aksesibilitas vertikal untuk disabilitas fisik pada rumah sakit)', *Jurnal Arsitektur dan Perencanaan (JUARA)*, 6(2), pp. 23–35. Available at: https://doi.org/10.31101/juara.v6i2.2914.

Pratama, D. A. and Sutriaadi, E. (2024) *Ramp drive on wheelchair user cars (penggerak ramp pada mobil pengguna kursi roda), Disertasi doktoral*. Politeknik Manufaktur Negeri Bangka Belitung.

Sadi, M. S. *et al.* (2022) 'Finger-gesture controlled wheelchair with enabling IoT', *Sensors*, 22(8716), pp. 1–16. Available at: https://doi.org/10.3390/s22228716.

Shashidhar, R. *et al.* (2023) 'Smart electric wheelchair for disabled and paralyzed person using attention values on Arduino', in *2023 International Conference on Recent Trends in Electronics and Communication (ICRTEC)*. Available at: https://doi.org/10.1109/ICRTEC56977.2023.10111911.

Tedja *et al.* (2025) 'Design of a wheelchair ramp for the needs of people with disabilities on the Hercules C-130 aircraft (perancangan ramp kursi roda untuk keperluan penderita disabilitas di pesawat Hercules C-130)', *Jurnal TNI Angkatan Udara*, 4(2). Available at: https://doi.org/10.62828/jpb.v4i2.155.

Ulrich, K.T. and Eppinger, S.D. (2001) *Product design and development*. New York: McGraw-Hill.

Umyati, A., Mariawati, A.S. and Peti, P. (2023) 'Work posture analysis and complaint risk using nordic body map (NBM) and rapid entire body assessment (REBA) methods', *Journal Industrial Servicess*, 9(2), p. 179. Available at: https://doi.org/10.36055/jiss.v9i2.22004.

Yusra, Y. (2017) *Lima tahap membuat desain produk startup*. Available at: https://dailysocial.id/post/lima-tahap-membuat-desain-produk-startup (Accessed: 14 October 2019).

Zhou, H. *et al.* (2023) 'Design and implementation on multi-function smart wheelchair', *Embedded Selforganising Systems*, 10(7), pp. 18–22. Available at: https://doi.org/10.14464/ess.v10i7.601.