



Electric Wheelchair Manufacturing Analysis For Physical Disabilities Reviewed from the Aspect of Ergonomics

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Abstract. The high rate of physical disability is a trigger and spur in the development of research/research for people with disabilities to help with their daily activities, one of which is with a wheelchair. There is a sense of concern to see manual wheelchairs used daily by people with physical disabilities, especially with their abnormal hands and feet, so it becomes a problem in itself because they are quite tricky and tired of pedaling a manual wheelchair. This condition impacts their work productivity, thereby reducing their income/economy. Therefore, the purpose of this research is to manufacture electric wheelchairs belonging to two people with physical disabilities (i.e., belonging to Bagus and Huda). The ergonomics tests are carried out, including (a) Compatibility of the anthropometry of the user's body and the dimensions of the wheelchair, (b) Results of the user's postural analysis with RULA (*Rapid Upper Limb Assessment*) (c) Conformity of the dimensions of the wheelchair with the standard, and (d) Evaluation of the usability of the wheelchair based on observation. The results obtained for the Bagus electric wheelchair are from the anthropometric side. The popliteal height is longer than the distance between the seat and the footrest in the wheelchair. For Bagus to be more comfortable in using his wheelchair and for his legs not to be crooked (which will potentially cause more excellent musculoskeletal disorders), it is recommended that the distance between the seat and the footrest be extended. As for Huda electric wheelchairs, in general, they have been modified to adjust to the needs and conditions of Huda's body and make the design of Huda wheelchairs more ergonomic. However, the postural analysis showed that the forearm position was raised, and the hand was twisted when Huda operated the electric wheelchair controller. It is, therefore, recommended to lower the position of the controller in line with the wheelchair mount.

Keywords: Physical disability, electric wheelchair, manufacturing, ergonomic test

INTRODUCTION

Sustainable Development Goals (SDGs) are sustainable development that aims to improve the welfare of the world community. One of them is the welfare of entrepreneurs with physical disabilities. Definitively, the definition of limb dysfunction (physical disability/disability) is the inability of the limb to carry out its function caused by a reduced ability of the limb to carry out its function normally due to injury, disease, or imperfect growth [a]. According to the Ministry of Social Affairs quoted by Mangunsong [b] that physical disability is defined as the incompleteness of the limb caused by

congenital factors from birth, accidents, or due to diseases that cause impaired mobility, such as hand/foot amputations, *paraplegia*, bone deformities, and *cerebral palsy*. [1] (Efendi, 2009).

However, they have the right to equality and no discrimination in various accesses, such as in education, employment, equality in development, and enjoying the results of development, accessibility, rehabilitation, and social welfare, as well as talent development and equal social life. Physical disabilities are distinguished into three age categories: (a) The age of children (under 14 years old) who are still under the guidance and care of their parents, (b) The age of adolescents and adults (15-23 years old), as well as those who are still under the guidance and care of their parents, but they must be taught independence, and (c) The age of independence (over 24 years old), at this age there are many possibilities that they are already working or married. [2] (BPS, 2020).

Based on Susenas 2020 (BPS 2020) data [3] Sidoarjo In Numbers (2019), the number of people with disabilities in Indonesia is estimated to reach 22.97 million people spread throughout Indonesia with the following details: as many as 6.1 million people with severe category disabilities with details of 1.2 million people with physical disabilities, 3.07 million people with sensory disabilities, 149 thousand people with mental disabilities, and 1.7 million people with intellectual disabilities. In East Java itself, there are 4879 people with severe disabilities, with details of 578 people with physical disabilities, some spread across Surabaya, Sidoarjo, and Pasuruan. For the Surabaya area, the highest number of people with disabilities is in Sawahan, Tambaksari, and Wonokromo Districts. Meanwhile, for Sidoarjo district, the number of people with physical disabilities is 1767 people. [4] (Tjahjanti et al., 2017).

This high rate of physical disability is a trigger and spur in the development of further innovations for people with disabilities to help with their daily activities, one of which is with a wheelchair. There is a sense of concern to see manual wheelchairs used daily by people with physical disabilities, especially with their abnormal hands and feet, so it becomes a problem in itself because they are pretty tricky and tired to pedal a manual wheelchair. This condition impacts their work productivity, thereby reducing their income/economy.

This research was initially aimed at converting/converting manual wheelchairs belonging to physical disabilities (belonging to Bagus and Huda) into electric wheelchairs whose manufacture is adapted to their physical disability conditions. The tests carried out

are ergonomics tests, including (a) the suitability of the anthropometry of the user's body and the dimensions of the wheelchair, (b) the results of the user's postural analysis with RULA (*Rapid Upper Limb Assessment*), (c) the suitability of the dimensions of the wheelchair with the standard, and (d) the evaluation of the usability of the wheelchair based on observation.

METHOD

Nice Manual Wheelchair and Huda

There are two manual wheelchairs (belonging to Huda and Bagus) that have been converted into electric wheelchairs. Bagus is called, with the full name Ajar Bagus Prianggono is a physically disabled entrepreneur who has a business making invitation papers, posters, and others, with the home address of Pejantran 003/004 Wonoplintahan Village, Prambanan District, Sidoarjo Regency. Bagus's manual wheelchair before conversion (blue circle) is shown in Figure 1.



Figure 1 During the discussion of the Team Leader, students, and Bagus (blue t-shirt), the owner of the manual wheelchair



Figure 2
(a) Huda, with his limited condition
(b) Huda's manual wheelchair

The second wheelchair belongs to Huda (his full name is Choirul Huda), a physically disabled entrepreneur with an electric credit business and other payments using the help of *a mobile phone*. The address of the house is Jati Krajan RT 01 RW 02 Ds. Jatikalang Kec. Figure 2 (a) shows Huda's limited condition and (b) his manual wheelchair.

Convert a Good Manual Wheelchair and Huda to an Electric Wheelchair

Figure 3 shows an electric wheelchair converted from Bagus's manual wheelchair, and Figure 4 shows an electric wheelchair converted from Huda's manual wheelchair.



Figure 3 Electric wheelchair converted from

Bagus manual wheelchair



Figure 4 Electric wheelchair converted from Huda's manual wheelchair.

Ergonomics Testing

Ergonomics testing was carried out for two electric wheelchairs belonging to Huda and Bagus. The ergonomics tests are (a) the suitability of the anthropometry of the user's body and the dimensions of the wheelchair, (b) the results of the user's postural analysis with RULA (*Rapid Upper Limb Assessment*) and REBA (*Rapid Entire Body Assessment*), (c) the suitability of the dimensions of the wheelchair with the standard, and (d) the evaluation of the usability of the wheelchair based on observations.

RESULTS AND DISCUSSION

Results of the conformity of the anthropometry of the user's body and the dimensions of the wheelchair.

Body Anthropometric Dimensions

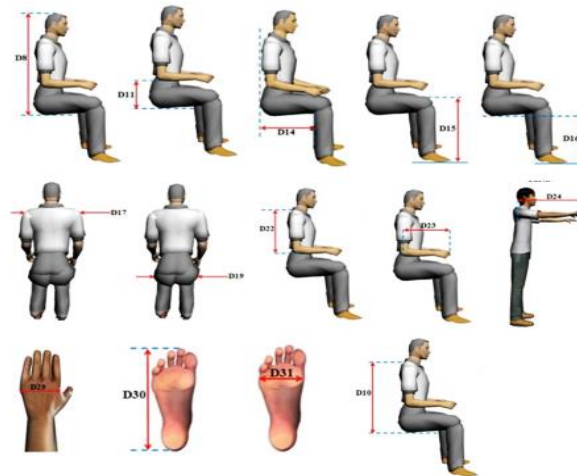


Figure 5. Anthropometric dimensions

Table 1 Anthropometer dimensions

Dimensi	Nilai (cm)
D8 (Height of seat position)	72.5
D10 (Shoulder Height on seat position)*	10.8
D11 (arms rest height)*	18.5
D13 (knee length dimensions)	57
D14 (Popliteal Length)	48
D15 (Sitting height)	42
D16 (Popliteal Height)	34.5
D17 (Shoulder side width)	41
D19 (hip width)	25.5
D22 (Upper arm length)	35.3
D23 (forearm length)	26
D24 (Hand length)	72
D29 Lebar tangan	kiri : 9 . kanan : 9.6
D30 Panjang telapak kaki	22
D31 Lebar telapak kaki	8

* Didekati dengan data antropometri Indonesia persentil 5

Table 1 and Figure 5 show the anthropometric dimensions. Meanwhile, Table 2 presents the results of the dimensions of the electric wheelchair, and Table 3 presents a comparative analysis of the anthropometric dimensions of Bagus's body with his wheelchair.

Table 2 Dimensional results of electric wheelchair Bagus

Pengukuran Kursi Roda	Nilai Pengukuran
Handrest ke Controler	47
Panjang Handrest	39
Tinggi pijakan kaki ke tempat duduk	30.5
Lebar Pijakan kaki bawah	15.5
Panjang pijakan kaki bawah	16,5
Tinggi handrest dari tempat duduk	28
Panjang ujung handrest ke controler	7
Panjang bantalan handrest	36.5
Lebar bantalan handrest	5
Tinggi handrest ke roda	22
Diameter roda kecil belakang	49.2
Diameter roda besar	62
Diameter roda kecil depan	20
Lebar sandaran duduk	49
Tinggi sandaran duduk	43
Tinggi keseluruhan	92
Lebar kursi roda	47.3
Tinggi pijakan kaki dari tanah	14

Satuan pengukuran: cm

Table 3 Comparative analysis of anthropometric dimensions of Bagus body with his wheelchair

Dimensi Antropometri	Data Antropometri Mas Bagus	Dimensi Kursi Roda	Dimensi Kursi Roda Mas Bagus	Note
D23 (forearm length)	26	Panjang Handrest	39	Sesuai
D16 (Popliteal Height)	34.5	Tinggi pijakan kaki ke tempat duduk	30.5	Tidak sesuai
D31 Lebar telapak kaki	8	Lebar Pijakan kaki bawah	15.5	Sesuai
D30 Panjang telapak kaki	22	Panjang pijakan kaki bawah	16.5	Tidak sesuai
D11 (arms rest height)*	10.8	Tinggi handrest dari tempat duduk	28	Tidak sesuai
D17 (Shoulder side width)	41	Lebar sandaran duduk	49	Sesuai
D10 (Shoulder Height on seat position)*	37.75	Tinggi sandaran duduk	43	Sesuai
D19 (hip width)	25.5	Lebar kursi roda	47.3	Sesuai

Satuan pengukuran: cm

*Didekati dengan data antropometri Indonesia persentil 5

Evaluation of Suitability of Anthropometric Aspects Good.

In general, the body proportions of the left and right sides of Bagus are not the same. The right shoulder looks higher than the left shoulder. *The popliteal height* is longer than the distance between the seat and the wheelchair footrest, causing the position of the legs to bend/oblique. The distance between *the handrest/armrest* and the wheelchair mount is longer than the height of the upper arm in the sitting position. Therefore, the position of the right shoulder is raised upwards when the forearm is placed on the handrest, and the hand operates the controller. The length of the footrest of the lower foot is shorter than the length of the foot so that not the entire surface of the foot can be supported by the footrest. The width and height of the wheelchair backrest are sufficient and, according to the anthropometric size, Good.

Results of Postural Analysis of Users with RULA (*Rapid Upper Limb Assessment*)

The RULA method was used to assess Bagus's posture (Table 3.4) while sitting in a wheelchair. This method is used to determine the level of musculoskeletal danger due to inappropriate posture.

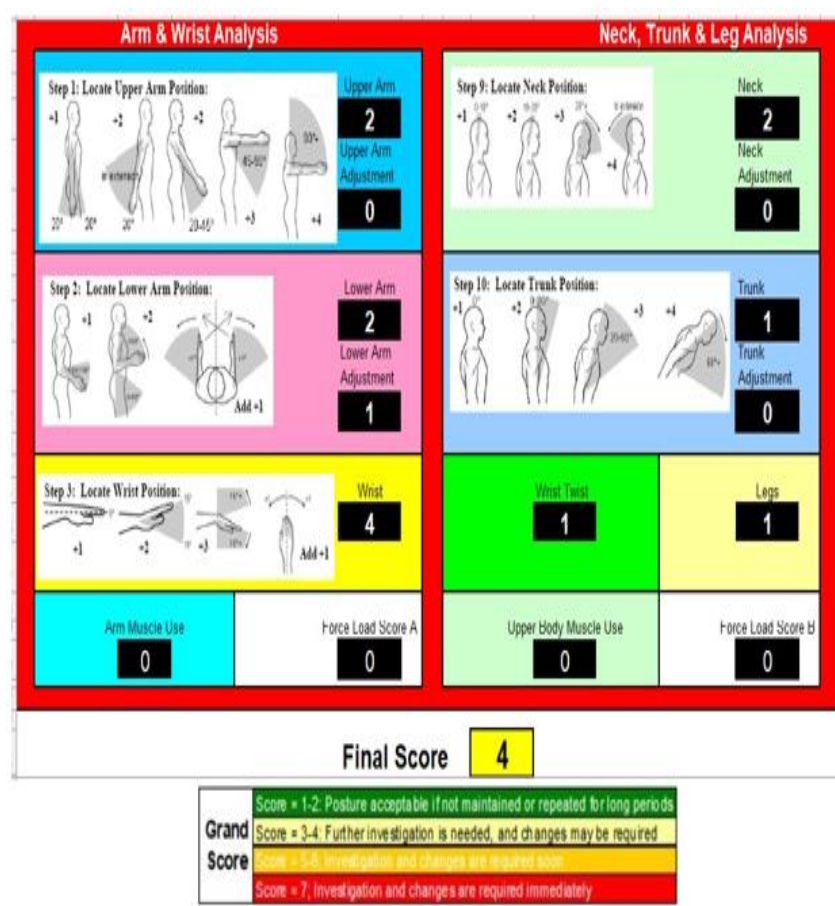
Table 4 RULA Results (for Good)

Arm & Wrist Analysis				Neck, Trunk & Leg Analysis			
Step 1: Locate Upper Arm Position: 		Upper Arm 2 Upper Arm Adjustment 0		Step 9: Locate Neck Position: 		Neck 2 Neck Adjustment 0	
Step 2: Locate Lower Arm Position: 		Lower Arm 1 Lower Arm Adjustment 1		Step 10: Locate Trunk Position: 		Trunk 2 Trunk Adjustment 1	
Step 3: Locate Wrist Position: 		Wrist 4 Wrist Adjustment 1		Wrist Twist 1		Legs 1	
Arm Muscle Use 0		Force Load Score A 0		Upper body Muscle Use 0		Force Load Score B 0	
Final Score 4							
Grand Score							
Score = 1-2: Posture acceptable if not maintained or repeated for long periods Score = 3-4: Further investigation is needed, and changes may be required Score = 5-6: Investigation and changes are required soon Score = 7: Investigation and changes are required immediately							

The score on RULA was obtained as a result of 4, which means that in order to get a more ideal upper posture, some changes need to be made.

The same method, RULA was used to assess Huda’s posture (Table 3.5) while sitting in a wheelchair. This method is used to determine the level of musculoskeletal danger due to inappropriate posture.

Table 5 RULA Results (for Huda)



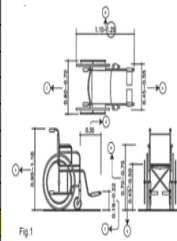
The score on RULA was 4, which means that several changes need to be made to achieve a more ideal upper posture of Huda.

Results of the conformity of the dimensions of the wheelchair with the standard.

The Good wheelchair based on *the United Nation* (UN) standard is intended for Table 6 and the Huda wheelchair based on the UN standard in Table 7.

Table 6 Nice Wheelchair

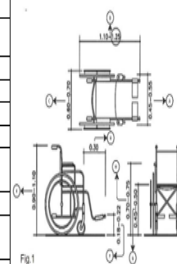
Dimensi Kursi Roda	Nilai Pengukuran	Standard UN	Nilai Ukuran UN	Keterangan
Handrest ke Controller	47	Tidak ada data	-	
Panjang Handrest	39	Tidak ada data	-	
Tinggi pijakan kaki ke tempat duduk	30.5	Tidak ada data	-	
Lebar Pijakan kaki bawah	15.5	Tidak ada data	-	
Panjang pijakan kaki bawah	16.5	Tidak ada data	-	
Tinggi handrest dari tempat duduk	28	Tidak ada data	-	
Panjang ujung handrest ke controller	7	Tidak ada data	-	
Panjang bantalan handrest	36.5	Tidak ada data	-	
Lebar bantalan handrest	5	Tidak ada data	-	
Tinggi handrest ke roda	22	Tidak ada data	-	
Diameter roda kecil samping	49.2	Diameter Roda kecil samping (G)	45-50	Sesuai
Diameter roda besar	62	Tidak ada data	-	
Diameter roda kecil depan	20	Tidak ada data	-	
Lebar sandaran duduk	49	Tidak ada data	-	
Tinggi sandaran duduk	43	Tidak ada data	-	
Tinggi keseluruhan	92	Tinggi Kursi Roda (E)	90-110	Sesuai
Lebar kursi roda	47.3	Lebar Kursi Roda (A)	45-55	Sesuai
Tinggi pijakan kaki dari tanah	14	Jarak pijakan kaki dari lantai (F)	18-22	Tidak Sesuai
Tidak ada data	-	Panjang keseluruhan kursi roda (B)	110-125	
Tidak ada data	-	Lebar keseluruhan kursi roda (C)	60-70	
Tidak ada data	-	Jarak Tempat duduk ke pijakan kaki (D)	30	
Tinggi handrest dari lantai	72.5	Tinggi handrest dari lantai (H)	70-75	Sesuai



Source:
<https://www.un.org/esa/socdev/enable/designm/AD5-02.htm>

Table 7 Huda wheelchair

Dimensi Kursi Roda	Nilai Pengukuran	Standard UN	Nilai Ukuran UN	Keterangan
Handrest ke Controller	51	Tidak ada data	-	
Panjang Handrest	37,5	Tidak ada data	-	
Tinggi pijakan kaki ke tempat duduk	43	Tidak ada data	-	
Lebar Pijakan kaki bawah	13,2	Tidak ada data	-	
Panjang pijakan kaki bawah	17,5	Tidak ada data	-	
Tinggi handrest dari tempat duduk	22,5	Tidak ada data	-	
Panjang ujung handrest ke controller	7	Tidak ada data	-	
Panjang bantalan handrest	33	Tidak ada data	-	
Lebar bantalan handrest	5	Tidak ada data	-	
Tinggi handrest ke roda	34	Tidak ada data	-	
Diameter roda kecil samping	Tidak Ada	45-50	Diameter Roda kecil samping(G)	Tidak ada roda kecil
Diameter roda besar	48	Tidak ada data	-	
Diameter roda kecil depan	19	Tidak ada data	-	
Lebar sandaran duduk	49,5	Tidak ada data	-	
Tinggi sandaran duduk	46	Tidak ada data	-	
Tinggi keseluruhan	122	90-110	Tinggi Kursi Roda (E)	Sudah ada penambahan sandaran kepala
Lebar kursi roda	49,5	45-55	Lebar Kursi Roda (A)	Sesuai
Tinggi pijakan kaki dari tanah	8,5	18-22	Jarak pijakan kaki dari lantai (F)	Pijakan kaki tidak digunakan
Tidak ada data	-	110-125	Panjang keseluruhan kursi roda (B)	
Tidak ada data	-	60-70	Lebar keseluruhan kursi roda (C)	
Tidak ada data	-	30	Jarak Tempat duduk ke pijakan kaki (D)	
Tinggi handrest dari lantai	74	70-75	Tinggi handrest dari lantai (H)	Sesuai



Source:
<https://www.un.org/esa/socdev/enable/designm/AD5-02.htm>

The evaluation of the suitability of the dimensions of the wheelchair with the standard is that several dimensions of the Bagus and Huda wheelchairs have met the

criteria in the UN standard. There are several dimensions that have not met/do not meet the appropriate standards because the wheelchair has been modified. For example, the headrest on Huda's wheelchair. In Bagus wheelchairs, the height of the footrest from the ground level is recommended to be higher, which is at least 18 cm

Evaluation of Wheelchair Usability Based on Observation

The usability of using Bagus's electric wheelchair based on observations obtained the following results: (a) When using a wheelchair, Bagus's shoulder position is unbalanced, the left side is lower than the right side, (b) The right side of the body is in a higher position, mainly when the right hand is used to operate the wheelchair both manual and electric, (c) Bagus said that it is quite comfortable in using his electric wheelchair, (d) Bagus does not dare to operate a wheelchair on a ramp, and (e) Not all parts of the sole are supported with the overall area of the footrest.

Furthermore, the use of Huda electric wheelchairs based on observations obtained the following results: (a) Usability of using Huda's wheelchair, with the backrest, head, and neck being well supported, (b) The seat has been made longer to adjust the sitting posture of Huda, (c) Huda does not require the footrest, (d) The position of the left and right shoulders is quite balanced, and (e) The position of the wheelchair controller on top (parallel to *the hand rest*) makes the position and posture of Huda's hands bend (*twisting*), and a lower location would presumably be more ideal posturally.

CONCLUSION

The conclusions and recommendations for the Bagus electric wheelchair are as follows: (1) from the anthropometric side, the popliteal height is longer than the distance between the seat and the footrest in the wheelchair. For Bagus to be more comfortable in using his wheelchair and his legs not crooked (which will potentially cause more excellent musculoskeletal disorders), it is recommended that the distance between the seat and the footrest be extended, (2) the length of the footrest of the lower foot (make it longer) so that the footrest, (3) can support all surfaces of the foot To meet UN standards, some dimensions of the wheelchair need to be adjusted, and (4) From anthropometric and postural analysis, the position of Bagus's right shoulder is raised upwards when the forearm is placed on the handrest, and the hand is operating the controller. Therefore, the following two alternatives are suggested: (a) the height of the handrest is reduced, and (b) the position of the electric wheelchair controller is placed next to the knee and at the height of the upper

thigh so that Bagus's hand can be supported by the upper thigh when operating the wheelchair.

The conclusions and recommendations for the Huda electric wheelchair are (a) In general, the Huda electric wheelchair has been modified to adapt to the needs and conditions of Huda's body while making the design of the Huda wheelchair more ergonomic, and (b) Postural analysis shows that the position of the forearm is raised and the hand is twisted (bent) when Huda operates the electric wheelchair controller. It is, therefore, recommended that the position of the controller be lowered parallel to the wheelchair seat.

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For Disabilities

<https://youtu.be/atBSbeI7Fjc>