Investigation of the Effectiveness of Wheelchair Based On Ergonomic Study

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***Abstract*— This document has been prepared to provide the reader with information about ergonomics in designing a wheelchair base from the anthropometry of human body. Ergonomic provide an ultimate comfort in workplace to eliminate or at least to reduce musculoskeletal disorders. Automotive ergonomics is the study of how automotive can be designed better for human use [1]. Biomechanical study of wheelchair posture is one of the most referenced aspects for the ergonomic design process of the whole vehicle [2]. The aim of this work is to study customer satisfaction as the wheelchair user, to compare design and seat dimensions to comfort factors by means of measuring and survey as well as using ergonomic software and to recommend the best dimension of user in aspect of anthropometric data percentile. Portions of a reliable and valid survey were used for this investigation. From the result, gives a high validity and reliability of the survey questionnaire responds and correlate with the result from the Ergonomic Analysis in Catia V5 and the RULA Analysis Assessment of the manikin in Catia V5. It can be seen that the dimension of the wheelchair design affects the ergonomic factors. By looking into specific dimension parameters, one can see the differentiation between the two wheelchairs. For user's comfort as well as reach factors, survey shows majority respondents give a different respond of the wheelchairs. However from discomfort assessment using Ergonomic Analysis in Catia V5, it was suggested that future design simulation gives better comfort for taller population while actual design simulation gives better comfort for shorter population.**

***Index Terms*—Ergonomics, Ergonomic Software, Anthropometry, Anthropometric Percentile.**

I. INTRODUCTION

Ergonomic provide an ultimate comfort for the user while seating in a short or a long period of time just to avoid back pain problem but not to comfort for the user. This paper is an investigation of the effectiveness of wheelchair based on ergonomic study.

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The anthropometry study of wheelchair user posture is one of the most referenced aspects for the ergonomic design process. It is a technique to provide comfort and effective comfort space for the user. Therefore, in this paper, wheelchair dimensions to comfort factors by means of measuring and survey as well as using ergonomic software have been considered. From the result, it can be perceived that factors of actual wheelchair design affect the ergonomic factors.

II. LITERATURE REVIEW

A. Overview of Ergonomics

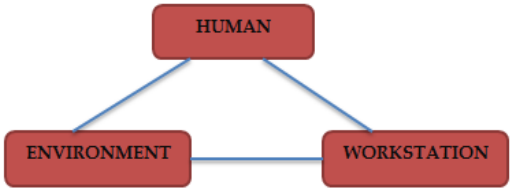

Figure 1: Ergonomic Relationship.

1. Basic Definition

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance [3]. Figure 1 represents the relationship of Ergonomics.

2. Wheelchair Ergonomic

In generally, define ergonomics as a scientific discipline that uses principles of biotechnology and engineering to make products more comfortable for workers and consumers. But ergonomics is not focus on the design of the certain product. It also factors in how effective and efficient we consume and conduct the appliance [4].

3. Sitting Posture

The seat back should be angled back to the same degree that the spine arches back as it ascends out of user lumbar hollow. In a sense, this allows the back at high-waist level to rest on the back support. If users are lucky enough to have an inflatable protuberance in the seat back and should make it as full as comfortably possible, as well as angling the seat back. With the angle quite extreme, it will feel odd - even perhaps a bit 'too laid back' for sitting. But, this small adjustment will be critically important to user sitting comfort and will make a huge difference to the on-going health of user back [5]. Figure 2 below indicated the sitting posture in a wheelchair to reduce MSD's.

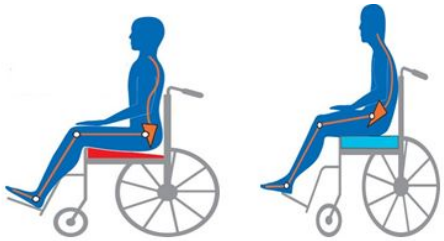

Figure 2: Sitting Posture.

4. Musculoskeletal Disorders

MSDs consist of minor physical disabilities. MSDs can affect all major areas of the body which include neck, shoulders, wrists, back (upper and lower), hips, legs, knees and feet. Given the different area of the bodies, the common MSDs include low back pain and gout. MSDs are the primary problem in long sitting period, and the risk increases with age and the problem that define as Ergonomics Injuries.

B. Overview of Anthropometry

1. Basic Definition

Anthropometrics, the study on human dimension such as measurement, shape, mass, centre of gravity, inertia of the human body and work capacity is necessary for ergonomic application. In determining the shape and dimension of a product, the features of the human body form the basis in determining size measurements.

2. Design Principle

Before a product is designed, the product must fit its user exactly, and the designer must decide which range of relevant body sizes that the designer want to accommodate. To achieve the product the designer should approach one of the design principles: Custom-fit each individual, have several fixed sizes, make it adjustable, design for extreme bodies and select the person with body fit the existing design [6].

3. Wheelchair Seat Consideration

The measurement need to be considering the wheelchair seat fit and suit as many users as possible. And the important measure must follow the standard of the sitting posture of the user as refer to figure 3 below:

Measurement	Letter	Female 5th – 95th%	Male 5th – 95th%	Overall Range 5th – 95th%
Sitting Height	A	31.3" – 35.8"	33.6" – 38.3"	31.3" – 38.3"
Sitting Eye Height	B	42.6" – 48.8"	46.3" – 52.6"	42.6" – 52.6"
Waist Depth	C	7.3" – 10.7"	7.8" – 11.4"	7.3" – 11.4"
Thigh Clearance	D	21.0" – 24.5"	23.0" – 26.8"	21.0" – 26.8"
Buttock-to-Knee	E	21.3" – 25.2"	22.4" – 26.3"	21.3 – 26.3"
Knee Height	F	19.8" – 23.2"	21.4" – 25.0"	19.8" – 28.0"
Seat Length/Depth	G	16.9" – 20.4"	17.7" – 21.1"	16.9" – 21.1"
Popliteal Height	H	15.0" – 18.1"	16.7" – 19.9"	15.0" – 19.9"
Seat Width	Not Shown	14.5" – 18.0"	13.9" – 17.2"	13.9" – 18.0"

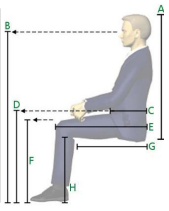

Figure 3: Measurement consideration for seating posture [7].

4. Measurement Parameter

Parameter is the distance that needs to be considering in measuring the dynamic factor of the user while doing their activity in the wheelchair. It is the dynamic parameter for the user especially for the moving using his or her own energy.

5. Percentile

A percentile value of an anthropometric dimension represents the percentage of the population with a body dimension of a certain size or smaller. This information is particularly important in design because it helps us estimate the percentage of a user population that will accommodated by a specific design. Percentiles are shown in anthropometry tables are specified that the measurement given in the tables relates to the 'average' person, or someone who is above or below average in a certain dimension. For normal distributions, the 50th percentile value is equivalent to the mean of the distribution. If a distribution is not normally distributed, the 50th percentile value may not be identical to the mean [9]. Figure 4 below shows a typical distribution of anthropometric data percentile.

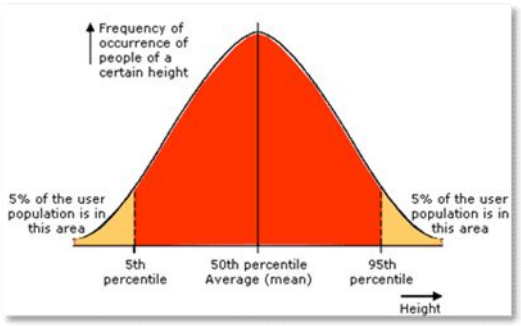

Figure 4: Typical distribution of anthropometric data [8].

III. METHODOLOGY

In order to meet the objective, the manual wheelchair is selected to be measured in order to investigate for the dimension parameters that contributed to automotive ergonomics consideration. Wheelchair user input will be taken into account from questionnaires that are intended to seek customer's preference. Through dimension measurement and Ergonomic Analysis data, sitting parameters for the user will be analyzed. Seating comfort level of all said wheelchairs will be evaluated and discussed simulated comfort measurement will be made to use for comfort and clearance study. The end result will report on the findings from survey, measurement, and analysis. Refer to figure 5 for the Major Flow of the Project Analysis.

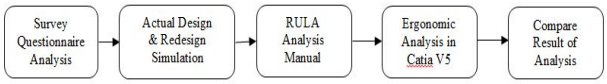

Figure 5: Major Flow of the Project Analysis.

A. Survey Questionnaire

Key informant survey was carried out by sending a set of questionnaires to few organizations which are involved directly and indirectly with wheelchair or vehicle seat development [9]. At least two set of survey questionnaires are developed with high statistical validity and reliability from all the users. It is important aspect of the design and seat comfort in a manual wheelchair. The proposed wheelchair design and seat discomfort survey questionnaire is developed in English language. And the target population is above 50 people, which means it will be distribute to 50 to 100 people. Seat comfort or discomfort evaluation is a key aspect in seat design. These objective of the survey are then correlated with subjective data to determine the relative effects of each measure related to comfort [10]. The survey result are then

evaluate by using the SPSS Statistics which is a software package that is used for statistical analysis to determine the reliability of the questionnaire by evaluating the percentage of the Cronbach's Alpha and the Means of each question refers to the satisfactory of the respondents. Figure 6 below shows the window of SPSS Tool in PASW Statistics.

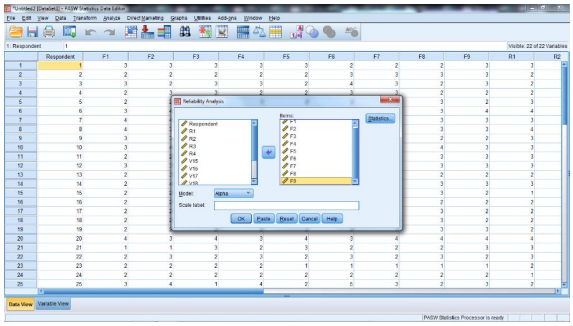

Figure 6: SPSS Tool used to analyse validity and reliability of the survey questionnaire [10].

B. *Actual Design Simulation*

Actual Measurement Simulation is the simulation for a design and seat actual dimension drawing in Catia V5. The simulation is the execution of a model in a manual wheelchair, represented by a computer program that provides the information about the system being investigated. The simulation approach of analyzing a model is opposed to the analytical approach, where the method of analyzing the system is purely theoretical. A simulation approach may be more reliable, depending on the quality of the model [10]. The simulation conducted by measuring the actual dimension by referring from the standard measurement of design and seat dimension. The important of Actual Measurement Simulation in the project is to enable the actual data produce during RULA Analysis in Catia V5.

C. *RULA Analysis*

RULA (Rapid Upper Limb Assessment) is a survey method developed for use in ergonomics investigations of workplaces where work-related upper limb disorders are reported. This tool requires no special equipment in providing a quick assessment of the postures of the neck, trunk and upper limbs along with muscle function and the external loads experienced by the body. A coding system is used to generate an action list which indicates the level of intervention required to reduce the risks of injury due to physical loading on the operator. It is of particular assistance in fulfilling the assessment requirements of both the European Community Directive (90/270/EEC) on the minimum safety and health requirements for work with display screen equipment and the UK Guidelines on the prevention of work-related upper limb disorders [11]. Refer to Figure 7 of the RULA Assessment Worksheet.

RULA was developed to investigate the exposure of individual workers to risk factors associated with work related upper limb disorders. Part of the development took place in the garment-making industry, where assessment was made of operators who performed tasks including cutting while standing at a cutting block, machining using one of a variety of sewing machines, clipping, inspection operations, and packing. RULA was also developed through the evaluation of the postures adopted, forces required and muscle actions [12]. RULA was developed without the need for special equipment. This provided the opportunity for a number of investigators to be trained in doing the assessments without additional equipment expenditure. As the investigator only requires a clipboard and pen, RULA assessments can be done in confined workplaces without disruption to the workforce. Those who are trained to use it do not need previous skills in observation techniques although this would be an advantage [14].

D. *Ergonomic Analysis in CATIA V5*

CATIA V5R21 was included with Ergonomics Design and Analysis (EDA) module. By implementing and using the ergonomics facilities, a CAT Product in CATIA is generated. The ergonomics design processes are defined by 4 sub modules which are Human Builder, Human Measurements Editor, Human Posture Analysis and Human Activity Analysis [14]. Figure 8 below shows the window of Ergonomic Analysis in CATIA V5.

E. *The Development of RULA*

STAGE 1: The development of the method for recording working postures.
STAGE 2: Development of the system for grouping the body part posture scores.
STAGE 3: Development of the grand score and action list.

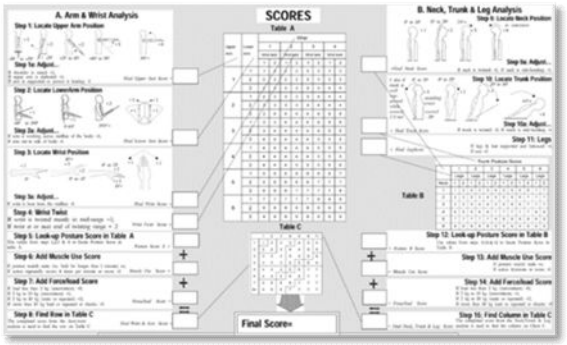

Figure 7: RULA Assessment Worksheet [11].

Figure 8: Ergonomic Design and Analysis in CATIA V5.

IV. RESULTS

Table 1: RULA Analysis Score in CATIA V5 [14].

No	Criteria	Concept Rating (0 – 7 as RULA analysis score)	
		Actual Design	Future Design
			
1	Upper Arm	2	1
2	Forearm	2	1
3	Wrist	3	2
4	Wrist Twist	2	1
5	Posture A	4	2
6	Muscle	1	0
7	Wrist and Arm	6	2
8	Neck	3	2
9	Trunk	4	1
10	Leg	1	1
11	Posture B	3	2
12	Neck, Trunk and Leg	5	2
13	Final Score	6	2

Table 2: RULA Assessment Score for Manikin in CATIA V5.

Details	MANUAL WHEELCHAIR	
	Actual Design	Future Design
Step A		
Locate Upper Arm Position	1	1
Locate Lower Arm Position	1	1
Locate Wrist Position	1 + 1	1
Wrist Twist	1	1
Table A	2	1
Add Muscle Use	1	1
Add Force/ Load	0	1
Table C	3	2
Step B		
Locate Neck Position	3	1
Locate Trunk Position	2	1
Locate Leg Position	2	1
Table B	4	1
Add Muscle Use Score	1	1
Add Force/ Load	1	0
Table C	6	2
FINAL SCORE	5	2

Table 3: RULA Analysis Final Score Range [11].

Final Score Range	Action
1 or 2	Acceptable
3 or 4	Investigate Further
5 or 6	Investigate Further and Change Soon
7	Investigate and Change Immediately

From the result in table 1 and table 2, it is observed that the comparison of the range of comfort for actual design and the future design of wheelchairs. From the range of the result computed the user can take further action at which part of the manikin is not comfort and as well compare to the factor of discomfort or dissatisfied respondent in the Survey Analysis. Besides that, from the Table 2 above shows that the final score for both analyses are the same. It is verified that the reliability and the validity of all result through the parts of the manikin body does not match the same score. Therefore, it can be summarize that during conducting the RULA Assessment Worksheet, the scorer might have made an error of reading the part of body posture.

Working postures and actions score of 1 or 2 are considered acceptable even if not maintained or repeated for long periods. The action score of 3 or 4 will be given to working postures which are out of suitable ranges of motion and also working postures which are within suitable ranges of motion but where repetitive actions, static loading or the exertion of force are required. Further investigation is needed for these operations and changes may be required. The action score of 5 or 6 specifies the working postures which are not in the suitable ranges of motion, the worker is required to perform repetitive movements and/or static muscle work. And there may be a need to exert force. It is suggested that these operations are investigated soon and changes made in the short term while long-term measures to reduce the levels of exposure to risk factors are planned. Finally, the action score of 7 would be given to any working postures at or near the end of range of movement where repetitive or static actions are required. Any postures where the forces or loads may be excessive are also included in this group. Ingestion and modification of these operations is required immediately to reduce excessive loading of the musculoskeletal system and the risk of injury [12].

V. Discussion

Before proceeding to the discussion of the analysis, the user had done a calculation of the percentage error to see the difference between the RULA Assessment using Worksheet and the RULA Analysis using CATIA V5. Percent error is used when the user are comparing the result to a known or accepted value. It is the absolute value of the difference of the values divided by the accepted value, and written as a percentage. In most cases, a percent error or difference of less than 10% will be acceptable. If the comparison shows a difference of more than 10%, there is a great probability that some mistake has occurred, and the user should look back over the investigation to find the source of the error [15].

$$\frac{|\text{Approximate Value} - \text{Exact Value}|}{|\text{Exact Value}|} \times 100\%$$

Figure 9: Error Percentage Equation [15].

By comparing the result between the survey questionnaire and the ergonomic analysis, the result will show the different between both of analysis. Survey was taken to identify user's perception towards in term of aspects that are often seen in wheelchair evaluation standards. Measurements were done to recognize the dimensions which are involved and afterwards ergonomic software (RULA Analysis in CATIA V5) applied to analyze the dimension involved.

For the user's comfort factor, the survey questionnaire analyzed by the discomfort factor that majority respond by the user use and experiences the comfort level for manual wheelchair. Since the survey does not take into account the anthropometrics of respondents, it cannot tell in terms of people size that gives such answer. However the result can be compute from discomfort assessment using RULA Analysis from Ergonomic Analysis in the Worksheet and CATIA V5.

The survey questionnaires were rated as very important and give a great mind-set impact of overall seat comfort perception by the user use and experience user. The questionnaire that distributed based on their understanding level in aspect of the language and the scientific term for the

Table 4: Summary of result from SPSS Tool [10].

design and seat section. SPSS Tool This step was also done to ensure high face validity of the survey and produced an assured result to be analysed.

	MANUAL WHEELCHAIR	
Design	Mean	Cronbach's Alpha
Seat Depth	2.59	0.728
Back Height	2.76	
Rear Seat to Floor	2.46	
Hanger Angle	2.91	
Seat Width	2.60	
Camber	2.65	
Front Seat to Floor	2.69	
Footrest Width	2.74	
Seat		
Lumbar Support	2.53	0.664
Shoulder Width	2.62	
Shoulder Height	2.76	
Cushion Width	2.43	
Cushion Length	2.63	
Backrest Height	2.54	

From the survey questionnaire result, the answer are divided into five categories of scale 1 to 5 which represent very comfort, comfort, moderate, discomfort and very discomfort. From a random hand out of 50 to 80 pieces of the questionnaire, 65 mark of manual wheelchair, 3 mark of power wheelchair, and 12 are not responded. The survey was meant to get the general idea of satisfaction of each manual wheelchair.

Based on the survey questionnaire analysis in Table 4, the study for customer current satisfaction of manual wheelchair are not as high as expected. The overall satisfaction based from the SPSS Tool Means for the Design is 2.91 on the "Hanger Angle" and "Back height" is 2.76 and still cannot be consider as satisfaction because of the Means are less than three (< 3). Therefore, the user cannot consider as satisfaction. The satisfaction level as well for Seat from SPSS Result, the highest Means is 2.76 on the "shoulder Width" and 2.63 on the "Cushion Length" for the seat. Therefore, the highest satisfaction of responses for both are less than three (< 3) and not consider as satisfactory.

From the result that have been compute in this analysis, it is observed that the comparison of the range of comfort for actual design and the future design of wheelchairs. From the range of the result computed the user can take further action at which part of the manikin is not comfort and as well compare to the factor of discomfort or dissatisfied respondent in the Survey Analysis. From the result table of RULA Analysis in CATIA V5 and RULA Assessment, the final score for both analyses are the same. It is demonstrated that the reliability and the validity of all result through some of the parts of the manikin body does not match the same score. It can be assume that during conducting the RULA Assessment Worksheet, the scorer might have made an error of reading the part of body posture.

The Actual Measurement Simulation progress in this investigation is an important factor that need to be consider to proceed for the RULA Analysis in CATIA V5 the measurement are accurate to produce a reliable and valid result. Based on the design both of the two wheelchairs, the overall dimension for actual dimension are smaller compare to future design. From a logic perception, the user assures that a bigger or wider seat provide more comfort for any different size of human anthropometric. But, uninsured was it bigger and wide enough to fit all different anthropometry of users. In the selection of anthropometry studies, to consider for a seat design it is cunning to select the 50th percentile so that the seat can fit the majority human size. It can be assume that seat nowadays can be supposed as in the range of acceptable to excellent for all users.

Therefore, the entire respondent on the survey questionnaire level for manual wheelchair did not assure that of the seat design does not meet the requirement because different people have different anthropometry data since the principle to design a seat is to consider 50th percentile anthropometric to fit the majority user.

VI. Conclusion

Based on what has been done in this paper of the investigation of the effectiveness of wheelchair based on ergonomic study, it can be conclude that this analysis has a high prospect if continued. The validity and reliability of the survey analysis conclude that the customer does not meet the satisfaction for actual design seat. Generally, quality of components could be the big factors since one who has experienced at least one part of defect in the wheelchair user will actually affected the judgement towards other factors in the wheelchair. Therefore, the measurement and comparison will give a better understanding of how wheelchair seat design contributes to ergonomics. Furthermore, it is also can be accomplish that satisfaction has no limit and base from the result analysis, the user will be able to focus which part of the most unsatisfactory part of the seat design. As a result, before the user wanted to proceed for constructing improvement, it needs to identify the least or the lowest means of the part of the wheelchair seat design. Other than that, the comfort factors which is been compared in this analysis are based on the future seat design. As a final point, the different anthropometry data of different sizes of human being gave different comfort factor for considering a wheelchair seat design. The designer also need to apply the 50th percentile of anthropometric in order to fit the majority user rather than focus on the 5th which is contributed a great unsatisfactory to

50^{th} and the 95^{th} percentile user, as well as 5^{th} percentile will provide a great un-satisfaction if the seat design are focusing on the 95^{th} percentile user.

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