第 49 卷 第 10 期
2022 年 10 月

湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences)

Vol. 49 No. 10
October 2022

Open Access Article https://doi.org/10.55463/issn.1674-2974.49.10.7

The Development of the Driving Simulator: Anthropometry and Occupant Packaging Evaluation in Ergonomic Study

Aiman Affandi, M. Z. Hassan, Nur Hazwani Mokhtar*

Faculty of Manufacturing and Mechanical Engineering Technology, Technical University of Malaysia Melaka, Durian Tunggal, Malaysia

Abstract: The primary purpose of this study was to produce a driving simulator guided by ergonomics and anthropometry in the population of Malaysians. The data obtained from previous studies on the Malaysian population are minimal, so this study should be highlighted in the automotive research industry. Hence, this study also aimed to improve the existing study, where the driving simulator can investigate driving behavior systematically and in more detail. Furthermore, the simulator can produce the same scenario on the road without involving actual vehicles. Therefore, using a driving simulator can reduce the risk and cost of the study done on a real road. The used monitor will broadcast the setup road scenario on the display that will be observed and evaluated afterward. The research observed anthropometry data from 103 participants in 23 different measurements of 11 standing and 12 sitting positions. This analysis continues with the study of occupant packaging measurement in an actual vehicle's driving area, determining the driving simulator dimension. The driving simulator design is then obtained by analyzing three different vehicle models: BMW i3, Toyota Prius, and Proton Preve. This phase includes the standard and optimum driver seat adjustment according to the required ergonomics study, which is proportional to the Malaysian population measurement based on the selected previous study. The design proceeds with the material selection with aluminum extrusion as its design material. Finally, the design created is analyzed in a CATIA V5 simulation to examine the displacement magnitude and von Mises stress of the rig frame structure when some load is appointed. The final phase included a physical test to measure the driving simulator's abilities to avoid the stated obstacles in measuring its accuracy compared to an actual on-road experiment. This phase included 10 participants with two different scenarios. Participants had a compulsory questionnaire to conclude the analysis based on their experience. In conclusion, this study discriminated against on-road driving behavior with high safety factors and low cost without involving an actual vehicle or road. Hence, the simulation of the designed product proves that the subject weight is directly proportional to the displacement magnitude and its von Mises stress, and vice versa.

Keywords: anthropometry measurement, occupant packaging, driving simulator design, displacement magnitude, von Mises stress.

駕駛模擬器的發展：人體工程學研究中的人體測量學和乘員包裝評價

摘要：這項研究的主要目的是在馬來西亞人中製作一種以人體工程學和人體測量學為指導的駕駛模擬器。從之前對馬來西亞人口的研究中獲得的數據很少，因此這項研究應該在汽車研究行業得到重視。因此，本研究還旨在改進現有研究，其中駕駛模擬器可以系統地、更詳細地研究駕駛行為。此外，模擬器可以在不涉及實際車輛的情況下在道路上產生相同的場景。因此，使用駕駛模擬器可以降低在真實道路上進行研究的風險和成本。使用的監視器將在顯示器上播放設置的道路場景，隨後將對其進行觀察和評估。該研究觀察了 103 名參與者在 11 種站立姿勢和 12 種坐姿的 23 種不同測量中的人體測量數據。該分析繼續研究實際車輛駕駛區域的乘員包裝測量，確定駕駛模擬器尺寸。然後通過分析三種不同的車型獲得駕駛模擬器設計：寶馬一世 3、豐田普銳斯和質子預防。此階段包括根據所需的人體工程學研究

Received: July 6, 2022 / Revised: August 2, 2022 / Accepted: September 10, 2022 / Published: October 30, 2022

About the authors: Aiman Affandi, M. Z. Hassan, Nur Hazwani Mokhtar, Faculty of Manufacturing and Mechanical Engineering Technology, Technical University of Malaysia Melaka, Durian Tunggal, Malaysia

Corresponding author Nur Hazwani Mokhtar, nurhazwani@utem.edu.my

對駕駛員座椅進行標準和最佳調整，該研究與基於選定的先前研究的馬來西亞人口測量成正比。設計以鋁型材為設計材料進行選材。最後，在 CATIA V5 仿真中對創建的設計進行分析，以檢查指定負載時鑽機框架結構的位移大小和馮·米塞斯應力。最後階段包括一項物理測試，以衡量駕駛模擬器的能力，以避開與實際道路實驗相比測量其準確性時規定的障礙。這個階段包括 10 名參與者，他們有兩種不同的場景。參與者有一份強制性問卷，以根據他們的經驗得出分析結論。總之，本研究在不涉及實際車輛或道路的情況下，區分了具有高安全係數和低成本的道路駕駛行為。因此，設計產品的仿真證明主體重量與位移大小及其馮·米塞斯應力成正比，反之亦然。

关键词：人體測量、乘員包裝、駕駛模擬器設計、位移幅度、馮·米塞斯應力。

1. Introduction

In Malaysia's statistical report, 15 thousand people were killed or injured in road accidents back in 2019. The accident number was a drop from 2012, when there were roughly 24.4 thousand casualties reported. Through the Malaysian Road Safety Plan Report 2014–2020, the status of road accidents shows that road deaths in 2017 were as many as 6,740 deaths, this number increased by 0.98% compared with deaths in 2014 which were 6,674 [1]. Although the number of traffic accidents has increased recently, fatalities have decreased.

Highway safety needs to be maintained to reduce the mortality due to road accidents. Despite the drop-in fatalities, more can be done to promote safe roads in Malaysia, particularly during peak travel seasons like Chinese New Year and Hari Raya Aidilfitri, when millions of Malaysians travel back to their hometowns via the highways [2]. The first contributing factor to Malaysian road accidents is the drivers' behavior. According to a survey conducted by MUFORS (Malaysian Unite for Road Safety), 61.1% of respondents agreed that most road accidents are caused by the driver's attitude [2]. A driving simulation is a practice of stimulating actual on-road scenarios of a study or experiment visually to obtain a similar event and examine selected participants according to the research objective. Per Malaysia's aim to maintain the decline of fatalities in road accidents, the driving simulator (DS) can evaluate human factors respected to the vehicle behavior.

One of the key areas considered by the design engineer when developing the design solution was ergonomics. Executing ergonomics solutions can make an individual more comfortable and drastically increase the output of their performance [3]. The ergonomic factor function ensures that vehicles are harmonized and fulfill customer expectations, where the seating position is essential in automotive design. Furthermore, ergonomic factors boost productivity while ensuring safety and fostering a healthy environment [5]. The car seat must be comfortable to ensure the driver's posture, health, and convenience while driving [6]. The ergonomics aspects consisting of much anthropometry data within a selected population are examined. Anthropometry, a branch of ergonomics, has a high potential to contribute to the design of various types of systems with people, such as work systems, workstations, products, and service systems [4]. Measurement by anthropometry is carried out to create a comfortable, safe, and healthy environment for humans, as well as to create efficient working conditions with effective results, or to achieve an ergonomic state [7].

Ergonomics is important in driving simulator design to determine the best fit between the driver and the vehicle to guarantee safety, comfort, accommodation, improved execution and proficiency, and diminished exhaustion. This aspect is concerned with human interaction and other system components, as well as improving human well-being and overall system performance [5].The keywords often describe ergonomics as both comfortable and safe environments. Besides car seats, other types of equipment such as steering wheel position, acceleration, and braking pedal position are essential to ensure the driver's comfort. The vehicle's interior is designed to maximize accommodation for the target population within the limits of space or car dimensions. Accommodation means the driver can perform the required tasks while sitting in a comfortable position. The driver is considered accommodated if the workspace components can be reached in the desired position without the limitations of the adjustment range [15].

Most of the studies are held in Europe, making the research on the average Asian population is lowest than expected. An earlier anthropometric database for the Malaysian elderly population has been developed for user-friendly designs of domestic furniture and appliances [6]. Because of this research, this study has helped in forming guidelines for designing basic fixtures in the households of older Malaysian. This research is designed to conduct engineering studies on vehicle interior parts for the driving simulator rig according to the Malaysian population considering the limitations of Malaysia's vehicle behavior research data. The automotive vehicle existing design is used as a benchmark to produce the driving simulator rig frame. We observed that the scale factor between the Malaysian anthropometric and the US anthropometric sizes position is around 0.9437 [7]. Road driving tests are a less expensive approach that may yield better and more objective measures. However, in some cases, legal and ethical considerations severely limit the range of tests that can be performed compared to the use of a driving simulator, as it is obvious that putting people in danger is unacceptable [8]. Furthermore, scenarios can be run in the simulator, which are probably too costly, dangerous, time-consuming, and complicated to test in the real world [14]. Different combinations of obstacle distribution and background generate a much richer set of data without requiring any additional data acquisition or labeling costs to create the scenario [9].

Driving simulators enable the controlled and reliable acquisition of various driving performance indicators, including lane deviation, reaction time, and lateral acceleration [10]. Nowadays, driving a simulator on the market is costly and primarily intended for gaming purposes. Some of their seats are fixed where the user cannot adjust the height of the headrest, angle of the back cushion, height of the seat, and space between the seat and steering. The structures of the cheaper driving simulator are not solid for the driver and monitor screen. The research gathers and analyzes data of three types of cars from different manufacturer regions by comparing the dimension measurements of these cars with their initial dimensions to develop a driving simulator rig. The reference points and dimensions in the driver workspace were from the selected previous study [12].

2. Methodology

This research is structured to focus on the research design and analysis. The procedures necessitate the data collection by using specific methods, which the processes that include measurements, data analysis, and design analysis. The methodology consists of three parts: the first part is anthropometry study, followed by occupant packaging, and the final part is the Driving Simulator study.

2.1. Anthropometric Data

Anthropometry is the study of the dimension's characteristics of the human body in terms of measurement. In the most general static anthropometry, the measurement of the human participant is in fixed and predetermined positions, where landmarks on the body are used to identify the measuring points. Measurements are taken vertically or horizontally in a linear form or along the body's surface from one point to another. The participants for the anthropometric study are 103 males ranging from 21 to 28 years, with an average age of 24. Meanwhile, height and weight of each participant were considered, with the average weight of all individuals being around 56.2 kg. All participants are students of Technical University Malaysia Melaka from various Malaysian states. Because of this heterogeneity, the data obtained are expected to reflect the local population. The data consist of 23 anthropometric measurements comprising 11 standing positions and 12 sitting positions.

The measuring instrument used to obtain the anthropometric measurement readings is a measuring tape. The acquired anthropometry data are sorted and analyzed to determine its percentile. According to SAE Rule A1.2.2, the vehicle must accommodate drivers ranging in height from the 5th percentile female to the 95th percentile male. The comparison factor of SAE J833 was developed using the US population's statistics, SAE J833:1989. This analysis was constructed to determine all 23 participants' anthropometric measurements, anthropometric body measurements, and stature. The anthropometry measurements obtained are recorded and evaluated for the driving simulator design process. Anthropometric evaluations are quantitative non-invasive measurements of the human body [11]. In contrast, anthropometry measurements use essential equipment, which is economical, fast, and straightforward. Hence, three body segments cover all anthropometry parts, as shown in Table 1. The segment consisted of the standing position, the sitting position, and feet measurement. Fig. 1 and Fig. 2 illustrate each 23-point segment for both standing and sitting positions accordingly.

Table 1 List of the measurement components

No	Body Segment 1	No	Body Segment 2	No	Body Segment 3
1	Stature	1	Sitting height	1	Foot width
2	Arm span	2	Eye height	2	Foot length
3	Hand length	3	Shoulder height	3	Ball of foot length
4	Forearm length	4	Knee height		
5	Upper arm length	5	Thumb tip reach		
6	Ankle height	6	Head length		
7	Knee height	7	Chest depth		
8	Thigh height	8	Elbow to Fingertips		
9	Trunk length	9	Buttock – knee length		
10	Shoulder width				
11	Head width				

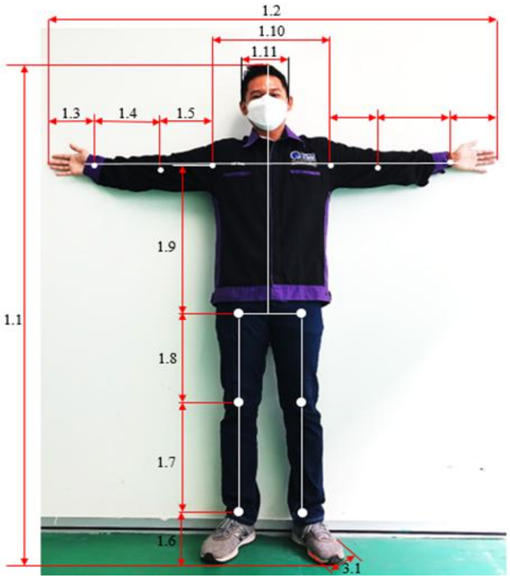

Fig. 1 Point segment of standing position

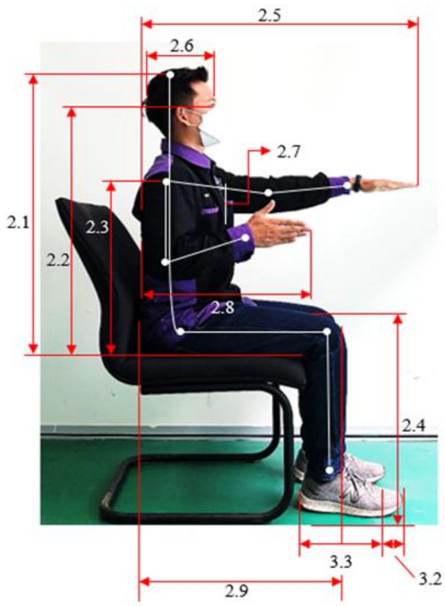

Fig. 2 Point segment for sitting position

2.2. Occupant Packaging Data

Driver workspace is the focus of the occupant packaging study. A driver workspace commonly refers to the area and adjustment distances of the steering wheel and seat concerning the pedals. It includes the controls and displays the physical locations with which the driver interacts. Analysis of both direct and indirect internal and external vision driver zones is often considered an aspect of the packaging practice. Thus, this study used the reference measurement from Parkinson and Reed's study [12]. The analysis was carried out with two side view dimensions. The accelerator heel point (AHP) is measured from the ground data. Apart from that, the steering wheel pivot, upper daylight opening, cowl point is measured from AHP as the starting point, while the measurement of roof height was from the ground.

Driving simulators are the most advanced use of computer-aided kinematic and dynamic simulations, as well as one of its most significant achievements. Driving simulators immerse the driver in a synthetic environment intended to replace one or more components of the actual driving experience. Engineers and researchers use driving simulators in vehicle design, intelligent highway design, and human factors studies such as driver behavior in severe weather or road conditions. They provide a safe environment for testing in which cost-effective, regulated, and made repeatable measurements. The data acquired can help them forecast corresponding measures in the real world, resulting in a greater understanding of the complex driver–vehicle–roadway interaction in critical driving circumstances. The findings of this research will eventually result in fewer traffic-related fatalities and injuries on the local's highways.

The driving simulator design consisted of a single-seat, steering, gear, and foot pedals to control the fuel, brakes, and clutch. Hence, in designing the driving simulator, measurement reading of several respondents must be conducted in the seating position for each participant in the driver seat. Therefore, 61 male respondents aged between 21 and 28 were selected randomly out of the 110 respondents from the anthropometry study. Throughout this experiment, various driving postures were observed and recorded while each respondent was sitting comfortably. The equipment used for taking the measurement was a measuring tape. Then, the results obtained will be sorted to calculate the five percentiles, 50 percentiles, and 95 percentiles mean, with the standard deviation for each component. The required anthropometry measurement for the driving simulator design dimension is illustrated in Fig. 3.

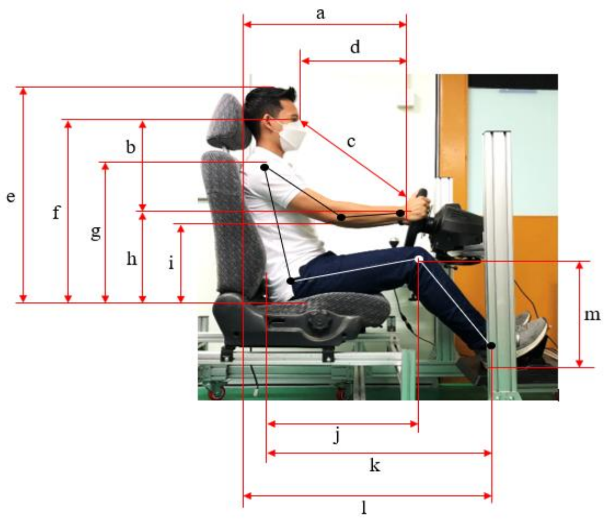

Fig. 3 Driver body dimension

2.2.1. Study of Vehicle Dimension

In completing the dimensions of the driving simulator design, three types of cars from various manufacturers are examined. These three vehicles were chosen to be measured and compared in dimensions. Therefore, BMW i3, Toyota Prius, and Proton Preve were selected for testing and comparison. BMW i3 is manufactured in Germany. However, Toyota Prius is manufactured in Japan, and the third vehicle is the Proton Preve, manufactured in Malaysia. As illustrated in Fig. 4, the BMW i3 is a B-segment, five-door hatchback-designed vehicle with the power of an electric motor of 125 kW (168 HP). This model is an electric-powered vehicle that produces zero amount emissions. Meanwhile, Fig. 5 depicts the second selected Toyota Prius model. This model is also a B-segment, five-door hatchback designed with a semi-hybrid vehicle system. This car produces 73 kW (98 HP) of a 1.8-liter engine mechanism and 100 kW (134 HP) of its electrical motor. The final model chosen is a Proton Preve shown in Fig. 6. The Proton Preve is a C-segment compact car with a 1.6 liter turbo engine capacity that produces 103 kW (138 HP). In analyzing the data, dimension parameters must consider: the accelerator heel point (AHP), the steering wheel pivot relative to the AHP, the steering wheel diameter, and the hood point on both the x- and z-axes. Hence, it shows in Fig. 7 each point for every element, where all measurements set the ground as a reference point, except for the steering wheel's starting point is at the AHP.

Fig. 4 BMW i3

Fig. 5 Toyota Prius

Fig. 6 Proton Preve

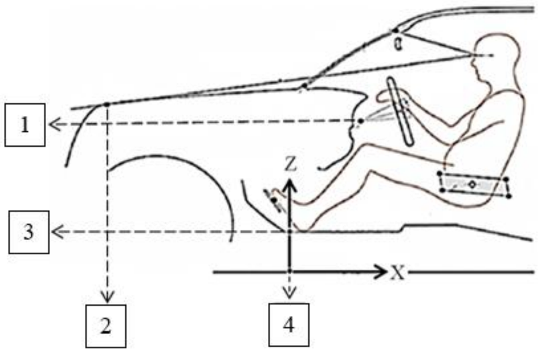

Fig. 7 Occupant packaging measurements

2.3. Driving Simulator Design and Development

In developing the driving simulator, essential aspects in deciding the rig frame design are ensuring all components of the steering wheel, seat, and pedal set are adjustable according to Malaysian population anthropometry measurement. Furthermore, the position of all elements is crucial to be determined according to the safety ergonomics of the vehicle's user to ensure occupant comfort and health. The ergonomics factors that are considered include the user's body size and the body's position and posture, which some of the required criteria are listed and evaluated in this section. Apart from that, the geometry features of the seat design are observed thoroughly to get the best fit for the driving simulator's seat.

This section starts with the design selection, where the existing driving simulators on the market are used as the primary reference source to determine the actual design for this simulator. After that, the design is continued by selecting appropriate materials and extensions. The materials used for driving available simulators either from some products on the market or from previous studies have been researched and taken into accounts, such as PVC, wood and aluminum pipes. Finally, based on the anthropometric measurements carried out, dimensions for the driving simulator's rig frame have been formed to ensure that this product follows the Malaysians' population measurements. This section is completed by simulating the constructed design in CATIA V5 software, which the displacement magnitude and von Mises stress are examined and observed according to the assigned load toward the design's sitting area.

2.3.1. Design Selection

The design selection process is critical to ensure that the selection corresponds to the criteria of the designed product. The frame design consists of steering, gear knob, pedals, and seat mounting based on the actual vehicle design. This study emphasized the ergonomics dimension and safety factors aspects of the vehicle's driver, while the other passenger aspects included in a vehicle can be neglected. Thus, three designs are finalized and chosen following the weight decision matrix based on the objective research and budget. This method examines the best criteria of the design solution before selecting the right design. The score given for each criterion and element of the rig's criteria is in Table 2.

Deciding on the best design for the driving simulator can be fairly complicated and challenging for the researcher. Many types and characteristics need to be considered and examined. In short, this study uses a weighted decision matrix to compare every possible design for the rig frame. As shown in Table 3, the characteristics of the driving simulator are listed accordingly. Different driving simulator designs are listed in columns such as adjustable rig, fix rig, and fix the rig with adjustable seat.

All configurations are evaluated and scored based on the specified criteria. Next is to determine the influencing criteria; only then the requirements be rated with the specified score. Finally, sum up all scores, and the total score obtained is compared to pick the best results with the highest score reading. As a result, the adjustable rig and seat design comply with all the listed driving simulator design criteria, obtaining the highest results for the decision matrix. Therefore, this study proceeds with the highest score design to the next phase.

Table 2 Rig’s criteria score board

No	Criteria	1	2	3	4	5
1	A safety driving simulator			✔		
2	Comfort driving simulator					✔
3	Ergonomics driving simulator					✔
4	A portable driving simulator				✔	
5	A big dimension of driving simulator			✔		
6	Simple design for a driving simulator			✔		
7	An aesthetic design of a driving simulator		✔			
8	Easy maintenance of a driving simulator			✔		
9	Easy assembly of a driving simulator				✔	
10	A high-cost worth it driving simulator				✔	
11	Production time consumed				✔	

Table 3 Weight decision matrix

Criteria	Benchmark	Adjustable Rig + seat	Fix Rig + seat	Fix Rig + adjustable seat
Comfort	5	5	4	3
Safety	3	5	4	4
Ergonomics	5	5	1	2
Cost	4	2	3	4
Portable	4	2	3	3
Dimension	3	3	4	4
Simplicity	2	4	5	5
Maintenance	3	4	4	4
Production time consumption	4	4	3	3
Easy assembly	4	2	3	4
	Total score	134	119	127

2.3.2. Material Selection

The key to engineering applications and part design is the material selection process. Material selection is the basis of all engineering and design applications. The material selection process can define application requirements, possible materials, and physical principles in this process. The most common and necessary method to reinforce any material is densification. It can generally increase the tensile strength by reducing the porosity of the material. Selection can result in a change in stability, consistency, density, appearance, and durability. Three different materials for the rig's frame are considered, and the first is wood. Due to the various types of wood available for industry, this study will highlight hardwood materials commonly used in furniture production. Physically, wood is solid and stiff, but it is also light and flexible compared to other materials such as steel. It also has different attractive properties such as strength in tension and compression. While the internal structure of the metals, plastics, and ceramics is relatively uniform and isotropic, wood behaves precisely the same in all directions. Wood is different because of its annual ring structure and grain structure.

The second material considered is polyvinyl chloride (PVC). PVC material is the most commonly used material for plumbing and drainage. However, for metal piping, PVC has become a common substitute. PVC is a very dense material compared to most plastics with 1.4 g/cc. Moreover, PVC has relatively high durability and hardness with tremendous tensile stress; it is easy to set up and low-cost material, making it one of the most popular materials in the industry. Finally, PVC is a material that is chemicals-resistant and alkalis. This study does not involve any chemical or alkali’s reaction; hence, this material cannot be considered. The final material included in this study is an aluminum extrusion. The aluminum extrusion is selected for this design due to its feasibility and cost that is low. Additionally, this material is frequently used in vehicle production, where a high strength-to-weight ratio is required. The shaping process is determined as an extrusion by obliging it to flow through a shaped opening of a die. Hence, the extrusion material has the same profile as an elongated part of the die opening. Table 4 simplifies all three material's characteristics for further evaluation.

Table 4 Material characteristics

Material	Wood	Aluminum Extrusion	PVC
Characteristics	Complex Structure	Low weight	Readily available
	Has dark and light colors	High strength	Inexpensive.
	Expensive	High reflectivity	High density and hardness
	High density	High toughness	High tensile strength
	Heavy	High elasticity	Resistant to impact deformation
	High fire resistant	High malleability	Resistant to chemicals and alkalis
	Strong in compression and tension	Resistant to corrosion	
		Good thermal and electrical conductivity	

2.3.3. Design of the Rig Frame

The rig structure is drawn and simulated using the Computer-Aided Three-Dimensional Interactive Application (CATIA V5) and Altair SimSolid software. CATIA V5 and SimSolid provide the ability to view 3D designs. It offers the basics of product structure, constraints, and moving to assemble parts throughout the drawing process. In assemble workbench functionality, all the components are connected to each part. This software includes a structure analysis study of the product after the assembly process, and the completed structure is shown in Fig. 8. The dimensions of the rig frame are structured from the results of analysing three different selected cars in the vehicle dimension study upon comparison with the reference measurement from Parkinson and Reed's study and the driver's body measurement in the anthropometry study, which includes 103 participants among UTeM students. Each part is customized with specific measurements to achieve the target and product design, where the frame must be adjustable to comply with the user's ergonomics. The driving simulator consists of about 28 different parts that need to be assembled, with most of the parts made of aluminum extrusion with a different profile lengths and measurement.

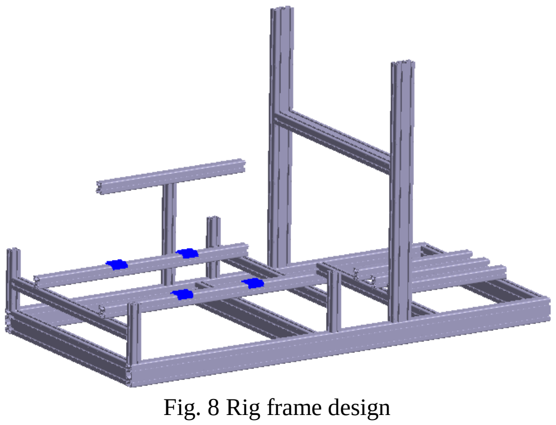

Fig. 8 Rig frame design

2.3.4. Rig Assembly Procedure

After completing the driving simulator analysis work, the construction of the assembly procedure is done with the required and obtained results. All parts and components for the driving simulator rig frame were purchased according to their specific sizes and lengths. Thus, each part and component measurement must be detailed and precise to get the targeted product designed. The rig frame consists of 28 different aluminum parts and components that need to be assembled, and most of the parts are aluminum extrusions with a different profile lengths and measurement. In starting the assembly procedure, the bottom frame of the driving simulator will be assembled, as shown in Fig. 9 to Fig. 11. These parts will be the support base for the seat, steering wheel, and pedal. After completing that the frame post will be attached to six caster wheels on its bottom to ensure it is easier to move or place anywhere needed. In this construction work, screw nut and metal strips were tied all-aluminium extrusion parts to ensure that the connection is solid and adjustable for future use. The steering wheel post, seat, and pedal set are installed afterward, where the steering wheel post possesses its clamp to connect it to the frame, while the seat (Fig. 12) and pedal set use the screw and metal strips to install and tighten its position. Lastly, the frame for the gear lever is installed at the left side of the driving simulator, as shown in Fig. 13. Then, according to the actual vehicle figure, the gear is placed on the driver's left side, whereby the gear part is tightened using a screw and metal strips. Hence, Figs. 9-13 illustrate all the assembly procedures until the designated product is obtained, as shown in Fig. 14.

Fig. 9 The bottom part of the rig frame (top view)

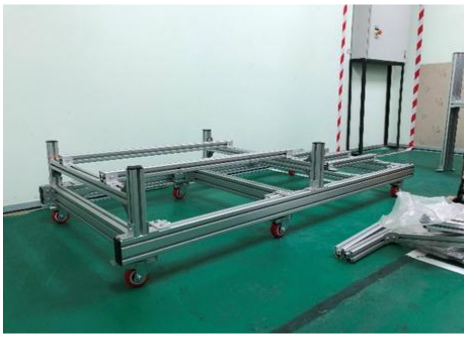
Fig. 10 Bottom part of the rig frame (ISO view)

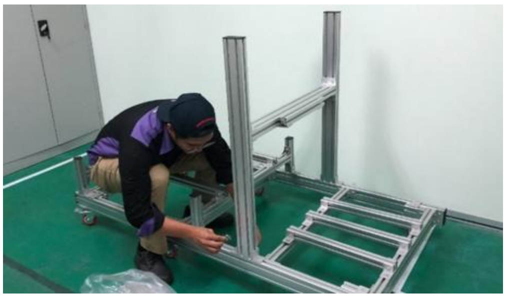
Fig. 11 Assembly procedure for steering wheel post frame


Fig. 12 Seat placement and testing


Fig. 13 Assembly procedure for gear lever frame installation


Fig. 14 Final designated product

2.4. Simulation Condition

In this study, the load area will represent the driving simulator seat area contact with the rig frame highlighted in the red point in Fig. 15. The load value applied to this area includes a seat weight of 28 kg. Three variables in weights: 150 kg, 70 kg and 40 kg, respectively, represent the overweight, average weight and underweight driver. All forces are divided by four because there are four contact points between the seat and rig frame. Hence, the calculation equation is as shown in the equations given below. Precisely, the mechanical properties of aluminum extrusion used for the rig frame, as shown in Table 5, are analyzed and included in setting up the boundary condition for the driving simulator.

$$(70 + 28 \text{ kg}) \text{ X } 9.81 \text{ m/s2} \div 4 = 37 \text{ N} \quad (1)$$
$$(70 \text{ kg} + 28 \text{ kg}) \text{ X } 9.81 \text{ m/s}^2 \div 4 = 240 \text{ N} \quad (2)$$
$$(40 \text{ kg} + 28 \text{ kg}) \text{ X } 9.8 \text{ m/s}^2 \div 4 = 167 \text{ N} \quad (3)$$

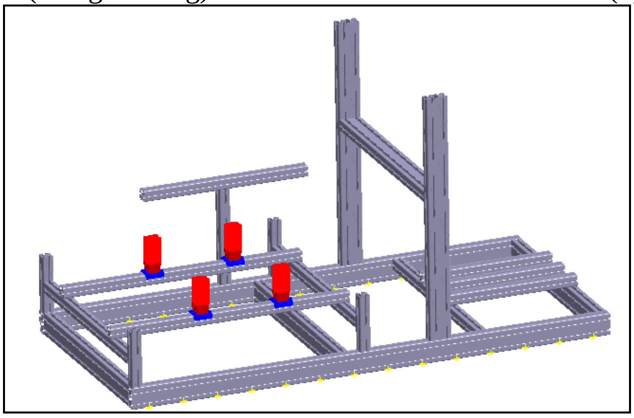
Fig. 15 Point of load

Table 5 Mechanical properties of aluminium

Modulus of elasticity (MPa)	**73000**
Poisson ratio	0.33
Density (g/cc)	2.78
Thermal expansion coefficient (C^{-1})	2.32×10^{-5}
Thermal conductivity (W/m.K)	1.21×10^{2}
Ultimate tensile stress (MPa)	469
Tensile yield stress (MPa)	324
Compressive yield stress (MPa)	324

2.5. Experiment Condition

One of these studies determines the participants' brake reaction time. Ten participants were involved in this experiment and attended briefing and pre-experiment sessions. The author explained the experiment details, instructions, rules, and regulations in the briefing session. The participant will give out personal information and signed the given forms if they agree to participate in this experiment. The main experiments consist of two driving scenarios. In scenario 1, the aim is to determine the braking reaction when the obstacle is the pedestrian, as shown in Fig. 16, while Fig. 17 shows Scenario 2 for the experiment to determine the participant braking reaction time when the traffic light turns red. Furthermore, Fig. 18 shows the flow and calculation for the recognition and reaction time for the participant reaction to the scenario. The participant must react to the brake pedal under the conditions of two different scenarios. Subsequently, a questionnaire will be given to each participant to determine their comfortability along with the experiment. The survey question focuses on the ergonomics design to measure the suitability of the driving simulator designed for local anthropometry.

Fig. 16 Scenario A (with a pedestrian)

Fig. 17 Scenario B (with red traffic light)

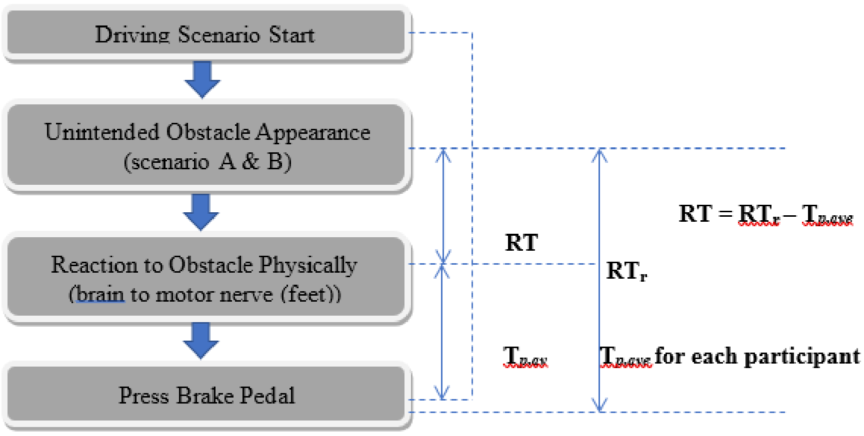

Fig. 18 Reaction time (RT) calculation flowchart for scenario A

3. Results and Discussion

3.1. Anthropometry Data

Anthropometry research is implemented in ergonomics to improve the fit and function of products during both design and evaluation. For example, to maximize the height and depth of the seat pan, the different leg segment measures must be included when analyzing the fit of a chair for a person. Both elbow and knee heights are considered when establishing the optimal height of the design solution. Likewise, when analyzing the grip of a hammer or the fit of a computer mouse, hand measurements like breadth and length are evaluated. The results of the body anthropometric measurements obtained for the 95th percentile and 50th percentile segments for young male adult respondents are compared with the SAE J833:1998 readings. The SAE J833 dimensions represent the North American population, which is generally higher than the locals. Hence, the data collected from examining the standing and sitting postural height for both the 95th percentile and 50th percentile explain that the SAE J833: 1998 measurement is higher than the data obtained from the experiment.

Anthropometry data can widen the scale of the population ratio in one's experiment and study. Moreover, existing data from the previous research might be limited, which might cause an unwanted result from the problem statement made at the beginning of the research. Hence, to ensure that the design made is compatible with the average anthropometry measurement, this data analysis must be made. Furthermore, anthropometry studies also help in defining the comfortability and ergonomics safety of the users, where it can assist in finding the perfect or optimum measurement for the driving simulator rig frame with the locals satisfactory. Hence, Table 6 shows the anthropometric data for both local and North American population measurements. The resulting pattern proves that the global standard behavior is not suitable for the design guideline parameters, with most of the SAE J833 containing a higher reading of the body segment.

Based on Fig. 19, it can be summarized that most of the percentage difference for the 95th percentile is higher or similar to the 50th percentile from 23 body segments except for the hand length, ankle height, eye height, knee height, chest depth, and buttock knee length. Hence, the other segment, such as upper arm length, tight height, trunk length, shoulder width, and many more, from the 95th percentile, needs to be considered to identify the best dimension for the driving simulator. The graph trend proves that the percentage difference for 95th percentile males is relatively high when comparing the SAE J833 and the local's measurement. Meanwhile, the percentage difference gap for both populations in the 50th percentile males was average and almost similar, proving that the 50th percentile population fulfilled the experiment's requirement. Lastly, the overall body segment percentage different from the 5th percentile female shows that 14 segments contain a higher percentage difference compared to the 95th and 50th percentile. These circumstances exclude the eight segments: the upper arm length, knee height, thigh height, shoulder width, head width, shoulder height, thumb tip reach, and foot width. Consequently, the highest percentage difference in all body segments among the three percentiles is the ankle height with 55.74% reading on its fifth percentile. The lowest goes to the elbow-to-fingertip segment with 0% value at its 50th percentile.

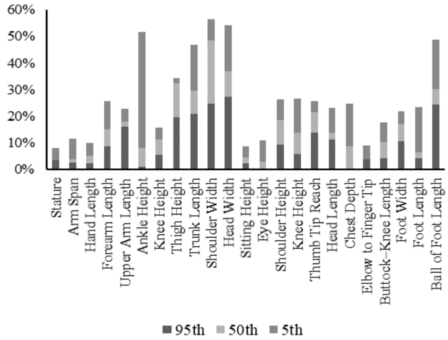

Fig. 19 Comparison of percentage difference for all percentiles

As a result, the top three body segments with the highest percentage difference reading in the 95th percentile between young male adults consisted of the head width with the highest percentage difference reading, followed by the shoulder width and the trunk length. Hence, the percentage difference in data in Fig. 20 shows a 24% difference for the head width; meanwhile, the shoulder width measurement differs by 20.42%, and the trunk length shows an 18.87% difference accordingly. This comparison of percentage differences is essential to determine the human factor affected in designing the driving simulator. For example, in this analysis, the head width measurement can be neglected due to the involvement of upper and lower body parts instead of the head. In contrast, the shoulder width and trunk length need to be considered when deciding the best fit and suitable seat dimension for the driving simulator.

Table 6 Comparison of 95^{th}, 50^{th} and 5^{th} percentile data from local and SAE J833 measurement

No.	Body segment	95% Percentile Males			50% Percentile Males			5% Percentile Female		
		SAE J833	**Local**	**Δ %**	**SAE J833**	**Local**	**Δ %**	**SAE J833**	**Local**	**Δ %**
1	Stature	185.4	179.0	3.5	168.9	169.0	0.1	152.4	145.4	4.6
2	Arm span	192.0	186.9	2.7	174.2	172.0	1.3	156.4	144.6	7.5
3	Hand length	20.5	21.0	2.4	18.5	19.0	2.7	16.5	15.7	4.8
4	Forearm length	26.7	29.0	8.6	24.4	26.0	6.6	22.1	19.8	10.4
5	Upper arm length	30.0	34.85	16.2	27.5	28.0	1.8	25.0	26.2	4.8
6	Ankle height	9.4	9.5	1.1	8.6	8.0	7.0	7.8	4.4	43.6
7	Knee height	44.5	47.0	5.6	39.8	42.0	5.5	35.1	33.4	4.8
8	Thigh height	45.2	54.0	19.5	40.7	46.0	13.0	36.2	36.8	1.7
9	Trunk length	48.0	58.0	20.8	44.2	48.0	8.6	40.4	33.4	17.3
10	Shoulder width	37.6	46.85	24.6	33.4	41.3	23.7	29.2	31.6	8.2
11	Head width	16.5	21.0	27.3	15.5	17.0	9.7	14.5	12.0	17.2
12	Sitting height	96.0	93.9	2.2	87.9	86.0	2.2	79.8	76.3	4.4
13	Eye height	84.2	83.9	0.4	76.9	75.0	2.5	69.6	64.1	7.9
14	Shoulder height	57.6	63.0	9.4	52.2	57.0	9.2	46.8	50.4	7.7
15	Knee height	61.4	57.9	5.7	55.5	51.0	8.1	49.5	43.2	12.7
16	Thumb tip reach	82.6	93.9	13.7	75.1	81.0	7.9	67.6	64.8	4.1
17	Head length	20.6	22.9	11.2	19.5	20.0	2.6	18.4	16.7	9.2
18	Chest depth	28.0	27.9	0.4	24.0	22.0	8.3	20.0	16.8	16.0
19	Elbow to Fingertip	51.0	49.0	3.9	46.0	46.0	0.0	41.0	38.9	5.1
20	Buttock–knee length	64.8	62.0	4.3	58.6	55.0	6.1	52.4	48.5	7.4
21	Foot width	10.4	11.5	10.6	9.4	10.0	6.4	8.4	8.0	4.8
22	Foot length	28.4	27.2	4.2	25.6	25.0	2.3	25.0	20.8	16.8
23	Ball of foot length	20.0	24.9	24.5	18.0	19.0	5.6	16.0	13.0	18.8

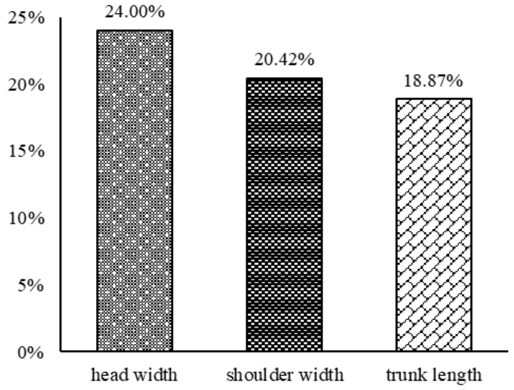

Fig. 20 Highest percentage difference in 95th percentile

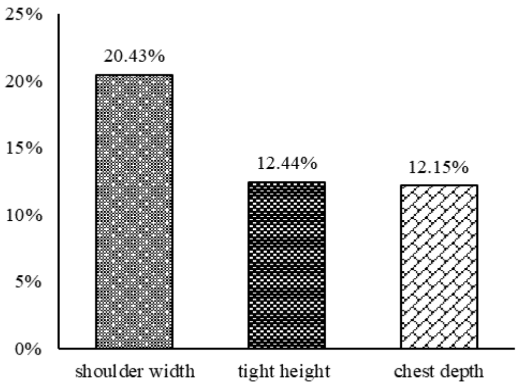

Fig. 21 Highest percentage difference in 50th percentile

Apart from the 95th percentile percentage difference between the local and SAE J833 measurement thus, Fig. 21 simplified the 50th percentile percentage difference. The top three body segments with the highest percentage difference reading were shoulder width, thigh height, and chest depth. The evaluation of the data obtained resulted in 20.43% of the shoulder width difference comparing Malaysian and SAE J833. In comparison, the thigh height comes out with a 12.44%, and the chest depth contained a difference of 12.15%. In this section, all rate differences include the body parts that are involved in the driving simulator structure. Therefore, all three percentage differences need to be evaluated and considered to determine the best dimension that can comply with the 50th percentile population.

Clearly, the difference between each participant and Malaysian and SAE J833 is illustrated in Fig. 22 to prove a massive gap in human model sizes between these two varied populations when compared on their 95th and fifth percentile. Meanwhile, the 50th percentile dimension shows a slight difference when compared, where the body segments are pretty similar. Generally, it was depicted that the local sample is shorter than the SAE J833 standard population. In contrast, the Malaysian sample is shorter, 4.70%, than North American males for 95th percentile males, while for 50th percentile males, the SAE J833 is slightly higher, 0.53% from the locals. For the arm span, 95th percentile male of SAE J833 is higher, 2.87% and 1.42% higher for 50th percentile male compared with the local sample. Usually, SAE J833 possesses higher dimensions compared to the local sample. However, the local's sample data chosen for examination is categorized as the higher than the average local's size among the population groups. This is the cause of the different results obtained. However, the local population has slightly greater (or longer) dimensions in the body segments than the SAE J833 [13]. Hence, based on the study, the included dimensions are the hand segment, the height of the trunk, the length of the trunk, forearm, shoulder dimension, knee height, thigh height, head and foot width, which is slightly wider. Thus, these variations should be considered for specific vehicle package designs, particularly concerning accessibility and vision. Additionally, the results can be used for the ergonomic design of the cockpit, particularly suitable for the anthropometry data in Malaysia.

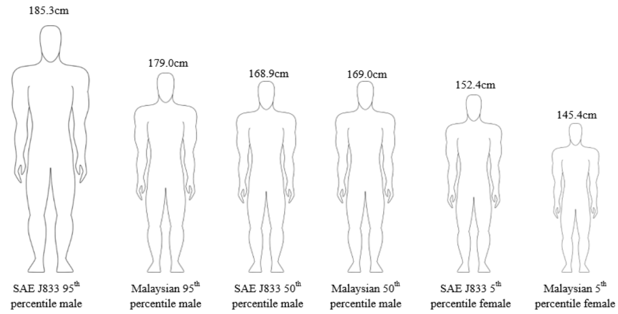

Fig. 22 Comparison of the human model on SAE J833 and Malaysian for 95^{th}, 50^{th}, and 5^{th} percentiles

3.2. The Study of Occupant Packaging

Assessing occupational ergonomics risk factors is a proactive approach to assessing the working environment's circumstances. The ergonomics risk elements must be ranked since decision-makers must prioritize their activities in planning their implementation. The significance weights of the measures are required for this purpose. As a result, the dimensions of the driving simulator are derived from the analysis of three different car models chosen. All measurements are then compared with the reference measurement from Parkinson and Reed's study for optimizing the driver workspace. The reference dimension provides a new method for modeling driver accommodation based on optimization methods that was approved by the Engineering Meeting Board and Society of Automotive Engineers (SAE) [12].

The accelerator heel point (AHP) of the steering wheel pivot is used to specify the height of the steering wheel pivot of the simulator instead of the telescope of the range pivot, which is the point of the steering wheel centered on the steering wheel pivot. Another measurement that can be neglected in this study is the upper daylight opening and cowl point due to the simulator's lack of a front windscreen, which uses a rig frame. Finally, the hood point is used in simulator development to monitor screen measurement even though it is excluded from the reference measurement. Hence, the measurement results show that all AHPs of the three measured cars have almost the same height. This analysis indicates that three-car manufacturers' dimensions are between 270 mm to 280 mm of size AHP from the ground in the z-axis rather than 400 mm, as stated in the reference measurement.

The results obtained show that the steering wheel pivot of the Toyota Prius is the closest to the reference measurement value for both the x and z-axis, with a 5mm difference in the x-axis and 10 mm for the z-axis in the comparison. The steering wheel diameter for all three cars measured shows that each steering wheel dimension is the closest to the reference measurement value, which is not round. Consequently, the hood point dimension result indicates that the BMW i3 has a smaller hood point distance due to the lack of an engine, an electrically powered vehicle. The electric motor and battery pack are located in the rear luggage compartment. In contrast, Toyota Prius and Proton Preve have a more significant hood points because they contain an engine in the front bonnet, although, Parkinson and Reed's results do not state the value for the hood point.

According to Parkinson and Reed, the measurement of accelerator heel point is 400 mm, in contrast with the selected model, where all three models have a reading between 270 and 280 mm. Hence, this element will be neglected from the comparison due to the massive difference. To summarize, Proton Preve measurement is considered due to the highest AHP reading. Next, Toyota Prius fits the steering wheel pivot and hood point measurement best. The steering wheel pivot is closest to the reference reading, and its hood point is optimum comparably with 320 mm and 560 mm for the x and z-axis, respectively. Lastly, the standard steering wheel diameter is between 340 mm and 370 mm. Table 7 shows the summary of all measurements thoroughly, and the contemplated measurement is highlighted in yellow while Parkinson and Reed's reading is highlighted in red.

3.2.1. Anthropometry Dimension on Different Vehicle Models

The anthropometry survey results concerning the occupant packaging study are combined in a table for each vehicle model chosen. The BMW i3, in which all respondents' most significant standard deviation is the "l" body segment dimension value, as illustrated in the respondent body measurement data in Table 8. The "l" dimension measurement is taken from a headrest to accelerator heel point (AHP). Two causes can affect these results are the seat track and seatback cushion movement. This result shows that respondents often change their seat track and seatback cushion position from most frontward to most rearward to adjust their comfortable driving position. Unlike BMW i3, Toyota Prius model, "k" dimension acquired the most significant standard deviation of all respondents in the driver workspace. This dimension measurement is taken from the lower back seat to the AHP. It is shown that respondents often change their seat track movement from most frontward to most rearward, but does not have to make the most significant change of their seat back cushion movement to get a pleasant driving position. The results prove that the Toyota Prius driver's seat is slightly comfortable than the BMW i3 model. Same as Toyota Prius, the "k" dimension value for Proton Preve is also the most significant standard deviation. The smallest standard deviation value in Proton Preve is the "g" dimension measurement taken from the shoulder to bottom hip of the driver body. This shows that the "g" dimension has little difference in measurement of driver body measurement compared to another dimension in the Proton Preve's driving seating position.

3.3. Simulation Analysis of the Driving Simulator

The simulation study identifies the effects of loads on physical structures and their components are structural analysis. This analysis is essential because it can show where the design is affected under the applied load. For this analysis, displacement magnitude, von Mises stress, and safety factor are chosen. Displacement magnitude is the value of measurement that will occur when the load force is applied in that area. Displacement magnitude analysis is chosen to observe the measurement value when the load force is assigned to a particular area. The displacement magnitude is in millimeters for this design analysis, as listed in Table 9. The higher displacement magnitude is in the middle of the aluminum bar that supports the seat's weight and weight of the driver, as shown in Figs. 22-24. In contrast, the other area of the supporting bar was not affected that much. The maximum displacement is 2.1362e-1 mm that occurs in an overweight driver. Hence, for 70 and 40 kg weight, it is shown that there are no red and orange contour colors, which means their displacement magnitude reading is below 1.4242e-1.

Table 7 Dimension measurement of the car

No	**Vehicle Model**	**BMW i3**		**Toyota Prius**		**Proton Preve**		**Parkinson & Reed**	
	Axis	**x (mm)**	**z (mm)**	**x (mm)**	**z (mm)**	**x (mm)**	**z (mm)**	**x (mm)**	**z (mm)**
1	Reference point	0	0	0	0	0	0	0	0
2	Accelerator heel point (ahp)	0	270	0	270	0	280	0	400
3	Steering wheel pivot re AHP	310	620	320	560	260	540	325	570
4	Hood point	1040	820	1290	900	1460	940	-	-
5	Steering wheel diameter	360	350	370	340	360	350	355	-

Table 8 Respondent body measurement data of occupant packaging

Dimension	BMW i3		Toyota Prius		Proton Preve	
	Mean (mm)	Standard Deviation	Mean (mm)	Standard Deviation	Mean (mm)	Standard Deviation
a	474.8	50.0	475.78	52.67	460.6	55.9
b	237.1	58.0	246.59	55.22	236.6	64.7
c	507.4	79.2	538.92	50.04	512.0	56.1
d	640.0	57.8	664.20	44.35	636.3	45.4
e	806.4	58.0	785.33	27.61	785.2	31.2
f	705.1	39.6	666.81	55.28	678.5	53.8
g	531.6	37.6	504.31	36.90	526.3	27.8
h	436.3	29.3	406.62	34.46	416.5	44.1
i	305.5	65.5	288.80	62.92	281.8	33.6
j	536.4	80.1	556.70	46.57	556.7	43.4
k	834.4	103.1	813.75	117.69	822.8	88.6
l	988.3	130.6	954.41	92.95	971.4	64.6
m	443.7	111.8	454.78	41.21	442.9	42.6

Von Mises stress is worth using to decide whether a given material will yield or break. Von Mises stress is applied to most parts and used for bendable materials like metals. This research uses aluminum extrusions for most of the driving simulator rig's parts and connections. Von Mises stress analysis is selected to show the pressure area and its value to study how much pressure will be assigned to the designed product. Maximum and minimum von Mises stress for 150 kg, 70 kg, and 40 kg of the driver weight are shown in Table 10. Moreover, the red and orange contour will have appeared when the overweight driver sits on the simulator rig, and the coloured area represents the situation, as shown in Fig. 23. Meanwhile, for average weight and underweight driver, the von Mises stress is shown starting on the yellow contour and below, which is below 3.2405 MPa, as shown in Figs. 25-27.

Researchers use strength tests to assess how much weight a material can support. Certain materials, such as brittle materials, are more ductile than others, meaning that they bend to pressure before breaking. When brittle materials are subjected to the maximum force, they break. A safety factor improves people's safety while lowering the danger of a product failure. Regarding fall prevention and safety equipment, safety is crucial. A risk of harm, death, and financial loss exists if a structure falls. The safety factor tends to increase when there is a chance that failure will result in a product or component. Safety features do not imply that a system is risk-free or error-free. Even though all the parts of a system have the same factory of safety, the system does not experience the same. Similarly, the stress in one section of the entire can quickly alter the stress distribution throughout the whole. Factor safety is a valuable tool for understanding how to safely install and use equipment, even though there are many other aspects to consider.

Researchers use strength tests to assess how much weight a material can support. Certain materials, such as brittle materials, are more ductile than others, meaning that they bend to pressure before breaking. When brittle materials are subjected to the maximum force, they break. A safety factor improves people's safety while lowering the danger of a product failure. Regarding fall prevention and safety equipment, safety is crucial. A risk of harm, death, and financial loss exists if a structure falls. The safety factor tends to increase when there is a chance that failure will result in a product or component. Safety features do not imply that a system is risk-free or error-free. Even though all the parts of a system have the same factory of safety, the system does not experience the same. Similarly, the stress in one section of the entire can quickly alter the stress distribution throughout the whole. A safety factor is a valuable tool for understanding how to safely install and use equipment, even though there are many other aspects to consider.

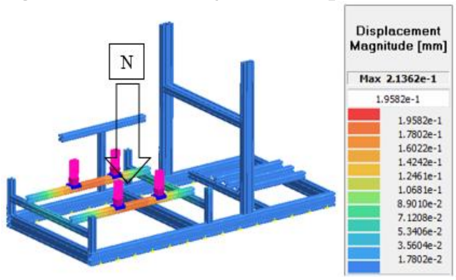

Fig. 22 Contour color for displacement magnitude area of 150 kg driver's weight

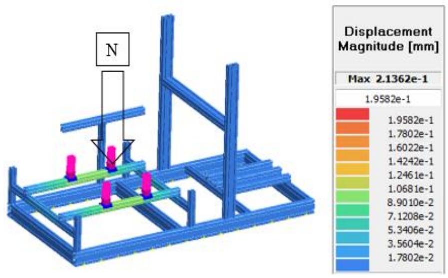

Fig. 23 Contour color for displacement magnitude area of 70 kg driver's weight

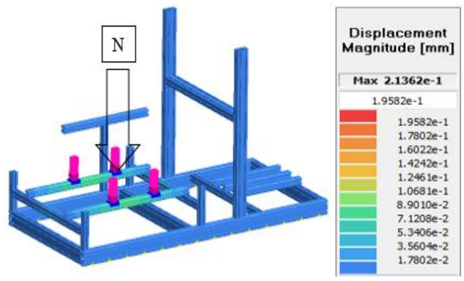

Fig. 24 Contour color for displacement magnitude area of 40 kg driver weight

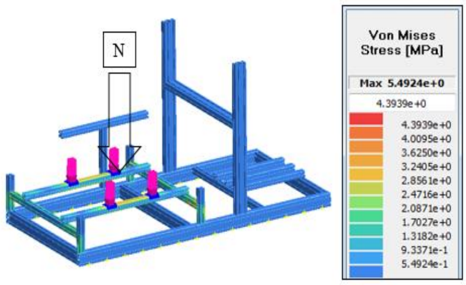

Fig. 25 Contour color for von Mises area of 150 kg driver weight

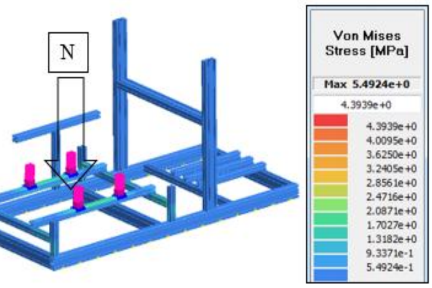

Fig. 26 Contour color for von Mises area of 70 kg driver weight

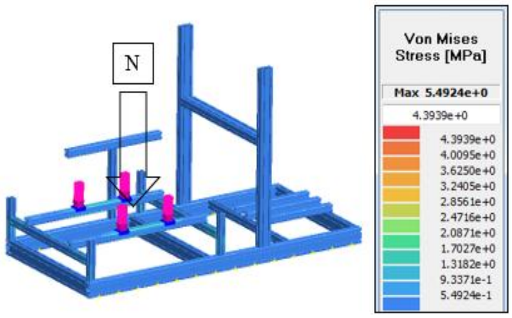

Fig. 27 Contour color for von Mises area of 40 kg driver weight

A safety factor is a ratio of the strength of the material and the maximum stress in part. The formula for the safety factor is in equation 4. When the model's stress remains much lower than the material's strength, the safety factor remains higher than one, and the design is safe. If the safety factor is less than one, the model is unsafe for the load force put in that design. For this design, the safety factor is reduced to 5.8990e+1 from the maximum safety factor value, 1.0000e+2, when a load of 150 kg of driver weight is loaded, as shown in Table 11, while below than 70 kg weight of driver does not affect the safety factor of the simulator rig.

Table 9 Displacement magnitude reading

Weight of the driver (kg)	**Force (N)**	**Minimum (mm)**	**Maximum (mm)**
150	437	8.5090e-12	2.1362e-1
70	240	4.6731e-12	1.1732e-1
40	167	3.2517e-12	8.1636e-2

Table 10 Von Mises stress reading

Weight of the driver (kg)	**Force, N**	**Minimum, MPa**	**Maximum, MPa**
150	437	7.1059e-15	5.4924e+0
70	240	3.9024e-15	3.0164e+0
40	167	2.7156e-15	2.0989e+0

Table 11 Safety factor values

Weight of the driver (kg)	**Force, N**	**Minimum, MPa**	**Maximum, MPa**
150	437	5.8990e+1	1.0000e+2
70	240	1.0000e+2	1.0000e+2
40	167	1.0000e+2	1.0000e+2

3.4. Reaction Time

A driving simulator acts as an actual driving scenario that conducts the participant's braking response when handling the specified obstacles, addressed as scenarios 1 and 2. The driving simulator needs to be observed to conclude whether it is reliable enough for further reaction and ergonomics design survey research. Each scenario is created as an unexpected event to ensure that all participants will experience an actual situation while avoiding the obstacles and an accurate analysis will be obtained. The period between when the driver notices the presence of an object or hazard in the road ahead and when the driver uses the brakes are known as the brake response time or reaction time. This time includes the time it took to decide whether it was necessary to stop. Scenario 1 starts when the pedestrian appears until the participants react to brake; meanwhile, for Scenario 2, the time begins when the red traffic light suddenly appears, and the vehicle moves past the red traffic light.

The collected data varies by participants generally shows that the average times taken of both brake reactions are 1.026 seconds and 1.222 seconds. The range of the time taken of brake reaction is 0.43 seconds to 1.93 seconds for the driving condition in the first scene; meanwhile, for the second scene is 0.40 seconds to 2.33 seconds. Hence, to be compared with the data reported by Daniel in the study of driver reaction time in crash avoidance research: Validation of a driving simulator study on a test track [14]. The reaction time varies widely from one person to another, starting from the second of 0.7 onwards; hence, it shows that the driving simulator is valid for this study with the positive results in the range.

Consequently, the average time taken of both brake reactions is 1.026 seconds and 1.222 seconds. The range time taken off the brake reaction is 0.43 seconds to 1.93 seconds for the driving condition in the first scene; meanwhile, for the second scene is 0.40 seconds to 2.33 seconds. Scenario A's inter-quartile range is more precise than Scenario B's first quartile, and the third quartile is 0.79 seconds and 1.33 seconds. Scenario B's first quartile is 0.50 seconds, and the third quartile is 1.73 seconds. The median for Scenario A and B is 0.90 seconds and 0.96 seconds, respectively. Hence, the data of the time taken on the brake reaction achieved to be compared with the reported data from the 'Validation of a driving simulator study on a test track' literature review emphasizing driver reaction time in crash avoidance research [14]. The reaction time varies widely from one person to another in situations about 0.7 to 3 seconds or more, which show the validity of this driving simulator in a positive range. Fig. 28 illustrates the box plot graph for the reaction time for Scenario 1 and Scenario 2.

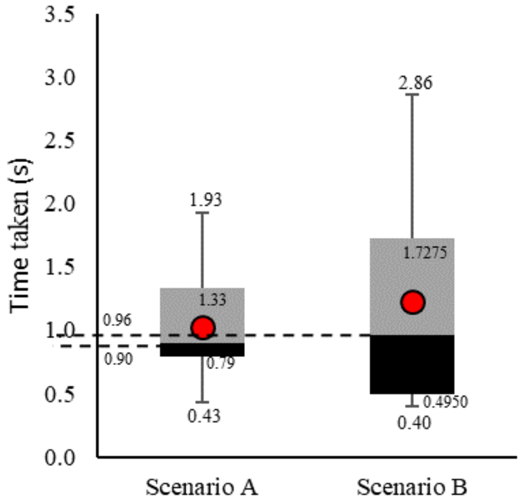

Fig. 28 Whisker box plot brake reaction time

3.5. Ergonomics Survey Form

The survey form is used to analyze the population pattern in the research. Ten participants filled out the ergonomics survey form after being examined on the driving simulator. Generally, this form evaluates the ergonomics design of the comfortability of drivers to indicate performance behavior. The questionnaire consisted of 160 total scores containing 16 questions, and ten scores will nominate to each question 10 scores. Each participant score is calculated in percentage form and its range varies from 34.10% to 96.47% as shown in Fig. 29. Out of 10 participants', only two participants scores are below 50%, and the rest are above, which proves that the analysis is succeeded. Consequently, the total mean score from these evaluation forms is 74.11%. Fig. 25 illustrates the segments A, B, C, D, and E representing each ergonomics criteria form from the survey questions indicating all segments criteria receive that are above mean points; meanwhile, y-axis represents respondent rating, which 1 represents unacceptable while 10 represents totally acceptable. The survey outcome shows that the driving simulator validity and reliability are applicable to an improvement. These mean points are from the sum of the total marks given by the participants. The highest mean points are from the criteria A segment's third question, scoring 8.3 over 10, where the third question is regarding the seat adjustments. It proves that an adjustable seat is compulsory in-vehicle occupant packaging to enhance user comfortability and safety rates. Meanwhile, the lowest mean point scoring 6.9 over ten is considered high compared to the average mark. This score comes from the first question on the criterion C segment: the smoothness of using the product.

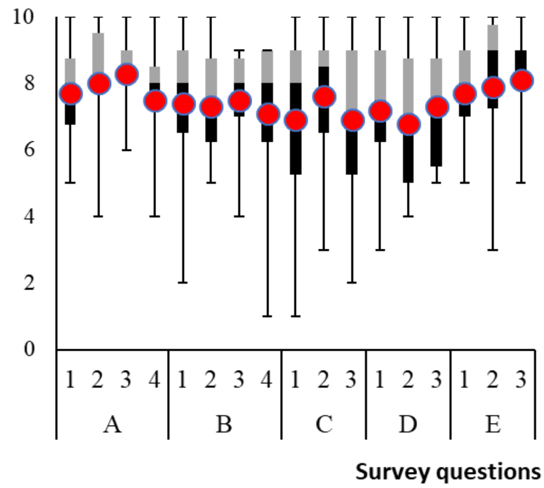

Fig. 29 Whisker box plot for survey questions

4. Conclusion

The main purpose of this research is to study the design and development of a driving simulator for local anthropometry. Based on the analysis conveyed, the study of local anthropometry measurements has been compared with the SAE J822 measurement. It proves that the body dimensions different and it determines the best measurement for the driving simulator design. According to literature reviews of SAE J833, North American data are unsuitable for designing ergonomics driving simulators for local anthropometry because of higher body measurements than local measurements. Generally, the Malaysian population was found to be shorter than the SAE J833 standard. Because of this research, a comparison of both measurements has been presented. The SAE J833 dimensions are always larger than those of the Malaysian population. However, our sample data among our group can be classified as taller than the Malaysian average height, resulting in various results.

The next finding of this study is the car dimensions comparison between three different types of vehicles from different manufacturer regions. With the reference measurement from Parkinson and Reed's study, it is concluded that the best measurement is taken to complete the driving simulator with the components such as the steering wheel, accelerator heel pedal, and monitor screen in the simulator rig frame. As a result, the Proton Preve dimension is chosen for the seat due to the lowest standard deviation for the AHP point to seatback length. The driving simulator's actual design is created in CATIA V5 software, and the boundary analysis is completed in Altair SimSolid software. The simulation analysis illustrated the part that is affected by the load assigned in the rig frame. The simulation analysis showed the part of the rig frame that is affected by the load. The displacement magnitude indicates that the seat supported bar will bend less than 0.3mm, while the Von Mises stress indicates that the most affected area is the seat supported bar's centre, where the driver is located. Furthermore, since the safety factor value obtained from the analysis is greater than one, it is proven that this simulator rig can accommodate 150 kg of driver weight. Finally, the product test was completed successfully with a positive range brake test result, proving the driving simulator validity and reliability, which can be used in further research on driving behavior.

In comparison with another driving simulator designed and developed by the Institute of Design and Manufacturing (IDF) of the Polytechnic University of Valencia (UPV), a low-cost simulator that allows rapid implementation and effectively a new methodology for validation studies of different roads through the implementation in the simulator scenarios of existing roads was developed. This methodology allows the development of new scenarios based on the analysis of a layers-file system. Each layer includes different information from the road, such as mapping, geometry, signaling, and aerial photos. This institution also strictly state that everything created in relation to the driving simulator must meet the local environment and characteristics. This vital principle should be taken seriously in every driving simulator development and design.

Indirectly, the driving simulator will provide more accurate and precise data because it is taken based on local anthropometry. Accurate data allow an organization to determine the cause of problems more effectively. Hence, it can improve the existing study, where the driving simulator can investigate the driving behavior in more detail and systematically. Thus, participants in different physical locations can drive under the same conditions. This is beneficial for creating standardized driving tests and reproducible research results. However, the simulator's discomfort will be a challenge, especially in older people or in challenging driving conditions. For example, discrepancies between the simulated motion in a simulator and the user's perception or expectation of motion can cause it. Lethargy, nausea, vomiting, sweating, headaches, uneasiness, drowsiness, disorientation, and ocular motor disturbances are all symptoms of simulator sickness. Individuals are affected to varying degrees by simulator sickness and may exhibit various symptoms. Although, this is not a big issue since this incident only happens often on flight simulators and is also associated with video gaming.

In conclusion, this study successfully achieved all objectives phase by phase. This shows good progress in designing and developing the driving simulator and able to expect something bigger and useful for the next step of this research. However, as a suggestion and improvement for future research, a more extensive and wider study needs to be conducted on other types of cars, such as Multi-Purpose-Vehicle (MPV). This is because this type of vehicle is also widely used on Malaysian roads. Furthermore, this type of vehicle is also among those with a higher accident rate in Malaysia. The anthropometry study involving this MPV car is hoped to work on solutions hopefully can reduce the accident rate on Malaysian roads.

References

[1] MIROS. *Book of Abstract*. Malaysian Institute of Road Safety Research, Malaysia, 2018.

[2] MUSA M.F., and HASSAN S. Prediction Model for Accident Severity on Malaysia Rural Road. *The Colloquium*, 2017, 10: 1-4. https://sps.utm.my/thecolloquium/files/2017/09/TC-10-1-4.pdf

[3] GAUTAM U. *Case study of ergonomics interventions in automotive parts*. [Online] Available from: https://www.researchgate.net/publication/349548183

[4] KHARB S.S., BELOKAR R.M., and KANT S. Study of the role of Anthropometry in Designing. *Journal of Mechanical and Mechanics Engineering*, 2017, 3(1, 2).

[5] ANDRIANI M., HASAN M.T., NAZARUDDIN N., and NINAFAHRIANA N. Application of Anthropometry to Overcome Musculoskeletal Problems *Journal of Physics: Conference Series*, 2018, 1114(1). DOI: 10.1088/1742-6596/1114/1/012008.

[6] DAWAL S.Z.M., ISMAIL Z., YUSUF K., ABDUL-RASHID S.H., SHALAHIM N.S.M., ABDULLAH N.S., and KAMIL N.S.M. Determination of the significant anthropometry dimensions for user-friendly designs of domestic furniture and appliances – Experience from a study in Malaysia. *Measurement*, 2015, 59: 205-215. DOI: 10.1016/j.measurement.2014.09.030.

[7] SAMAD A., NOR M.K.M., MAJID M.M.A., and KASSIM K.A.A. Investigation on the Effect of Malaysian Anthropometric Size in Vehicle Crash Safety by using Finite Element Method. *Journal of the Society of Automotive Engineers Malaysia*, 2021, 5(3): 449-466.

[8] EL GUABASSI I., AL ACHHAB M., JELLOULI I., and EL MOHAJIR B.E. Personalized ubiquitous learning via an adaptive engine. *International Journal of Emerging Technologies in Learning*, 2018, 13, 177-190.

[9] FANG J., ZHOU D., YAN F., ZHAO T., ZHANG F., MA Y., WANG L., and YANG R. Augmented LiDAR Simulator for Autonomous Driving. *IEEE Robotics and Automation*, 2018, 5(2). DOI: 10.1109/LRA.2020.2969927.

[10] TRONTELJ K., ČEGOVNIK T., DOVGAN E., and SODNIK J. Evaluating safe driving behavior in a driving simulator. In: *7th International Conference on Information Society and Technology*, 2017: 299-302.

[11] CASADEI K., and KIEL J. *Anthropometric Measurement*. Treasure Island (FL), StatPearls Publishing, 2020.

[12] PARKINSON M.B., and REED M.P. Optimizing *vehicle occupant packaging*. SAE Technical Paper 2006-01-0961, 2006. DOI: 10.4271/2006-01-0961.

[13] RASHID Z., BAKAR N.A., and GHAZILLA R.A.R. Comparison of Malaysian and SAE J833 Anthropometric Proportions for Vehicle Package Design. *Advanced Engineering Forum*, 2013, 10: 336-344. DOI: 10.4028/www.scientific.net/aef.10.336.

[14] MCGEHEE D.V., MAZZAE E.N., and BALDWIN G.H.S. Driver reaction time in crash avoidance research: Validation of a driving simulator study on a test track. *Proceedings of the Human Factors and Ergonomics Society*

Annual Meeting, 2000, 44(20): 320-323. DOI: 10.1177/154193120004402026.

参考文:

[1] 米羅斯。摘要書。馬來西亞道路安全研究所，馬來西亞，2018年。

[2] MUSA M.F. 和 HASSAN S. 馬來西亞鄉村道路事故嚴重程度預測模型。座談會，2017年，10：1-4。https://sps.utm.my/thecolloquium/files/2017/09/TC-10-1-4.pdf

[3] GAUTAM U. 汽車零部件人體工程學乾預案例研究。[在線]可從：https://www.researchgate.net/publication/349548183

[4] KHARB S.S.、BELOKAR R.M. 和 KANT S. 人體測量學在設計中的作用研究。機械與力學工程學報, 2017, 3(1, 2).

[5] ANDRIANI M.、HASAN M.T.、NAZARUDDIN N. 和 NINAFAHRIANA N. 應用人體測量學克服肌肉骨骼問題 物理學雜誌：系列會議，2018年，1114(1)。DOI：10.1088/1742-6596/1114/1/012008。

[6] DAWAL S.Z.M.、ISMAIL Z.、YUSUF K.、ABDUL-RASHID S.H.、SHALAHIM N.S.M.、ABDULLAH N.S. 和 KAMIL N.S.M. 確定用戶友好型家用家具和電器設計的重要人體測量尺寸——來自馬來西亞的一項研究的經驗。測量，2015, 59: 205-215. DOI：10.1016/j.measurement.2014.09.030。

[7] SAMAD A.、NOR M.K.M.、MAJID M.M.A. 和 KASSIM K.A.A. 使用有限元方法研究馬來西亞人體測量尺寸對車輛碰撞安全性的影響。馬來西亞汽車工程師協會雜誌，2021年，5(3)：449-466。

[8] EL GUABASSI I.、AL ACHHAB M.、JELLOULI I. 和 EL MOHAJIR B.E. 通過自適應引擎進行個性化無處不在的學習。國際新興學習技術雜誌，2018年，13，177-190。

[9] FANG J.、ZHOU D.、YAN F.、ZHAO T.、ZHANG F.、MA Y.、WANG L. 和 YANG R. 用於自動駕駛的增強激光雷達模擬器。電氣和電子工程師學會機器人與自動化, 2018, 5(2). DOI：10.1109/LRA.2020.2969927。

[10] TRONTELJ K.、ČEGOVNIK T.、DOVGAN E. 和 SODNIK J. 在駕駛模擬器中評估安全駕駛行為。在：第七屆信息社會與技術國際會議，2017：299-302。

[11] CASADEI K. 和 KIEL J. 人體測量。金銀島 (佛羅里達)，狀態珍珠出版社，2020年。

[12] PARKINSON M.B. 和 REED M.P. 優化車輛乘員包裝。汽车工程师学会技術論文 2006-01-0961，2006。DOI：10.4271/2006-01-0961。

[13] RASHID Z.、BAKAR N.A. 和 GHAZILLA R.A.R. 馬來西亞和美國汽車工程師學會J833 車輛包裝設計人體測量比例的比較。高級工程論壇, 2013, 10: 336-344. DOI：10.4028/www.scientific.net/aef.10.336。

[14] MCGEHEE D.V.、MAZZAE E.N. 和 BALDWIN G.H.S. 避免碰撞研究中的駕駛員反應時間：在測試跑道上驗證駕駛模擬器研究。人為因素和人體工程學學會年會論文集，2000年，44(20)：320-323。DOI：10.1177/154193120004402026。