ADAMA SCIENCE AND TECHNOLOGY UNVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

COMFORT ASSESSMENT AND DESIGN IMPROVEMENT OF LOCALLY MANUFACTURED PASSENGER SEAT:

A CASE STUDY ON MINIBUS TAXI AT ADAMA

A THESIS

SUBMITTED TO ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF SCIENCE IN AUTOMOTIVE ENGINEERING

BY

MELKAMU BEYENE

ADVISOR: **MEKONNEN LIBEN (ASST. PROF.)**

DEPARTMENT OF MECHANICAL SYSTEMS AND VEHICLE ENGINEERING

September, 2018

Adama, Ethiopia

CANDIDATE'S DECLARATION

I hereby declare that this thesis entitled **"Comfort Assessment and Design Improvement of Locally Manufactured Passenger Seat: A Case Study on Mini Bus Taxi at Adama"** in partial fulfilment of the requirements for the award of the degree of Master of Science in Automotive Engineering is an authentic record of my own work carried out from November 2017 to September 2018 under the supervision of Department Mechanical and Vehicle Engineering department, Adama Science and Technology University.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

Name	Signature	Date
Melkamu Beyene	----------------------	----------------
Student		

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Name	Signature	Date
Mekonnen Liben (Asst. Prof.)	-------------------------	----------------
(Advisor)		

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

MECHANICAL SYSTEMS AND VEHICLE ENGINEERING DEPARTMENT

Comfort Assessment and Design Improvement of Locally Manufactured Passenger Seat: A Case Study on Minibus Taxi at Adama

By

MELKAMU BEYENE

APPROVED BY BOARD OF EXAMINERS

--------------------------------	------------------	--------------
Chairman, dep. Graduate committee	Signature	Date
--------------------------------	------------------	----------------
Internal Examiner	Signature	Date
--------------------------------	------------------	---------------
External Examiner	Signature	Date

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to all who variously and collectively helped make this thesis possible. Throughout its writing, I have benefited a great deal from the critical comments and suggestions of people who were generous enough to find time not only to read, but also to offer me direction. To this end, I am particularly grateful to my advisor Mekonnen Liben (Asst. Prof.), for his immense help, comments and guidance without which this work would not have been possible.

My sincere appreciation goes to Adama science and Technology University for giving me the opportunity to be part of an excellent tradition, and to the Mechanical Engineering Department for providing funding in the form of teaching assistantships.

I further express my heartfelt gratitude to all the special friends and colleagues who listened to my partially articulated ideas, read drafts of earlier chapters, assisted me in mapping out my thesis, as well as offering the encouragement that ultimately carried me through. Special mention must be made of Recognition also goes to the numerous friends who in very diverse and special ways made this journey less stressful and more meaningful.

Last but certainly not least, I give glory to God Almighty for protecting and sustaining me throughout this journey. Even when it was lonely, stormy, and dark, you gave me the strength to go on, constantly reminding me that, the darker the night gets, the closer it is to dawn.

Given that this is my work, I am, however, solely responsible for any errors or omissions that may be found in this thesis. It merely reflects my mortal limitations.

Melkamu Beyene

Adama September 2018

ACRONYMS AND ABBREVIATIONS

IFD	Indentation Force Deflection
SH	seating height
SSH	Sitting to Shoulder Height
BPL	Buttocks to Popliteal Length
PH	Popliteal Height
SB	Shoulder Breadth
HB	Hip Breadth Seated

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Seat means a structure, which may or may not be integral with the vehicle intended to seat one adult person. Automotive seats are generally constructed from metallic frames covered by foam. Comfort is an attribute that today's consumers demand more and more. Automotive seat has an important role to play in fulfilling these comfort expectations of their customers. The discomfort factor of automotive seats is dictated by a combination of static and dynamic factors. This discomfort factors are seat structure and pressure distribution on the human seat interface. The basic feature in the urban life is the movement of large volume of people between residential area and places of work. Adama peoples almost they can use minibus taxi for intercity transportation which cannot have suitable space for the people and parts inside the vehicle. A descriptive survey was conducted on an ergonomics assessment of passenger seats. The Survey was carried out to study in subjective evaluation through direct response from local users on seat comfort during their journey on the road with 63% overall result were uncomfortable. Objective evaluation of seat parameter was carried out through anthropometric measurements of respondents. The results showed a degree of mismatch between the passengers' body dimensions and the seat dimensions were evaluated through objective evaluation. This may be an indication that the dimensions of locally manufactured passenger seats of minibus and passengers' anthropometric dimensions are far from anthropometric data standard. The new designed seat structure will provide passengers better satisfaction and improved to be more effective in achieving seat comfort. For design of seat feature first modelling using CATIA V5 had been employed and then ANSYS 16 software had been employed for its analysis. The strength of the main seat pan and backrest structure can be evaluated for the weight of passengers 1,079 N. The bending stress developed due to maximum bending moment and deflection on specified dimension of seat pan structure will be 502.65 MPa, 1.91 mm respectively. And the material of carbon steel Fe E 520 types was selected. The result had proved that the seat feature and layout inside the vehicle has sufficient free space to accommodate comfortably the knees and legs of the user.

Keywords: *passenger seat, ergonomics, anthropometry, subjective evaluation, objective evaluation.*

1 INTRODUCTION

Passenger seat is the most important link between occupant and vehicle. Seat means a structure, which may or may not be integral with the vehicle, structure complete with trim, intended to seat one adult person. The term covers both an individual seat and part of a bench seat intended to seat one person. The function of automotive seating is to support, protect and to provide comfortable seating posture to its occupants. There are three different occupants in the vehicle: Driver, front seat passenger and Rear seat passenger. Automotive seats are generally constructed from metallic frames covered by foam. Cushions, backrests, headrests, armrests, and other foam parts that make up a vehicle seat are designed according to four principal criteria: integration within the vehicle, safety, aesthetics, and comfort.

The demands from the customers of the automotive industry and the intense competitions from the international companies, make it necessary for all car manufacturers to reach a premium level of quality in order to be attractive and gain a share of the automotive market. Vehicle seats are one of the most important subsystems in the car, they provide the closest interaction with all the occupants in the vehicle, they are key in determining the user experience, and therefore they are connected to many of the functions and requirements for the whole product. But the ownership of cars in the undeveloped countries is low compared to the developed countries. In fact, the access of personal means of transportation, frequency of trips and choice of mode are closely related to income levels **[1].** In Ethiopia, commercial transport operators depend largely on imported fairly used vehicles popularly called ‘minibus’ which in most cases do not come with passenger seats or when they do they are modified to accommodate more passengers to maximize their profits.

Therefore, local manufacturers usually design or redesign the seats to suit the expectations of their customers without due consideration for the anthropometric data and ergonomics compatibility of the passenger. The question of the correct design of passenger seats with emphasis on comfort as regards the Ethiopian people arises due to the fact that required anthropometric measurements are few and the local manufacturers assume that manufacture of seats is an art rather than science. The physical dimensions of furniture, equipment, clothing and workspaces are specified using anthropometric data to achieve proper ergonomic design. Thus the use of anthropometric data in design may constitute improvement in the health and comfort of the users [3, 4] similarly, the anthropometric data is needed for ergonomically correct design of safe and efficient workplaces, equipment and tools [2]. During the initial design of a car, the position of the seating occupant is used to determine most of the interior dimensions for the passenger's compartment. One of the most basic references to drive the packaging of the components inside the car is the point where the occupant's hip will be located, this is known as the seating reference point during the design phase, and when it is measured on a finished physical seat it is named H-point.

Vehicle Packaging in short is the organization of space for people and the parts of a vehicle to suite a specific need or transport. It is the first consideration for shaping the vehicle. At Vehicle Package stage, factors such as engine size, weight, width, height, luggage, number of passengers and their seating arrangement are targeted. Knowing all the said parameters plus more will help to establish a range of dimension within a category of vehicle types and cost, enabling the designer to target the shape of vehicle that will make it competitive. Vehicle Packaging actually dictates of how a vehicle should be designed. It provides all the necessary information for the styling designers and part designers to proceed with it. Without vehicle packaging input, all the design engineers will not be able to proceed with the design concept in details. On the other hand, since Vehicle Packaging is meant to provide suitable space for people and parts in vehicle, human factor consideration is a must for the integration of the total design. In vehicle design, the term human factor is interchangeably called as automotive ergonomics.

1.1 Background

The first automotive seat, like the first automobile was adaptation from the horse drawn carriage. Spring to absorb road shocks where primitive, effective padding was non-existent and seat adjustability had not yet been considered Safety.

Front and rear vehicle seats are the main components to give the driver and occupants their position inside a vehicle. the close interaction that exists between these and the users make them one of the most important systems in the car, they also provide comfort and are important to assure a sense of quality and good appearance. To produce high quality seats, many factors have to be considered including different materials, design geometry and production strategy, the fact that they contain a large number of subsystems and components makes it a complex system to design.

A large number of internal and external requirements are connected to the seating position of the vehicle occupants; they are obtained from legislation, quality rating tests and subjective judgments from customers. If the measured seating position deviates from the theoretically assigned seating reference point it can, among other things, lead to legal requirements being unmet and the need for major redesign; it also affects the available space for the passengers inside the car and their relative position to other components around them. On top of this, the tight packaging that comes from including new systems in the car implies that all its components must be produced to high quality standards.

To meet all these requirements, it is of vital importance to assure that the final manufactured seats are corresponding to the design intent, and that the measurements that relate to them are located as the company define them. In recent years the seating position of the passengers has become a focus of attention to fulfil the expectations of the customer, and a reference point located at the pivot between the thigh and torso of the occupant (known as the H-point) has been identified as a key parameter whose position needs to be controlled to guarantee the quality of the seats.

Car seat design has been improved gradually. In the earlier days of car invention, the car seat is not as comfortable as it may have nowadays. The design is based on the adaptation of the horse-drawn carriage. The evolution of car seat started with bench seat in the earlier days to bucket seat in the present days.

Figure 1. 1 1885 Benz Motorwagen with bench seat (Logitech)[6]

The figure above shows the Karl Benz 1885 Motorwagen that had a hard, wood bench seat that stretch from driver to passenger and a thin, curved beam that hit the upper back providing minimal support (Logitech). The main point of this seat is that it is fixed in only one position. Even though there are many alterations being made such as padded upholstery and additional substantial back support, the fixed position leads for many problems, as different people has different shape of lumbar.

Next, for the Ford Model which is the first automobile built by mass production by Ford Britain during 1914. The seat has not changed much. The car seat is the same fixed position with padded upholstery. The changes of the car seat design happen tremendously after that year. The Ford Model A for the year 1930 seat had been revolutionized with added adjustability to the front seats with a 'worm gear controller' which is the metal rod that ran beneath the front seat to move the seat forward and rearward.

Today, the automotive industry is advancing very rapidly. Each year new and better automotive components are introduced by the automotive manufacturers in view of improving passengers' safety and comfort as well as aesthetics. Intelligent Safety System for example, is aimed at optimising passenger safety and comfort [5] is equipped with safety equipment to warn drivers on incoming road hazards. Developments related to automotive safety cost billions of dollars each year and that exclude casualties, death as well as its adverse effects to the environment [6,7].

1.2 Statement of problem

The basic feature in the urban life is the movement of large volume of people between residential area and places of work. People tends to use taxi due to several factor such as it is available when required, economic level of the users, takes the people from starting point to destination point besides ensuring the privacy and comfort. Most of Adama peoples almost they can use minibus taxi for intercity transportation which cannot have suitable space for the people and parts inside the vehicle. Most of passenger seat is manufactured in local body builder with poor design and without standard. The space of occupant (passengers) can be provided with seating position in side to these vehicles. While the occupant transported on this vehicle the seat structure is not well designed with considerations of anthropometric measurement of the human being. The seat feature was allowed to seat two guys side to side and three guys at rear position. Even the passenger seat was structured to hold two guys at once the owner or driver of these vehicles trying to seat three person on two person holding seat and four person for three person holding seat feature which is not allowed by the rule of the country and fatigue condition for traffic police in the intercity transportation control.

A vehicle on the road today requires an improved automotive seat to provide adequate comfort, effective support and sufficient adjustments to meet the varied requirements of their occupants. The space or place for people and parts in this serving vehicle is not related with ergonomics of human being. To provide suitable space for the passengers; the passenger seat which is locally manufactured needs to redesign the seat structure which can have a basic comfort and better ergonomics out looks for existing minibus taxi.

1.3 Objectives

1.4 General objective

- The general objective of this research is assessment of passenger seat comfort and structural design improvement for local manufactured seat.

1.5 Specific objectives

- Need assessment of the problem through primary survey;
- evaluation of existing seat features based on result of the survey;
- evaluation of existing seat features with anthropometric measured data;
- Design improved passenger seat structure with consideration of comfort;
- Develop 3D model of main parts of passenger seat by CATIA V5 software.
- Analyse the strength of the seat through FEA in ANSYS software.
- Modelling the seat feature with the aid of existing materials.
- Preparing manufacturing drawing for parts of the developed seat structure.

1.6 Significance of the study

The thesis is important to those who are in the field of passenger seat manufacturing and maintainers garage to enable them to get the necessary theoretical knowledge as well as the design background automotive seat in various local bus passenger seat designs. Furthermore the research helps the responsible authority to see the effect of how sever the issue is, such that great attention and participation have to be given research on intercity public transport taxis.

Passenger seat manufacturer must develop seat that are light in weight and offer more free space for occupants. Space creation inside the vehicle has become critical with explosion of added content and features. The study ensures transferring technology for comfortable seat design in terms of occupant needs anthropometric measurements. Therefore vehicle owner, customers, in the country as whole will be benefitted from this study and to builds up comfortable transportation services for the users.

Designing and developing of light dead load materials on the vehicle structure can lead vehicle to have reduced weight which needs to propel the vehicle with simple traction force. While weight is reduced for the vehicle components the fuel consumption that vehicle for loaded materials is reduced.

1.7 Beneficiaries

The output this research will be used for

- Automotive industry those conducting on automotive body building and seat builders.
- Garage owner those who are trying to manufacture passengers seat for commercial vehicles.
- For graduate students who’s the government trying to open job opportunities for Ethiopian youngsters.
- Researchers those conducting a community service for their leaving societies.
- Every individual which uses (take) minibus taxi in intercity transportation for their personal problems.

1.8 Delimitation

The scope of this research is conducting survey among public to gain subjective evaluation towards the design of current existing passenger seat. This subjective assessment would conduct to gather information on existing passenger seat of minibus taxi availing in Adama towns and to evaluate perceived comfort of the users.

The assessment of objective evaluation could be conducted through measuring the dimensions of seat features in order to gain information on compatibility of existing seat feature with anthropometrical measurements of the users. The result of subjective and objective evaluations leads to design a passenger seat structure in order to fit with human ergonomics by measuring anthropometrical measurements of the user. The decision of initial designing parameters can depend up on genetic variation and physical appearance of the users. The new developed seat structure can be designed 95^{th} percentile of maximum measurement and 5^{th} percentile of minimum anthropometric measurements requirements to satisfy passengers with 90% of the population.

The automobile passenger’s seat is structure which is fixed on the body of the vehicle which is handling the weight of passengers in static condition. For this situation the main parameters to be designed is in static condition.

2 LITERATURE REVIEW

2.1 Physical definition of seat

Conceptually a seat is a system of necessarily two and usually three planes. The first one is called the seat surface. It is the very essence of the concept since one has to sit on a surface. The second one is the ground on which one lives. The third plane is called the back-rest. The total sets of seating criteria define the relations between these planes and also their physical properties.

- Major elements:
  - ✓ Seat surface (seat pan): The surface on which the person rests his buttocks and to which transfers a part of his body weight.
  - ✓ The ground surface: The surface on which the person places his feet and to which transfers a part of his body weight.
  - ✓ Back-rest: the surface by which the person stabilizes his torso.
- Minor elements:
  - ✓ Arm-rests: Surfaces on which the person rests his forearms.
  - ✓ Head-rest: Surface against which the person rests his head.
  - ✓ Support structure: The structure through which the body weight on the seat surface is transferred to the ground.
  - ✓ Seat structure: The structure which ensures a certain set of relations between the major and minor elements.

2.2 Passenger seat categories

Automotive seat for passenger vehicle have a number of basic configurations and sizes depending on intended use and location. Position adjustments depend on factors such as;

- ✓ location (front or rear)
- ✓ availability of comfort features
- ✓ including center armrests
- ✓ depend on vehicle price
- ✓ depend on vehicle type
- ✓ purpose and country of origin

2.3 Automotive Seats Architecture

Car sets have several purposes that, when combined, make it one of the most crucial and complex parts of the vehicle. The primary purpose of the driver seat is to position the driver in a manner that allows him/her to reach all the instruments and provide an adequate field of sight in order to operate the vehicle in a safe and comfortable way [8]. Additionally, in order to assure safety and comfort for all individuals within the target group the seat is adjustable (height, translation, tilt, lumbar support). Different functionality can also be included in the seat; examples are climate control (heating and cooling), airbags and massage. [9]

The requirements on functionality, comfort and an appealing design result in a complex product with many interlinked components. Most car seats could be described as consisting of a track/adjuster assembly base, a seat frame, a cushion, a backrest and a headrest (in some cases integrated in the backrest). The cushion and backrest consist of several components, for example foam, electrical components, springs and upholstery. The track/adjuster assembly base make up the connection between the car and the seat and provides the adjustability of the seat. An example of a seat structure can be seen in Figure 2.1.

Figure 2. 1 Picture showing that as seat complex and its main parts [9].

A wide variety of materials and production techniques are used in car seats. The track/adjuster assembly and the frame are for instance metal components and plastic is used to make covers and fasteners. A particularly interesting material to mention is urethane foam. It has been widely used in car seats since the 1960’s with different manufacturing techniques and chemical composition. Cold cured/high resilience molded urethane foam is the most commonly used material in car seat cushions/pads today [9]. The strength of this particular material and manufacturing technique is that it allows for complex forms to be molded, so that wires or other structures can be molded into the cushion. As the name of the material suggests it is also very resilient, which is important for good comfort, aesthetics and safety. The properties of the foam can be altered by changes in the chemistry of the material. The following foam properties are closely connected to the occupant position in the seat.

- *Density a*ffects the foam's ability to provide support, comfort and durability. Generally, as foam density increases, durability also increases. Some of the factors related to durability are loss of firmness (flex fatigue), breakdown in the sitting area of the cushion (dishing), and fabric bagging caused by loss of foam dimensions (compression set) [3]. Different densities can be assigned to certain areas of the cushion foam to achieve a desired feeling for the occupant, by changing the composition of the material. This in turn will create areas of different compression load around the seat that are hard to calculate.
- *Indentation force deflection* is a measure of foam firmness that is independent of density. IFD is determined by measuring the pounds of force required to indent a 4-inch thick sample 25% of its thickness, or one-inch [9]. Firmness affects how much the occupant will sink into the seat (ride) of a cushion. The test to measure this property uses standard procedures and machines as shown in Figure 2.2.

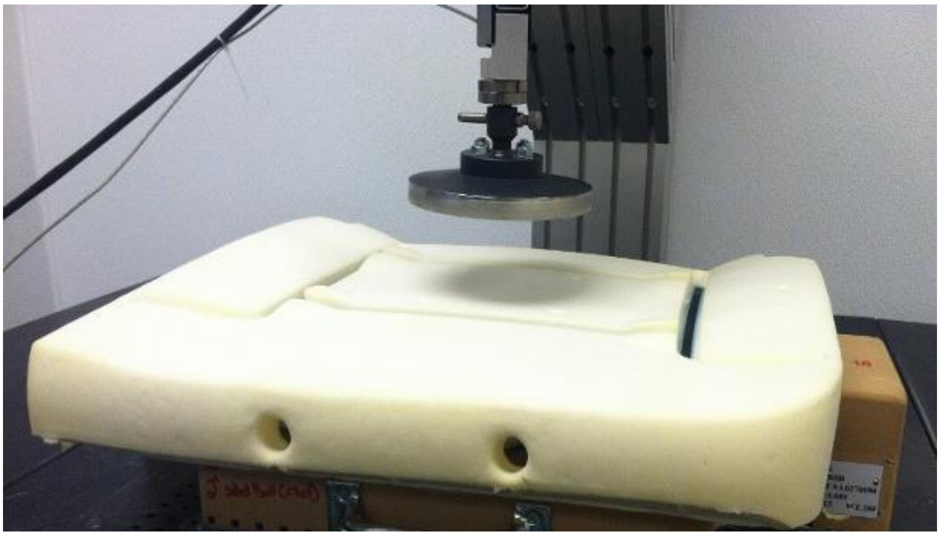


Figure 2. 2 *IFD testing machine.*

- *Support Factor* is the ratio of 65% IFD divided by 25% IFD [10]. The higher the number, the greater the foam’s ability to provide support. For greatest comfort, the support factor should be selected to maximize cradling, allowing a seated person to sit into the cushion rather than on top of it. When cushions are thick, lower support factor foam may be used to improve cradling and to achieve more even distribution of body weight. For thinner cushions, where the ride is limited, higher support factor can be used to provide softer initial contact and resist bottoming out.

- *Resilience* is an indicator of the surface elasticity of foam. It is measured by dropping a standard steel ball onto the cushion from a given height and measuring what percentage the ball rebounds. The surface resilience of foam also affects comfort and design [2].

The seat trim, consisting of the upholstery and in some cases a thin layer of comfort foam, can be of various kinds and the buyer and/or designer can choose between colors and materials. The materials can be divided into two categories, fabrics and leather. Important aspects of the trim material are that it offers an aesthetically pleasing finish to the seat and should for example not wear, wrinkle or stain. Different coatings can be applied to the material in order to assure some of these factors. The manufacturing process (such as woven or knitted) and what raw material that is used (e.g. organic or synthetic) are factors influencing the fabrics elasticity, durability and look [11].

All these different components, materials and manufacturing techniques make up a complex structure each with their own variations. This complex structure is the key component in assuring the seating position of the driver. In order to assure the seating position a method to define and measure it is needed, one way to achieve this is by using SAE standards.

2.4 Standards and Regulations for Automotive Seats

SAE International is a global association of more than 138,000 engineers and related technical experts in the aerospace, automotive and commercial-vehicle industries. SAE International's core competencies are life-long learning and voluntary consensus standards development [12]. Several of the SAE standards are used to develop regulations in different countries and are therefore very important to consider when developing the components of a car.

Car manufacturers use the SAE J1100 standard, named Motor Vehicle Dimensions [13], to define the most relevant dimensions of the vehicle interior that are used for determining important benchmarking and regulatory parameters. One of the most important points that are defined in this standard is the one referred to as H-point, in the document the following four definitions of this reference point are presented:

- H-point: The H-point is the Pivot Center of the torso and thigh on the Two-or Three-Dimensional devices used in defining and measuring vehicle seating accommodation.
- Design H-point: The Design H-point is located on a drawing by the H-point on the two-dimensional drafting template placed in any designated seating position. If the designated seating position can be adjusted, the path of the Design H-point through the full seat adjustment establishes the Design H-point travel path, and can be dimensionally described by coordinates relative to the three-dimensional reference system
- Seating point reference: The manufacturer's design reference point is a unique Design H-point which:
  - ✓ Establishes the rearmost normal design driving or riding position of each designated seating position which includes consideration of all modes of adjustment, horizontal, vertical, and tilt, in a vehicle,
  - ✓ Has X, Y, Z coordinates established relative to the designed vehicle structure,
  - ✓ Simulates the position of the Pivot Center of the human torso and thigh, and
  - ✓ Is the reference point employed to position the two-dimensional drafting template with the 95th percentile leg described in SAE J826.
- Actual H-point: The actual H-point is located in an actual vehicle by the H-point on the three-dimensional H-point Machine with the 95th percentile leg installed in any designated seating position per instruction in SAE J826 and can be dimensionally located by coordinates relative to the three-dimensional reference system.

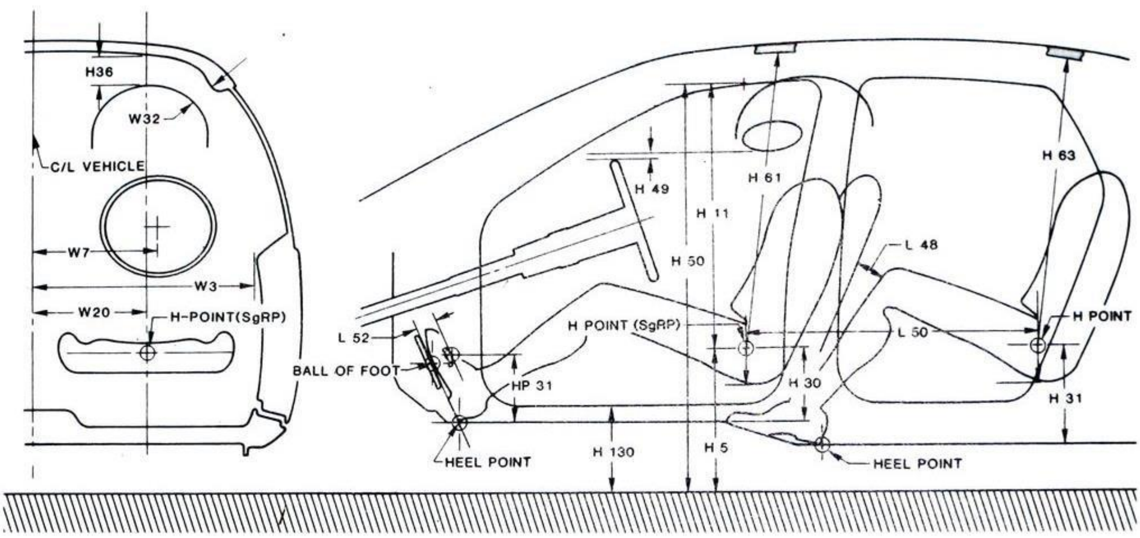


Figure 2. 3 Main interior dimensions for passenger packaging (SAE J1100)

The importance of the H-point is evident in the J1100 standard since it is used as the reference for defining not only the position of the driver but also other key dimensions as: Entrance Height (H11), Belt Height (H25), Effective head room (H61), Leg room (L33), Shoulder room (W3). Elbow room (W31), Hip room (W5), Knee clearance (L62), Thigh room (H13) among others, all of which are used in determining the packaging strategy for a new vehicle.

Other SAE standards such as J941, J1052 and J287, which define measurements, which are important for driver packaging and ergonomics also make direct reference to the H-point location.

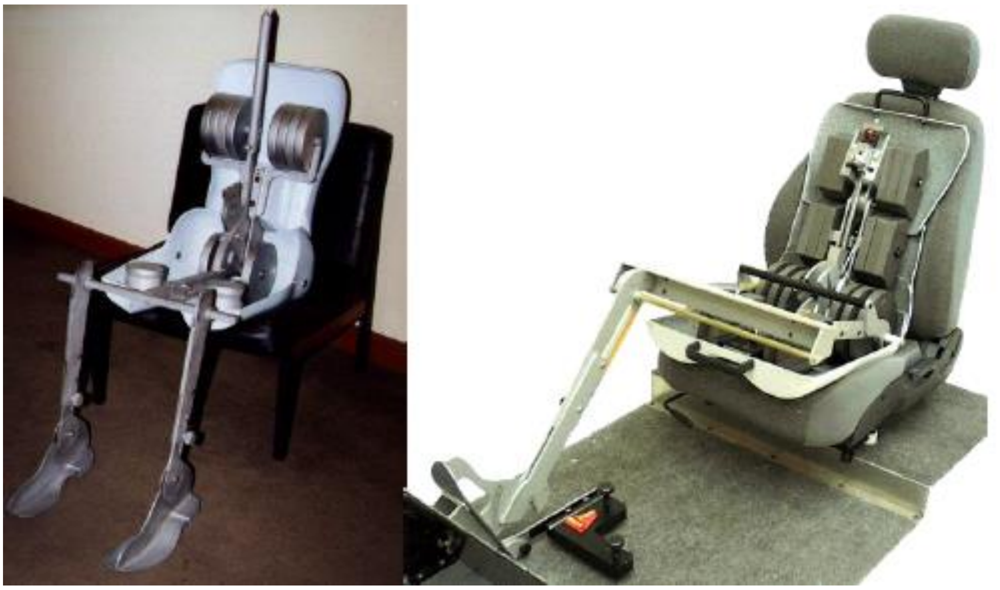


Figure 2. 4 Devices for measuring H-point, from SAE J826 and J4002

In the early 2000's a new machine and revised procedure for H-point measurement were developed to substitute the J826 standard resulting in the SAE J4002 standard (SAE 11 International, 2010) which aims at resolving some issues with the previous model. While the old standard is still referred to mostly by the regulatory documents, a change into the new standard is planned for the next couple of years, therefore it should be considered when working with seating position definition and measurements

2.5 Ergonomics

The word 'ergonomics' comes from the Greek: ergos, work; nomos, natural law. The word was coined by the late Professor Hywell Murrell, as a result of a meeting of a working party, which was held in Room 1101 of the Admiralty building at Queen Anne's Mansions on 8

July 1949—at which it was resolved to form a society for ‘the study of human beings in their working environment’.

Ergonomics is the science of work: of the people who do it and the ways it is done; the tools and equipment they use, the places they work in, and the psychosocial aspects of the working situation. Ergonomics is the scientific discipline concerned with designing according to the human needs, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance which is also called human engineering and human factors (Wikipedia a). When ergonomics factor is taken into account, the human capabilities and limitations of the certain design is being considered.

Proper ergonomic design is necessary to prevent repetitive strain injuries, which can develop over time and can lead to long-term disability. The main causes of these injuries are quick, repetitive actions, awkward position, use of force, and lack of rest. Minimization of repetitive tasks and awkward body positions can help to prevent such injuries from occurring (Lawrence).

2.6 Body weight and muscle activity in sitting position

Parcells (1999) citing Zacharkow D. (1988) argues that, the adverse effects of body weight and muscle activity in sitting position for inadequate school furniture have been known for a long time [14]. He also expresses that the dynamics of a seated position can be better understood by studying the mechanical parts of the body and the external support system involved. For example, 75% of total body weight is supported to be seated in an area of only 26 cm^2 of surface. This small area is under ischial tuberosities of the pelvic which is heavy burden is concentrated in this area, Structurally, the tuberosities are two-point supports system that is inherently unstable, so the center of gravity of a person sitting on top of that zone cannot be directly on the tuberosities and the area is insufficient to stabilize which makes it necessary to use the legs, feet, back in contact with other surfaces, as well as muscle forces to produce equilibrium. The legs, when sitting, distribute and reduce the load on the buttocks and the back of the thighs. The legs must rest firmly on the floor or foot support, thus the weight of the lower leg is not supported by the front of the thigh resting on the seat. If pressure is applied on the thigh near the knee swelling can occur in the legs and pressure on the sciatic nerve.

2.6.1 Relationship popliteal height and seat height

Chaffin (1999) says that, when the seat height is very low, the knee bending angle becomes sharp, and the weight of the trunk should be transferred to the seat through the back of the thigh, it is transferred through a small area on the isquial tuberosities on the pelvis [15]. When the seat height is so high that the feet do not touch the ground pressure on the back of the thigh is not very comfortable and the person tends to go to the front of the seat of the chair, allowing to support feet on the floor but the support is not used properly, resulting in low back pain if the position is for a long time. Feet should rest firmly on the floor or on the foot support so the weight of the lower leg is not supported by the thighs that rest on the seat. In addition to ISO 9241-5: 2003 states: It is not acceptable to assume that people stay with the legs vertical it is convenient, therefore, that the lower leg can reach the ground in front of the knee, so that it presents a greater articulation angle of 90 º [16].

2.6.2 Buttock-knee length with a deep seat

In the ISO 9241-5: 2003 notes: seat depth is important both to ensure that the legs can be placed without compressing the back of the knees and to be able to rely fully on the back [16]. The back of the knee is a fairly sensitive skin and tendons have little protection, so the depth of the seat should be slightly shorter than the length between the back of the knee and thigh. A big depth of the seat does not an appropriate use of back support which causes curvature of the spine (kyphosis) and may lead to no comfort.

2.6.3 Relationship wide hips and wide seat

In the ISO 9241-5: 2003 also states: Besides the obvious need to ensure that a reasonable proportion of the population of potential users can easily get up and sit down, this is one of the most important way to ensure that the user lessens the burden by taking the postural position. Due to the flattening of the buttocks and the tendency to open her legs while sitting, the anthropometric measure width of the hips should be lower than what should be allowed for width of the seat. There must be added, on each side, an extra width for movement of the arms if the seat is equipped with armrests.

Considerable efforts have been made in the past by researchers to provide the designers of car seats with effective guidelines towards providing the automobile industry with more comfortable seats. The capability to understand the comfort level provided by the automotive seat requires an in depth understanding of biomechanics of seated posture, seat geometry effect on humans, seat properties and the vehicle environment on perceived comfort.

Seat comfort is a complex phenomenon (Looze et al, 2003). Many researchers have studied factors that influence subjective comfort or the perception of comfort in humans. Also he made an analysis of the scientific literature concerning the relationship between sitting comfort and discomfort and objective measures. He found pressure distribution was the objective measure that provided absolute transparency in its association with the subjective ratings [14]. Looze et al (2003) focused on comfort effects and Nordin (2004) on the effects of sitting and back complaints [15]. Lueder (2004) uses the literature to show the importance of movement while seated and Zenk (2008) made a literary review of comfort and sitting while driving [16, 17]. Factors influencing the subjective ratings also include skin perception, muscular activity, posture, joint angle interface, pressure, stiffness and suspension of the seat cushion and backrest. Posture variation and frequencies of posture changes are also measured. Mergl (2006) states that the seat should reduce postural stress and optimize muscular tension [18]. Porter et al. (2003) explained the importance of pressure distribution to avoid high pressure areas [19]. For instance, the tissues around the ischial tuberosities are subjected to extremely high pressure while sitting that can result in reduction of blood circulation through the capillaries. In such cases it is necessary to realign body position, else then the symptoms of aches, pain, discomfort and numbness start surfacing up. Nordin (2004) also showed that sitting in restricted postures as well as sitting in combination with vibration is a risk factor [15]. This means that for car seats the risk is there. Ariens (2001) showed that unsupported static postures also increase the chance of neck pain [20].

Kolich. M, (2002) published a paper refuting the claim that ergonomics criteria related to anthropometry satisfied the consumer comfort. In this he discovered the discrepancies between the survey conducted for 12 subjects in five compact car seats and the contour characteristics scanned for those seat environments. This led to the conclusion that ergonomic criteria could not be blindly applied for ensuring comfortable automobile seats [21].

In 2008, Kolich published a work concerning the automobile seat comfort development process presently in work and the restrictions associated with it in detail [22]. Through this he initiated a regulated framework intended to lead the investigative process related to seat comfort research. The framework aimed at producing theories and methods that could provide guidelines and further validate the discipline of automobile seat comfort.

Siefert et al. (2008) published a work on the optimisation of the car passenger seat in a virtual environment [23]. He used an adequate human model for the virtual experimentation of the static and dynamic effects caused during seating comfort. This method when applied at an early stage of the procedure enabled the user to optimise a car passenger seat structure accordingly to both types of comforts. The construction of vehicle seats after considering the boundary conditions as higher load amplitudes and accelerations can be done putting the advantages of virtual development into use. Yang et al. (2007) presented a new digitized human model for performing assessments of the vehicle interior design [24]. A digital human helps in reducing the procedure followed during design cycle along with time and money. This method differs from the traditional digital human environment in the aspect that this method is optimization-based. Gragg et al. (2012) projected a method for the accommodation of drivers in car seat putting in use an optimization-based digital human model [25]. The proposed hybrid method combined three dissimilar approaches: a boundary manikin approach, a population sampling approach, and a special population approach. Using this method is beneficial as the human aspect of design could be included early in the design process, thereby reducing or eliminating prototypes and hence reducing cost of manufacturing

Fazlollahtabar H (2010) [26] proposed a framework of subjective nature for the seat comfort based on the heuristic multi criteria decision making technique and human anthropometry. This satisfied the essentiality for a theoretical and methodological automobile seat comfort criteria by providing a numeric value to the consumers' preferences. The applicability and effectiveness of the proposed approach was validated using a case study. Bower-Carnahan et al. [25] conducted survey on preference of heavy truck drivers regarding seat design. The overall ratings for driver comfort and adjustable suspension damping featured them as the most important features. The importance of adjustable lumbar, kidney and thigh support was also highlighted, obtaining scores of 4.56, 4.5 and 4.12, respectively. This study also specified the regions of physical discomfort through a discomfort point plot. The five areas in particular that were highly related to seating discomfort:

- Discomfort in upper neck and back; caused mainly due to strain of driving all day and due to the requirement of maintain the head in proper position for extended durations.
- Discomfort in shoulders; originating mainly due to improper positioning of seat with respect to steering wheel and steering wheel angle.
- Discomfort in lower back due to insufficient and improper lumbar supports

- Discomfort in buttocks attributed to the uneven pressure applied at the human-seat contact region.
- Discomfort in back region of thighs just above the knee region caused due to improper pressure distribution.

Even though the workstation and geometry of truck and automobile are different, the concerns pertaining to the seat comfort and sense of discomfort can be generally addressed. Adequate adjustable lumbar support, sufficient cushion contouring with appropriate padding to reduce magnitudes of peak pressure and evenly redistribute interface pressure are the essential features that can help eliminate discomfort among drivers.

The review of literature for evaluation of seat comfort by using subjective assessment methods has shown that this method is an essential tool in distinguishing the seat features that provide comfort or discomfort.

2.7 Sitting Characteristics as a Natural Human Posture

The human body is complex and very flexible. It has a tremendous capability and capacity to change its form, style and posture in unlimited types and varieties. The ability of the human body to move flexibly is due to a widely distributed system of muscles, which together make up approximately 40% of the total body weight. A muscle is made of between 100 000 and 1 million fibres. The most important characteristic of a muscle is called muscular contraction. This is its ability to shrink to half its normal length.

The flexibility and elasticity of the human body provide the opportunity to select specific postures and deal with a variety of tasks which sometimes seems to be quite impossible or very difficult to perform, thereby requiring strenuous effort. Among the other types of body activities such as standing and lying sitting has been known to be natural and relaxing and may provide rather high comfort for the human body. Sitting however can be performed in many more or less uncomfortable ways.

Sitting has been defined as a body position in which the weight of the body is transferred to a supporting area mainly by the is chial tuberosities (two bony prominences forming the lowest end of the pelvis which carry the weight of the body when seated, functioning as a rotation axis of the body) and their surrounding soft tissues. Sitting is a stable posture in which the body weight can be transferred to a relatively wide seat area.

In other words, the major part of the body weight is transferred to the seat surface where the back of the thigh touches the seating area. Depending on the seat characteristics and posture, some proportion of the total body weight will also be transferred to the floor via the feet, as well as to the backrest and armrest of the seat via hands or arms (see Figure 2-5). When a person leans backwards, a part of the body weight is transferred to the lumbar supports in use. This reduces the load on the lumbar spine caused by the upper body weight. The use of lumbar support changes the posture of the lumbar spine towards lordosis (abnormal forward curvature of the spine) and reduces the deformation of the lumbar spine and the corresponding disc pressure. The use of armrests supports the weight of the arms and reduces the disc pressure

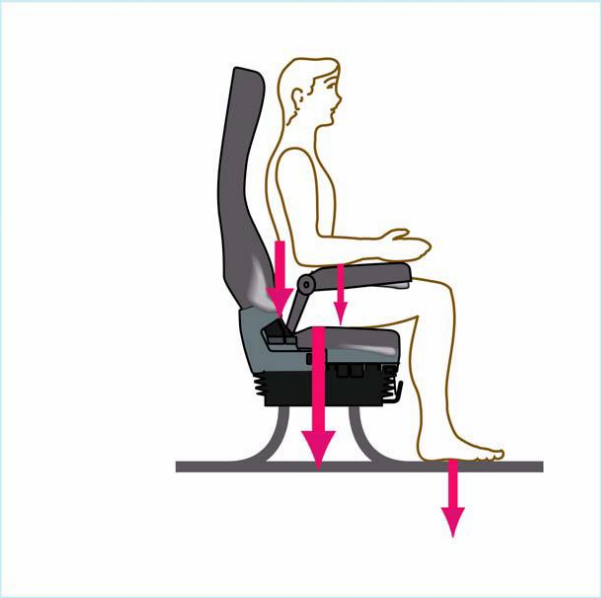


Figure 2. 5 Body weight distribution

The proportion of the total body weight as expressed in the arrows, transferred to the seat, floor and armrest (reproduced from Chaffin and Andersson, 1991) [13].

The posture that a person adopts when performing a particular task is determined by the relationship between the dimensions of the person’s body and the dimensions of the various items in his or her workspace. The extent to which posture is constrained in this way is dependent upon the number and the nature of the connections between the person and the workspace. Posture may be defined as the relative orientation of the parts of the body in space. To maintain such an orientation over a period of time, muscle must be used to counteract any external forces (such as gravity) acting upon the body.

The purpose of sitting is to achieve a rather comfortable (over a period of time), satisfactory and stable body posture appropriate to a required task or activity. Sitting posture is important because it influences the subjective feeling of comfort, as well as the objective physical factors which can improve or impair spinal health. Posture also influences the transportation of nutrients into and out of the intervertebral discs.

Note the following: Sitting in comparison to some other natural postures such as standing, has many notable benefits:

- It provides stability and good balance
- energy consumption is less during sitting than standing
- It places less stress on the lower extremity joints
- It lowers the hydrostatic pressure on the lower extremity circulation.

In order to achieve these benefits in designing work stations, the biomechanical aspects should be taken into consideration, without causing undue stresses to the back and shoulder as well as to the upper extremities (Chaffin and Andersson, 1991)[13]. Therefore, the seat as a work apparatus must be given more attention by designers and users alike. It should also be noted that the lower and upper back of the body play a significant role in transferring the load in the sitting posture. The distribution of these loads may vary depending on the type of posture and seat structure.

A seat may be comfortable for one individual but uncomfortable for another depending on many factors. The period of sitting and the task to be done have been argued to have a major impact on comfort judgment. A comfortable seat may become uncomfortable in the long run or some seats may become uncomfortable more rapidly than others. Therefore it can be concluded that comfort (or more strictly discomfort) depends upon the interaction between seat characteristics, user characteristics and task characteristics. Regarding the user characteristics, anthropometric factors are of major importance but not sufficient.

1.1.1 The anatomical description of spinal column

The upper extremities as well as the lower extremities, specifically the spine, are important when considering the biomechanical aspects of sitting. The upper extremities consist of five bones (two scapulas, two calvicles and one sternum) which form the shoulder girdle with a great range of motion. The shoulder joint is formed where the rounded head of the humerus meets the scapula so that the natural weight of both arms directly burdens the shoulder girdle with 50-100 N (Diebschlag et al., 1995) [27]. If the muscles of the upper back are poorly formed and their ability to take a load is restricted, the burden of the arms is largely transmitted by the clavicle, sternum and thorax. Therefore, sitting for hours with a backrest of insufficient height or without proper support to the shoulder blades and shoulder girdle can lead to fatigue, hardening of the muscles and produce pains to the head and arms.

Regarding the lower extremities, the thighs are joined to the pelvis at the hip joint and rest with it upon the surface of the seat. Regarding the shape of the spine in sitting or standing postures, there is a vast amount of individual variations. The configuration of the lumbar spine is altered when going from a standing position to a sitting position and spinal forces are created within the spine motion segments. The cervical spine is also influenced by sitting, as the field of vision needed to perform a task may require the head to be in a certain position. The increase risk of low-back pain in subjects who work in a predominantly sitting posture has been confirmed in many studies. These studies also showed an increase in back symptomology in subjects who suffered back pain when required to sit for prolonged periods.

Theoretically, an upright position with the joints of the hip, knee and ankle at right angles has been regarded as the correct position. To maintain an upright trunk posture, the lumbar spine must move towards concavity which is sometimes called lordosis (abnormal forward curvature of the spine) when the pelvis rotates forwards. When the pelvis is tilted backwards, on the other hand, the lumbar spine tends to flatten, and sometimes a convexity called kyphosis (abnormal backward curvature of spine) can develop. This is typically what happens when sitting down on a flat stool (Figure 2.6). Sitting with poor back support, even more than standing, can lead to marked kyphosis, especially in the cervical and lumbar regions. Long-term seated work with restricted movement may seriously damage the spinal column. This is why frequent disability due to degenerative disorders of the spinal column among professional bus drivers is very common. In this respect, special medical checkups for biomechanically stressed truck and bus drivers are essential.

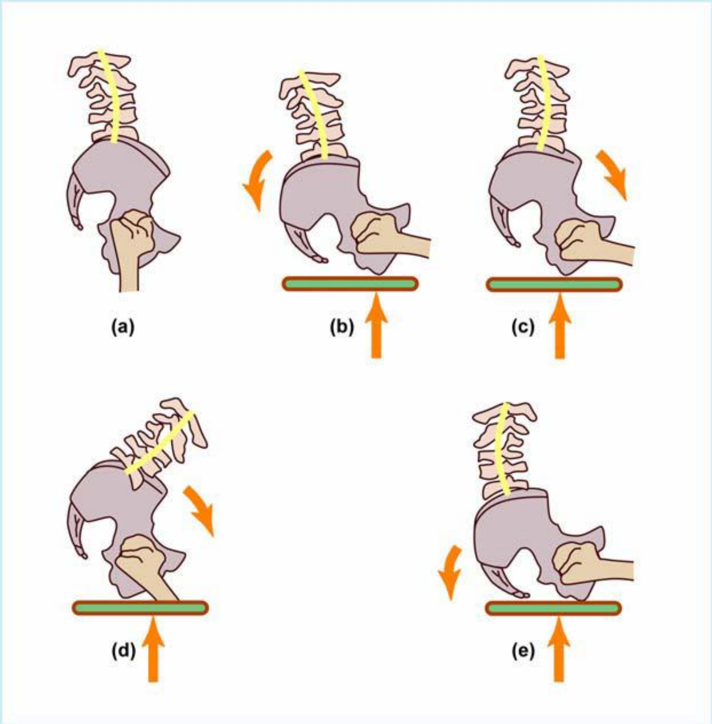


Figure 2. 6 Rotation of pelvis.

The pelvis and lumbar part of the spine when (a) standing; (b) sitting relaxed unsupported in the middle position; (c) sitting erect, unsupported in the middle position; (d) sitting in the anterior posture; (e) sitting in the posterior posture.

As illustrated in the above figure, sitting has been divided into middle, anterior and posterior sitting postures depending on the seat characteristics and task. This category is based on the location of the center of mass of the body and affects the proportion of body weight transmitted to the different support surfaces. In the middle (upright) posture the center of mass is directly above the ischial tuberosities and the floor supports about 25% of the body weight. The forward leaning, called anterior (inclined) posture, is reached from the middle posture either by forward rotation of the pelvis or with large induced kyphosis of the spine. In this posture the center of mass is in front of the ischial tuberosit and the floor supports more than 25% of the body weight. In the backward leaning the so called posterior (reclined) posture, less than 25% of the body weight is supported by the floor and the center of mass is behind the is chialtuberosit.

The posterior posture can be obtained by a backward rotation of the pelvis and simultaneous kyphosis of the spine. Using the backrest to support the spine would influence the configuration.

When sitting, the pelvis rotates backwards and the lumbar spine flattens. A well designed low-back support can therefore prevent the flattening of the lumbar lordosis in sitting. Traditionally, the proper sitting position recommended was the right angle and upright or erect position which later on became the basis for international standardizations. Based on these recommendations, the work chairs/seats in various workstations (offices and industries) have been designed for sitting upright, with the hip, knees and ankles all at right angles. Until recently, it was widely believed that people sat with a 90-degree bending of the hip joint while preserving lordosis (concavity) of the back.

There are differences in changes and arrangements of the body between male and female during sitting. The female pelvis is shaped differently from that of the male and flexion of the thighs on the trunk is less restricted by heavy muscles and ligaments. This permits women to sit at a right angle and to stoop with less flattening of the lumbar curve.

Generally, the best sitting posture is thought to be obtained on horseback. “The hip joints in this posture are in the resting position with a bend of forty-five degrees. Thus the hip joints and lumbar spine are not loaded in an extreme position. The lumbar curve is maintained and a perfect balanced position is obtained in which the body adjusts its centre of gravity- it is level with the 9^{th} thoracic vertebra- the entire time with small correcting movements above the supporting surface. The use of riding has increased for the rehabilitation and treatment of people suffering from complaints of the motor system”.

Changing the body position from a standing to an unsupported sitting position will decrease the lumbar lordosis by an average of 38° [13]. There are also small angular changes between L1 and L2 and between L2 and L3.

Another aspect which has a major effect on the configuration of the lumbar spine and pelvis is the hamstring muscles of the back of the thighs. This configuration effect exists because the hamstring muscles run from the lower limb to the pelvis, crossing both the hip and knee joints (see Figure 2-7).

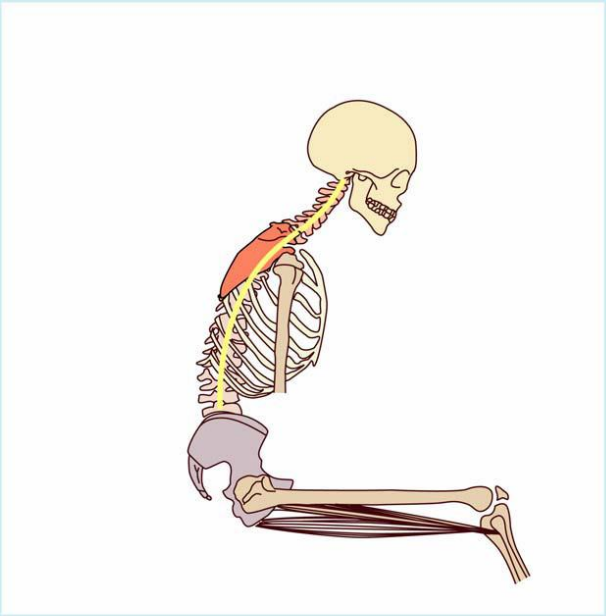


Figure 2. 7 The pelvis rotation affected by lower limb [28]

The hamstring muscles cross two joints (the knee and the hip). Movement of the lower limb can therefore affect pelvis rotation and influence the posture of the spine. [28]. since there is no single ideal posture and as nobody posture can be maintained indefinitely, the alterations in one's posture are also considered to be permitted by the chair. The postures of the neck, shoulders and upper extremities while working in sitting postures depend on the task and the location of the work area. Therefore, the seat and associated sitting posture should not be considered separately without taking the task to be performed into account.

1.1.2 Sitting posture, disc pressure and muscle activities

The intervertebral disc consists of two parts; the center (called nucleus) and the surrounding parts (called annulus). The structure of these parts allows the disc to distribute the loads and transform compression loads such as flexion, extension, lateral bending and tension into radially directed tensile forces [13]. The intradiscal pressure measurement of a human body is the most direct and reliable method to assess loads on the spine. This measurement technique has been used in laboratory environment in various activities and postures.

In a study by Nachemson and Moris, 1994 [29], disc pressure measurements were performed on subjects in a standing posture as well as a sitting posture without support. The pressures measured during standing were found to be 35% lower than those during sitting. Later in the early 1970s these findings were supported by many other studies which confirmed that the disc pressures were considerably lower in standing than in unsupported sitting. Among different unsupported sitting postures, the back straight sitting was found to have the lowest pressure.

2.8 Anthropometry and its role on prediction of sitting posture

Anthropometry is a composite of the words anthropos (human) and metrikos (measuring). It is defined as the science of measurement and the art of application that establishes the physical geometry, mass properties and strength capabilities of the human body (Roebuck, 93) [30]. It has several applications and areas of use. Anthropometry is an important branch of the human sciences and ergonomics dealing with body measurements, and in particular the measurements of body size, shape, strength and working capacity.

Anthropometric methods are among the basic working tools for the analysis and development of engineering design requirements such as the design of tools, working stations, etc. Vehicle interior and driver interface design are good examples of engineering design benefitting significantly from anthropometric methods. In general, anthropometry considers the wide range of sizes, proportions, mobility, strengths and other factors that define human beings physically. The performance capabilities and human sensing are related to these physical characteristics and therefore, anthropometric concerns also influence many aspects of human factors related to physiology and the psychology of comfort and perception.

Anthropometry helps to evaluate postures and the distances required to reach controls and specify clearances, driver fit in vehicles, accommodation comfort and general human performance. It is frequently used in studies dealing with subjective judgments providing numerical data for comparing the subjects' body dimensions to seat characteristics. Many studies confirm a close correlation between these dimensions and the feeling of comfort or discomfort.

Carrying out the body measurement requires having some knowledge of human anatomy and identifying the locations, names and shapes of bones and muscles. It also demands an understanding of how to read and document the measurement scales, measure weights, and handle the instruments. Some other knowledge such as mathematics, physics and mechanical engineering are required depending on the applications.

Planning and deciding which parts and attributes of the human body to measure is not always so clear. Depending on the aims, the measurements could be planned for identifying and performing procedures. A goal of industrial applications for instance could be more a workplace design, which means collecting data on body segment lengths, heights, breadths, depths and in a few cases circumferences. By contrast, clothing design and size distribution decisions require many circumferences and distances along the surface contour but few lengths or heights. Physiological studies may require data on volumes, densities and areas of the human body. Computer modeling of the human form regarding work space design requires dimensions which help to locate joint centers of rotation and offsets in relation to consistent 3D coordinate systems.

Standard measurements are needed for comparative purposes and forecasting trends. The Society of Automotive Engineers (SAE) held committee meetings in the 1990s for the purpose of setting computer human modeling standards. The arguments resulting from these meetings concerned the standards for naming single dimensional anthropometric measurements that are frequently used in traditional anthropometry for engineering applications, performing measurements and selecting preferred minimum lists of measurements.

2.9 Anthropometrical variations and principles

In general, the measurements of human body dimensions are essential when dealing with different varieties of products and workplaces. Since the attitude of the trunk, arms and legs as natural postures and movements is a necessary part of efficient work, it is essential that the workplace be suited to the body size of the operator.

A number of factors may cause significant variation in human body size. Among different aspects, gender and races can be considered as the two main variations in body size between individuals which should be considered in the design process. Individuals from one part of a country may be taller and heavier than those from another part. A significant difference in stature between people having different occupations has been confirmed in various studies. Ethnicity has been also demonstrated to be one of the significant factors influencing body size. It has also been shown that the genetic basis of a population may significantly contribute to the differences among people. For instance, Japanese' torsos which are proportionately longer than their legs have shown a strong genetic component in body proportions.

Climate has also been shown to have a significant effect on body sizes. The dimensions making linearity of body form are associated with people living in warm climate, e.g. limbs were found to be greater in proportion to the overall size. People living in cold climates had spherical proportions more than the linear forms, e.g. greater limb and trunk girths relative to stature. Furthermore their bodies were heavier.

2.10 Fifth and ninety fifth percentile

Designing workplaces, equipment, or any other material intended to fit the requirements of all users (the biggest, tallest and widest as well as the smallest, shortest and narrowest) is almost impossible. Therefore, it must be satisfactory to fulfil the requirements of the majority by a selection of either 95% or 90% of the population respectively. The same problem arises in the vehicle industry.

Designing vehicle interiors and utilization of computerized representations of human models have become one of the most interesting aspects in passenger car and heavy duty vehicle manufacturing industries. Additionally, one of the major aspects of the successful design of restraint systems is how to accommodate the large number of potential occupants (Lehto and Foley,) [31]. Most automotive design standards attempt to accommodate occupants from at least the 5th percentile female to the 95th percentile male. To provide such a range is particularly relevant if there could be technical problems in trying to cover even the very extreme cases (100% of the population). By setting limits such as the 5th and 95th percentiles, a certain percentage of the population will be eliminated from the observation. It is worth noting that in a mixed 50/50 male/female population, using a range between the 5^{th} percentiles female to the 95th percentile male will cover 95% of a population, not 90%. The reason is an overlap between male and female body dimensions.

The meaning behind these two different terms (percent and percentile) can be explained by the general understanding that *p*% of people in a population is always shorter than the *p*th %ile of it. The percentiles are actually densely packed near the centre and thinly spread at the extremes. Based on this claim, there is a point in the left side of the horizontal axis, known as the 5th percentile, which indicates that 5% of people are shorter than the 5th percentile. Similarly, an equal distance from the mean towards the right side of the chart specifies the point known as the 95th percentile and indicates that 5% of people are longer than the 95th percentile. Figure 2.8 illustrates a normal distribution curve for stature of adult British men. The slope of the curve is greatest at the mean value (the point of maximum probability) and steadily diminishes as it approaches the extreme tails of the distribution. The curve is symmetric in both sides of its highest point (mean) and infinite in both tails

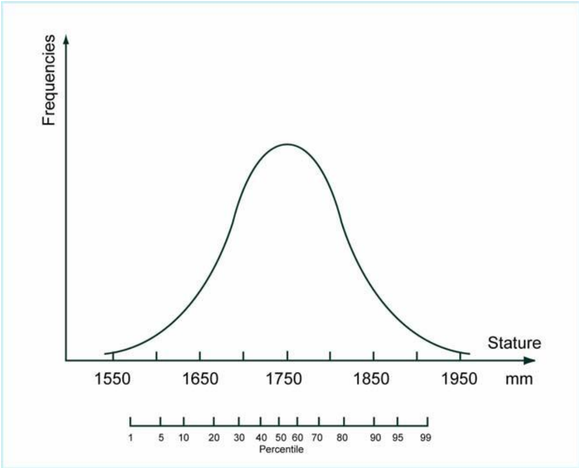


Figure 2. 8 The frequency distribution (probability density function) for the stature of adult (example of the normal or Gaussian distribution, adopted from Knight, 1984)[32].

2.11 Confidence interval (Ci)

When designing for a certain population of interest, a confidence interval (Ci) of 95% is that the smallest 2.5% and the largest 2.5% are excluded from consideration. Any particular percentage is called a percentile and in this example the only percentiles lying between 2.5% and 97.5% are being considered. A percentile may be calculated by two given specific parameters- mean and standard deviation, SD (an index of the degree of variability in a certain population) of a normal distribution. A normal distribution is actually defined by its mean and standard deviation. In other words, the normal distribution is described by a relatively simple mathematical equation which contains only these two parameters (mean and standard deviation). The *p*th %ile of a variable is given by:

$$X(p) = m + sz........................ .[2.1]$$

Where, z is a constant for the percentile concerned which can be selected from a statistical table.

The following equations show the confidence interval and its relation to the mean (x) and the standard deviation (SD) of any given population:

$$\text{Ci } 95\% = x \pm 1.95 \text{ SD}$$

$$\text{Ci } 90\% = x \pm 1.65 \text{ SD}$$

A frequency distribution curve of a certain dimension of a body such as stature is shown in Figure below.

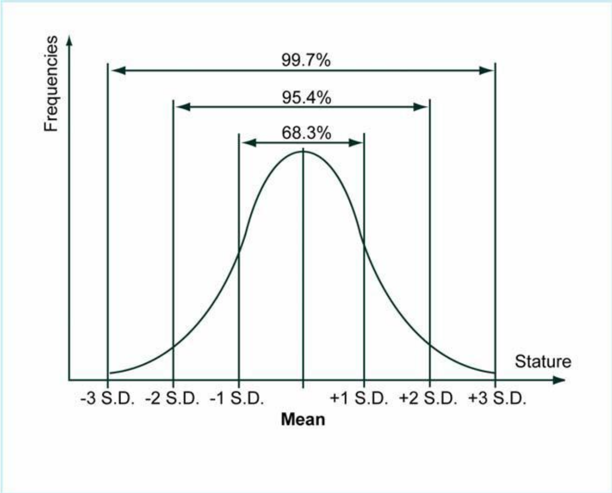


Figure 2. 9 The frequency distribution of stature with confidence interval.

Regarding the anthropometrical measures of the human body, the most linear dimensions are normally distributed. There are, however, other types of frequency distribution which may occur in measures. The combination of two normal distributions, such as males and females or adults and children, will lead to a new type of distribution called flat-topped or even double peaked (bimodal). In most populations, body weight and muscular strength showed a positive skew.

2.12 Anthropometric measurements

The domain of anthropometric measurements is one of a seemingly endless number and variety. Yet it has been well known for some time that large subgroups of these measures exhibit a high degree of interrelationship and interdependence. For a very long time, it has been realized that it makes good scientific sense to detect the reduced subset combination of measures that convey essential information of the total set.

It is necessary to adhere to standard methods and materials for reproducibility and comparability of the body measurements. Skeletal and body landmarks, instrument used and methods employed in performing measurements, are the most important aspects among them. The following provides some explanation of these aspects.

- Skeletal or anatomical landmarks specify the points from which the measurements are taken.
- Body landmarks are marks (points, crosses, lines, etc.) to be placed on the skin in order to assist in taking accurate measurements.
- Standard instruments used to measure body sizes include an anthropometry, compass, calliper, steel (canvas or plastic) measuring tapes, a weighing device, etc.

- Measurement methods can differ with corresponding different results. The definition of measurement describes the technique, the points from which the measurement is taken, the body posture adopted during the measuring and the instrument used for the measurement. There are several methods for measuring body sizes:
  - ✓ physical measurements or direct method measurements are usually taken using measuring instruments
  - ✓ Photographic measurements, which are indirect measurements methods. Photogrammetric is one of the simplest photographic methods of acquiring anthropometric data where photographs are taken of subjects positioned in front of a measuring grid which gives a 2D point to point measurement between prominent features.

Body size variability is the other term of anthropometry. Due to nutritional factors and higher standards of living, body sizes have changed between different periods. Differences in body dimensions exist not only between sexes or at different ages, but also between races or ethnic groups. There are remarkable variations in body dimensions between people living in different countries. In general the causes of body size variability have been attributed to several factors such as: Genetic, Climate, Activity, Nutrition, Sex, Age and Standard of living.

1.1.3 Types of measurements

Human beings should be able to move and work in different work places and must not only fit spatially in a man-task system. Therefore two types of body dimensions are related to the anthropometric aspects of the work place design, static as well as dynamic dimensions. Depending on purpose of the study, the measurements could be of a static or a dynamic dimension type.

Static dimensions or structural data are taken on the body (head, torso and trunk) with standardized body positions. Static dimensions refer to the actual sizes of the body components and include simple lengths or linear and circumferential dimensions, contours, areas and volumes. They include heights, widths, breadths and depths and usually imply no direction e.g. foot length, prominences e.g. ear prominence. In addition to the body form measurements, static anthropometry also includes area measurement and volume measurement.

Dynamic or functional measures are taken with the body in motion posture and are usually more complex and difficult to measure. Dynamic dimensions refer to the ability of the body to perform certain tasks within certain distances, spaces or enclosures and include the description of measurement of human mobility, agility or flexibility. Prior to the measurements it will be important to know the inertial properties, viz. total body weight, whole body centre of mass and distribution of mass throughout the body.

1.1.4 Application of Anthropometric Data

Anthropometry is an important requirement for the design of a work place, instruments and hand tools, furniture, clothing and many other aspects in our life. The main objectives of anthropometry are:

- To obtain an optimal working posture
- To enhance working efficiency
- To improve safety and the comfort aspects of work.

Whatever the objective, the application of anthropometry should be cost-beneficial. When carrying out the anthropometrical measurement and using the resulting data correctly, the following issues must be taken into account:

- Design for the extreme individuals
- Design for the average
- Design for the 90% user population
- Design for the handicapped and disabled
- Design for the specific individuals

2.13 Seat design recommendations for improved comfort

An ergonomic design of car seat will require data on compatibility of human size with the car seat. As it was described in above researchers work; hard seat cushion will adversely affect the pelvic bone. Seating on a flat wooden bench will cause peak pressure on the buttock as compared to seating on a foam cushion. They noted that such high pressures are tolerable for short period of time. A high peak pressure causes discomfort to the passenger and poor quality of driving. A well designed seat can avoid painful disorder such as low back pain that is due to improper sitting position. Anthropometrics, the study human dimensions such as measurement, shape, mass, center of gravity, inertia of human bodies and work capacity is necessary for ergonomic application. In determining the shape and dimension of product the feature of human body and factors affecting comfort of human can be considered with interaction between human and product.

The Design parameter could be considered to have good comfort;

- Fit parameters levels are determined by anthropometry of the occupant which include such measures as dimension of seat features.
- Feel parameters are related to physical contact between occupant and the seat. It can be set out by combination of subjective assessment and objective measurements out puts.
- Support parameters which are defined that are intended to influence the posture of occupant.

Generally, this research focused on the development of comfortable, reduced weight and cost effective seat for locally built passenger seat for minibus taxi. The method chosen can be subjective evaluation for statistical data was done through conducting survey in public to gather the opinions towards seat comfort. It was expected that the results from subjective method would be correlated to determine the discomfort factors and also the dimensions of seat feature of current existing seat to ensure improved seat design is possible. Chapter 3 on research methodology will described the approach and techniques used to describe the way of conducting and accomplishing the research.

3 RESEARCH METHODOLOGY

3.1 Sources of Data and Data Collection Techniques Methods

A descriptive survey research method was employed in order to assess the current status of passenger seats comfort in minibus around Adama city. This study tries to demonstrate facts and findings by using exact sources of data. The necessary data was obtained for subjective and objective evaluation. For the subjective evaluation, questionnaires were designed for the passenger in order to assess the comfort of locally manufactured passenger seats. This primary data was collected under varying circumstances such as riding in minibuses, waiting for minibuses to come and flow form minibuses taxi.

3.2 Subjective Evaluation

Subjective evaluation is carried out based on statistical analysis by gathering passengers' opinion towards the dimensions and comfort of minibus seats. The passengers were asked to evaluate the dimensions and comfort of the seats. Minibuses are chosen as most of the passengers are choosing these for transportation. The purpose of this method is to assess passengers' evaluation on the dimensions and comfort of existing locally manufactured minibus passenger seats. The survey was carried out at the bus station where all minibuses would stop to wait passengers and riding in minibuses. It was conducted in questionnaire based method. The researcher approached the passengers and asked for some of their time to answer for prepared questionnaires. It was necessary to explain any terms and questions that passengers might not be familiar with. They were asked to rate the seat dimensions and comfort using scale of 1 to 5. The target population for the study was adult respondents ageing from 15 to 85 years. The questionnaire was designed in such a way that the participants would respond to the questions by selecting the suitable rating scale.

All of the questions were close-ended questions to seek for participant's opinion. Such responses are useful and valuable to develop passenger seats of minibus which will reduce or minimize discomfort even during long-hour sitting. Therefore, users' point of view is very important for subjective evaluation of research studies. The questionnaire contained the following aspects:

- **Demographic questions:** Participants have given the rough measurement of their height, besides gender and age.

- **Seat dimensions:** Seat height, seat width, seat depth, backrest height, back rest width and gap between seats. Participants have been asked to assess each dimension in five rating scale.
- **Overall evaluation**: Participants have been asked to rate the overall comfort of passenger seat.

3.3 Objective Evaluation

For the objective evaluation dimensional measurements of existing locally manufactured seats of randomly selected minibuses and measurements of relevant anthropometric dimensions of available users of these seats were done. All the measurements were taken from the passengers who travel intercity of Adama town.

3.3.1 Measurement of Seat Dimensions

Measurement for seat dimensions' evaluation is important tool in the development of minibus seat to fulfil the criteria of ride comfort. The dimensions of existing locally manufactured passenger seats of minibus are assessed by taking measurements on seat height, seat width, seat depth, gap between seat, back rest height and back rest width using tape measure (meter).

3.3.2 Measurement of Passengers' Anthropometric Dimensions

Anthropometric dimensions (body dimensions) are important to minibus seat design dealing with the human shape. As shown in Appendix 1, the dimensions of passengers which are necessary to seat design are

- ✓ sitting height (SH),
- ✓ sitting to shoulder height (SSH)
- ✓ buttocks to popliteal length (BPL),
- ✓ popliteal height (PH),
- ✓ shoulder breadth (SB) and
- ✓ hip breadth seated (HB) were measured

3.4 Description of Measurements

i. Sitting Height

The passenger sits erect with the head in the franc fort plane with arms hanging at the sides and hands resting on the thighs. Vertical distance from the seat surface to vertex of the head with hair pressed down measured with a stadiometer.

ii. Sitting Elbow height

The vertical distance from the bottom of the tip of elbow (olecranon) to the sitting surface, measured with the elbow in 90^0 of flexion. The subject wears light clothing and sits fully erect with thighs fully supported and the lower legs hanging freely. The upper arms hang freely downwards and forearms are horizontal. The Sitting Elbow height is required to determine the arm rest height.

iii. Sitting Shoulder height

The passenger sits erect with his/her upper arms at the sides and hands on the thighs. The vertical distance from the top of the shoulder at the acromion process to the students' sitting surface measured with a stadiometer. This dimension is essential in the determination of Back rest Height (Upper).

iv. Sitting Knee Height

This is the vertical distance from the floor to the uppermost point on the knee. The subject sits erect on a chair and the knee was at the right angle. The measurement was taken with the use of a stadiometer.

v. Popliteal height

The vertical distance measured with 90^0 knee flexion from the foot resting surface to the posterior surface of the knee (popliteal space). The subject sits fully erect with thighs fully supported and sitting surface extending as far as possible into the hollow of the knee, the lower legs hanging freely. The distance is measured from the measuring block to the forward edge of the sitting surface. The measurement is necessary in the determination of seat height.

vi. Stature

This is the vertical distance from the floor to vertex of the head with hair pressed down. Subjects stand fully erect with both feet together and the head is orientated in the Frankfurt Plane. Measurements were read from the stadiometer.

vii. Buttock-Popliteal length

The horizontal distance is measured with 90^0 knee flexion from the posterior surface of the buttock to the posterior surface of the knee or popliteal space. The subject sits fully erect with thighs fully supported and sitting surface extending as far as possible into the hollow of the knee, the lower legs hanging freely. The distance is measured from the measuring block to the forward edge of the sitting surface. The buttock-popliteal length is needed to determine the seat depth.

viii. Sitting Hip Breadth

This is the maximum horizontal distance across the hips in the sitting position. The sitting hip breadth is essential to specify the seat width.

ix. Measurement of Body mass

The weight of the passenger was taken using a calibrated balance upon which the passenger stands.

x. Buttock-knee length

The participant sits erect with the feet on the floor at 90^0 knee flexion, arms at the sides and hands resting on thighs. The horizontal distance from the most posterior point on the buttocks to the most anterior point on the knee measured with a stadiometer.

xi. Forearm-Hand length

The occupant sits erect with the upper and lower arms at right angles to one another and the hand stretched out. The distance from the posterior end of the elbow to the longest finger of the hand while the upper arm was at an angle of 90^0 with the lower arm measured with a vernier caliper. The forearm-hand length is the relevant measurement that is necessary to specify the table depth.

xii. Seat depth

The passenger seat depth is the horizontal distance of the sitting surface from the back of the seat, at a point where it is assumed that the buttock begins at the front of the seat. This should be deep enough to ensure that the region behind the knees (popliteal) would not hit the front of the seat.

Generally, the data collected was analysed using descriptive statistics such as means, standard deviations, and fifth, fiftieth and ninety-fifth percentiles using Excel Microsoft Package. The data obtained from the passengers was compared with the relevant dimensions of the seats parameters. Form comparisons of anthropometric measurements and seat feature parameters; factors affecting seat feature design could be identified and measurable solution can be set out through this research output.

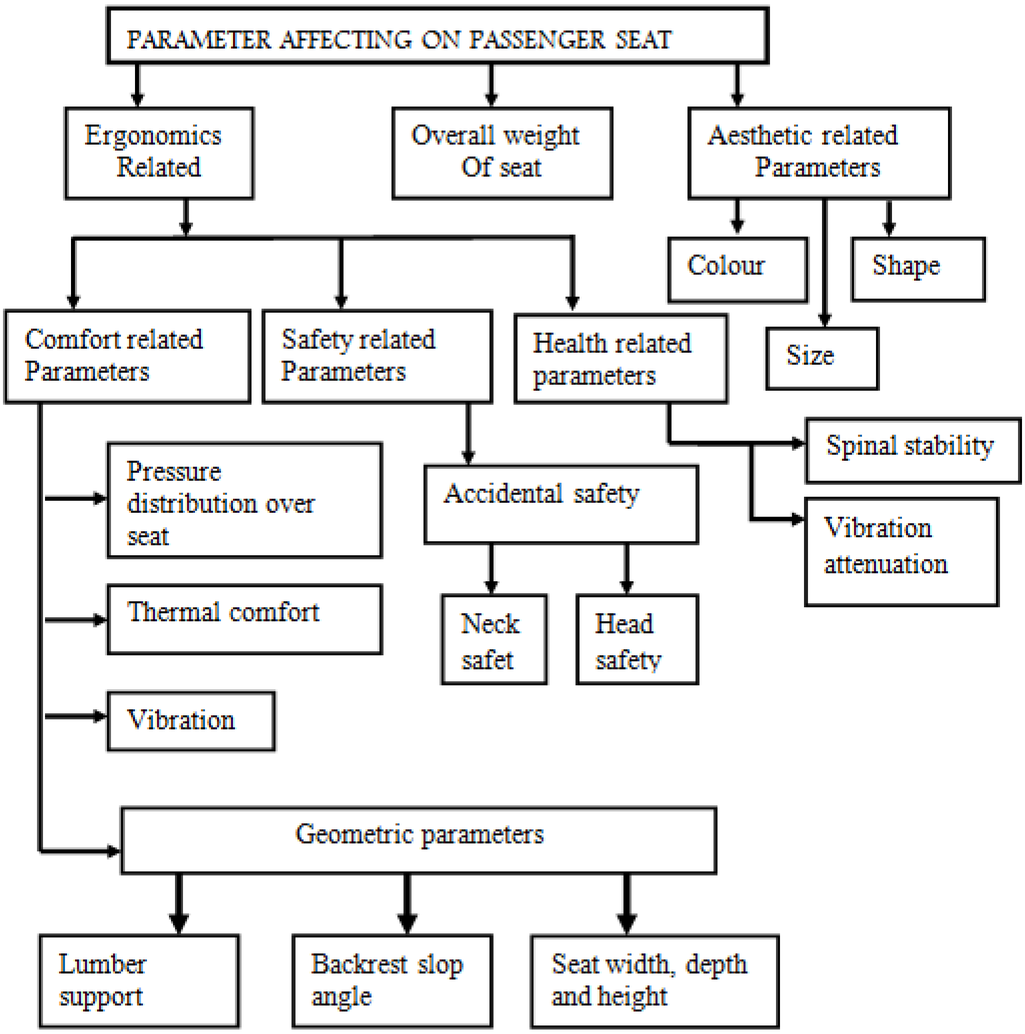


Figure 3. 1 Parameters Affecting Design of passenger Seat

3.5 Measuring Instruments

The measuring instruments used for this study were as follows:

i. Weighing machine floor type (stadiometer), Model-Health Scale ZT-160, Micro field, was used to measure the vertical dimensions such as sitting height, sitting elbow height, sitting shoulder height, knee height, popliteal height and eye height

ii. Vernier Caliper (Range 0-68cm with error 0.1mm) was used to measure the horizontal dimensions such as Buttock-Popliteal Length, Buttock-knee Length and Forearm- Hand Length.

iii. A metal tape was used to measure the seat feature and human dimensions.

3.6 Frame work of the research

In this chapter the line of approach of the study on passenger seat were stated. The first aspect deals with the method, population and sample of the study and the second part provides the tools and techniques employed in the research. The procedure of the study can be stated in frame work activities mentioned in the fig 3.2

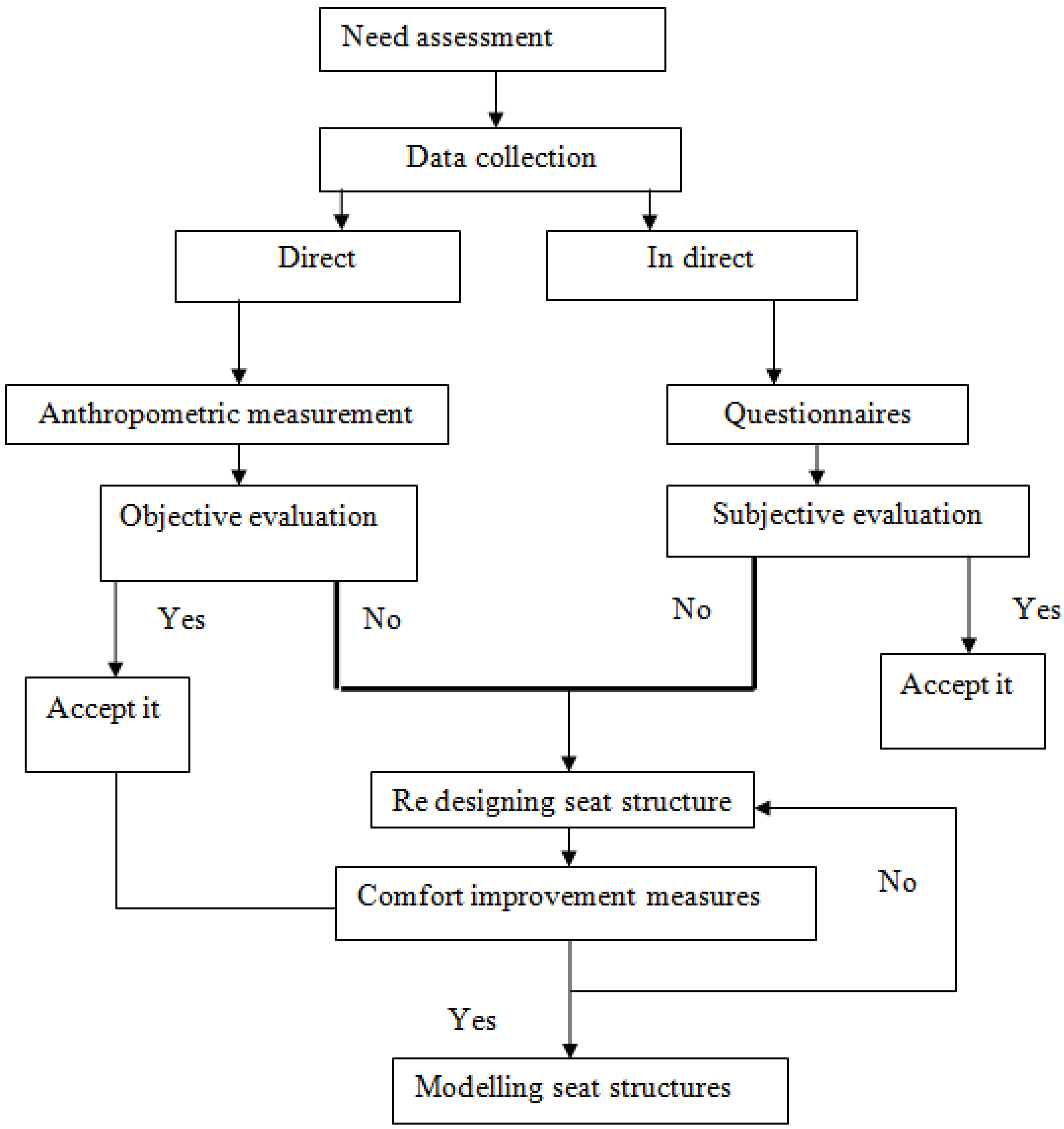


Figure 3. 2 frame work of comfortable passenger seat design.

4 RESULTS AND DISCUSSION

4.1 Statistical Summary of Respondents

There were 240 respondents, with 59% male and 41% female involved in this survey. These respondents can represent the population of studied area and they are taken as sample. Based on information obtained from sample it is possible to draw inference. Describing properties of the sample data, which is called descriptive statistics, and drawing conclusions about a population of interest from information extracted from a sample, which is called inferential statistics. Computing the single number to summarize the data was an operation of descriptive statistics; using it to make a statement about the population was an operation of inferential statistics[1].to determine this single data, the average value of sample was representing the population. This can be determined by measure of central location of data i.e. mean, median and mode.

Mean is the measure of central location which is similar to the usual term "average of data's" familiar to everyone. In the formula in the following definition we introduce the standard summation notation Σ, where Σ is the capital Greek letter sigma. In general, the notation Σ followed by a second mathematical symbol means to add up all the values that the second symbol can take in the context of the problem.

It can be determined from sample data or frequency function as illustrated in the following equations.

$$mean\ (\overline{x}) = \frac{\sum x}{n} \quad \text{..Equation 4.1}$$

Where x= sample of data's

n= number of samples

When the given data can be expressed in terms of frequency data table the mean value of sample can determined as

$$mean\ (\overline{x}) = \frac{\sum_{i=1}^{n} f_i * x_i}{\sum_{i=1}^{n} f_i} \quad \text{.......................... Equation 4.2}$$

Where x= sample of data's

f=frequencies of data's

Just as we have attached numbers to a data set to locate its center or its average value, we now wish to associate to each data set numbers that measure quantitatively how the data either scatter away from the center or cluster close to it. These quantities are called measures of variability of data; the first measure of variability that we discuss is the simplest range of data set. The range of a data set is the number R defined by the formula

$$R = X_{max} - X_{min} \text{ ....equation 4.3}$$

Where $X_{max}$is the largest measurement in the data set and

$X_{min}$is the smallest measurement in the data set.

The range is a measure of variability because it indicates the size of the interval over which the data points are distributed. A smaller range indicates less variability (less dispersion) among the data, whereas a larger range indicates the opposite. The other two measures of variability are Variance and the Standard Deviation which depends on whether the data set is just a sample drawn from a much larger population or is the whole population itself.

The sample variance of a set of *n* sample data is the number S^2 defined by the formula

$$S^2 = \frac{\sum (x-\overline{x})^2}{n-1} \text{ ....Equation 4.4}$$

Which is by algebra is equivalent to the formula

$$S^2 = \frac{\sum x^2 - \frac{1}{n}(\sum x)^2}{n-1} \text{ ....Equation 4.5}$$

The sample standard deviation of set of *n* sample data is the square root of the sample variance, hence is the number *S* given by formula

$$S = \sqrt{\frac{\sum (x-\overline{x})^2}{n-1}} = \sqrt{\frac{\sum x^2 - \frac{1}{n}(\sum x)^2}{n-1}} \text{ ....Equation 4.6}$$

If the given data is expressed as frequencies data table the variance and standard deviation of the data can be evaluated (computed) mathematically by using the following formulas

$$s^2 = \frac{n[\sum(f*x^2)] - [\sum(f*x)]^2}{n(n-1)} \text{ ....equation 4.7}$$

$$s = \sqrt{\frac{n[\sum(f*x^2)] - [\sum(f*x)]^2}{n(n-1)}} \text{ ....equation 4.8}$$

The demographic characteristics of the participants/inquired populations are depicted based on the number of respondents. During the campaign the age, weight and height of participants have been in different measuring value. This variability of participants can be analysed by determining mean value of statistical data. In order to determine the average size of studying population we have to determine range of statistical sample data set, mean value of statistical data set and standard deviation of sample data set. General personal information of the respondents described by data frequency table 4.1 can be computed for selecting the representative value of the populations.

Table 4. 1 Frequency data table of age of respondents.

Age range of respondents(years)	data mid value(x)	number of respondents	Frequencies (f) in percentage (%)
less than 15	10	10	4.166666667
15-25	20	56	23.33333333
26-34	30	75	31.25
35-45	40	61	25.41666667
46-54	50	28	11.66666667
55-65	60	6	2.5
65-74	70	3	1.25
75-85	80	1	0.416666667
above 85	90	0	0

The mean value and standard deviation of age of sample of population can be determined by using equation 4.2 and 4.8 respectively

$$mean\ (\overline{x}) = \frac{\sum_{i=1}^{n} f_i * x_i}{\sum_{i=1}^{n} f_i}$$

$$mean\ (\overline{x}) = \frac{(4.166*10)+(23.33*20)+(31.25*30)+(25.416*40)+(11.666*50)+(2.5*60)+(1.25*70)+(0.4166*80)}{4.166+23.33+31.25+25.416+11.666+2.5+1.25+0.4166}$$

Mean $(\overline{x}) \approx 33.16\ year$

Which indicate the average value of age of respondent can be studied in the range of 26 to 34 years old.

Standard deviation $(s) = \sqrt{\frac{n[\sum(f*x^2)]-[\sum(f*x)]^2}{n(n-1)}}$

S= 12.51

Table 4. 2 frequency data table of weight of respondents.

GRADE of weight range	data mid value(x)	number of respondent	Frequencies(f) in percentage
25- 35	30	22	9.166666667
36-44	40	53	22.08333333
45-55	50	26	10.83333333
55-65	60	30	12.5
66-74	70	38	15.83333333
75-85	80	52	21.66666667
86-94	90	19	7.916666667
above 95	100	0	0

The mean value and standard deviation of weight of sample of population can be determined by using equation 4.2 and 4.7 respectively

$$mean\ (\overline{x}) = \frac{\sum_{i=1}^{n} f_i * x_i}{\sum_{i=1}^{n} f_i}$$

Mean $(\overline{x}) \approx 60.04\ kg$

Which indicate the average value of weight of respondent can be studied in the range of 55 to 65 kg.

Standard deviation $(s) = \sqrt{\frac{n[\sum(f*x^2)]-[\sum(f*x)]^2}{n(n-1)}}$

S=18.94

Table 4. 3 frequencies data table of height of respondents.

GRADE of height range(cm)	data mid value(cm)	number of respondents		Frequencies in percentage (%)
		male	female	
140-150	145	2	6	3.333333333
150-160	155	9	18	11.25
160-170	165	38	49	36.25
170-180	175	93	17	45.83333333
180-190	185	8	0	3.333333333

The mean value and standard deviation of height of sample of population can be determined by using equation 4.2 and 4.7 respectively

$$mean\ (\overline{x}) = \frac{\sum_{i=1}^{n} f_i * x_i}{\sum_{i=1}^{n} f_i}$$

Mean $(\overline{x}) \approx 168\ cm$

Which indicate the average value of age of respondent can be studied in the range of 160 to 170 cm.

Standard deviation $(SD) = \sqrt{\frac{n[\sum(f*x^2)]-[\sum(f*x)]^2}{n(n-1)}}$

SD = 8.51

From frequencies data table above the general summary of demographic characteristics of inquired populations is depicted in table 4.2. Based on number of respondents during the campaign; the age of participants range from 10 to 85years old. Minimum age is 10 and maximum age is 77 with a mean value of falling under the range of 26 to 34 years old. Weight and height are varied from 25 to 95 kg and from 140 to 195cm respectively. The mean value of the sample of population 60 kg and 170 cm for weight and height respectively which represent the average population size and weight of Adama peoples.

Table 4. 4 general personal information of respondents

	Age (years)	Height (cm)	Weight (kg)
Minimum	15	130	28
Maximum	75	185	94
Mean	33	168	60
Standard deviation	12.51	8.51	18.94

4.2 Subjective Evaluation-Results and Discussion

4.2.1 Evaluation of seat features

Subjective analysis is the act of an individual describing their own experiences following introspection on physical or psychological effects under consideration. The method of subjective analysis also encompasses obtaining information from a subject's own recollection, such as verbal case histories, or experiences in the individual's daily routine. The concept of comfort is extremely subjective in nature as it varies according to subject’s perceptions about comfort and discomfort. Every individual has their own personal parameters to define their endurance for pain and comfort zone while travelling by objective vehicle. Subjective analysis is based on these personal opinions, interpretations, personalized point-of-view, emotions and judgment influenced by individual’s experiences. The comfort sensation for a passenger can be defined in many ways depending on various studies conducted in relation to seating dynamics.

Some of them are as follows:

- ✓ A feeling of relief or controlled well-being [34];
- ✓ Affording or enjoying physical comfort [34];
- ✓ Some state of well-being or being at ease [35];
- ✓ A state of conscious well-being [36];
- ✓ Occupant’s empirical perception of being at ease [37];
- ✓ Absence of discomfort [38];

The subjective analysis helps by providing a basic assessment of the customers’ need and requirements. This is helpful as the designers are provided with constraints that they have to adhere early in the designing process. This is beneficial as it improves the credibility of the product in the market. Giving consideration to the customer suggestion and feedback improves the product's demand and also comfort level.

The subjective assessment method is carried out in various ways. The analysis techniques may vary from open-ended interviews to formal questionnaires consisting of specific, response-constrained questions, the latter being used in quantitative and qualitative analyses. It also includes evidential, controlled methods of experimentation which yield objective information on processes that are objectively observed by the experimenter. The data obtained is then subjected to analysis including the subject's own opinion on a particular task and allows study of effects outside of the scope of controlled clinical analysis.

The major disadvantage of applying this assessment method is the time factor and the large inter-subject variability regarding comfort. Accurate results require a large population sample. In many of the studies, subjective measures are used along with objective measures so as to correlate the ratings along with measurable parameters. This enables to set the design target values with which a known level of comfort has been associated.

4.2.2 **Factors Considered in Subjective Analysis**

The protocols in subjective analysis mostly it require highly well thought out questionnaires that guide occupants to assign values for discomfort at the specific regions of the seat. The seat should provide optimum back-support, headrest and thigh-support. Shape, size and cushion compressibility also enhances the comfort level of the passengers.

The analysis of seat parameters can be determined by using various criteria; mostly based upon the data collected by subjective measurements in this study. These criteria contain various elements or parameters in this study and are believed to play a key role in the passenger's judgment and decision making as a whole in the selection of the desirable sitting posture. The detection and identification of these parameters which are linked together like a chain are essential for the designing of the passenger seat.

4.2.3 **Survey Assessment for Car Seats**

In the assessment procedure, it requires participation from a group of personnel with either varied interests and aspects or similar traits to each other. Numerous subjective rating strategies have been explored to establish the most appropriate scheme for designing and evaluating car seats. Participants (n=240) aged in the range of 10-85years having journey in their day today activities were interviewed. Seats of varied families of cars were utilized for the survey process and the ratings for each was obtained based on their features appeal to the passengers as well as separate measures of comfort and discomfort of the whole body and the local body parts. Survey questionnaire was based on how the car features affect seat comfort for each of the passengers. The questionnaire data set is classified under two categories:

(i) Assessment of seat features

(ii) Assessment of anthropometric measurement for pain perception in body parts of passengers

4.2.3.1 ***Assessment of Seat Features***

The questionnaire for obtaining ratings on the seat features of the various car models has been featured in Appendix 1. This feedback was obtained by using an open-end survey questionnaire from the consumers of 40 different minibus taxis. Their responses were recorded and weight age was added to their ratings. The questionnaire was formulated putting stress on the clarity of the questions for the layman whose manufacture passenger seat in their local area

In this study the assessment was formulated by providing grade for different features of the seat in order to generalize the comfort and discomfort of locally manufactured passenger seat.

Another aim of the study considered the identification of comfort/discomfort assessments which contained the questions on passenger seat components. The comfort assessments of these components were supplemented by the final judgements of the passengers and regarded as the overall feeling of comfort.

The preliminary analyses of comfort/discomfort assessments indicated that in general the comfort index increased gradually as the passengers received relatively more opportunities for component adjustments. These phenomena were lead to design adjustable seat feature to accommodate the need of different peoples.

Since the assessment of comfort/discomfort is relatively complex and sometimes very difficult to identify, especially in a travelling scenario consisting of many varieties of physical as well as mental activities, the following argument should be given in order to clarify in more detail the aspects surrounding these concepts.

As mentioned earlier, there is a vast amount of commentary and discussions available in the literature regarding the assessment of comfort/discomfort. Relevant parts of these comments were reviewed in the literature study in Chapter 2. Combining these arguments with the findings in the present research work through measurements, observations, unstructured interviews, etc. may suggest schematic structures regarding these concepts which are presented in the following figures.

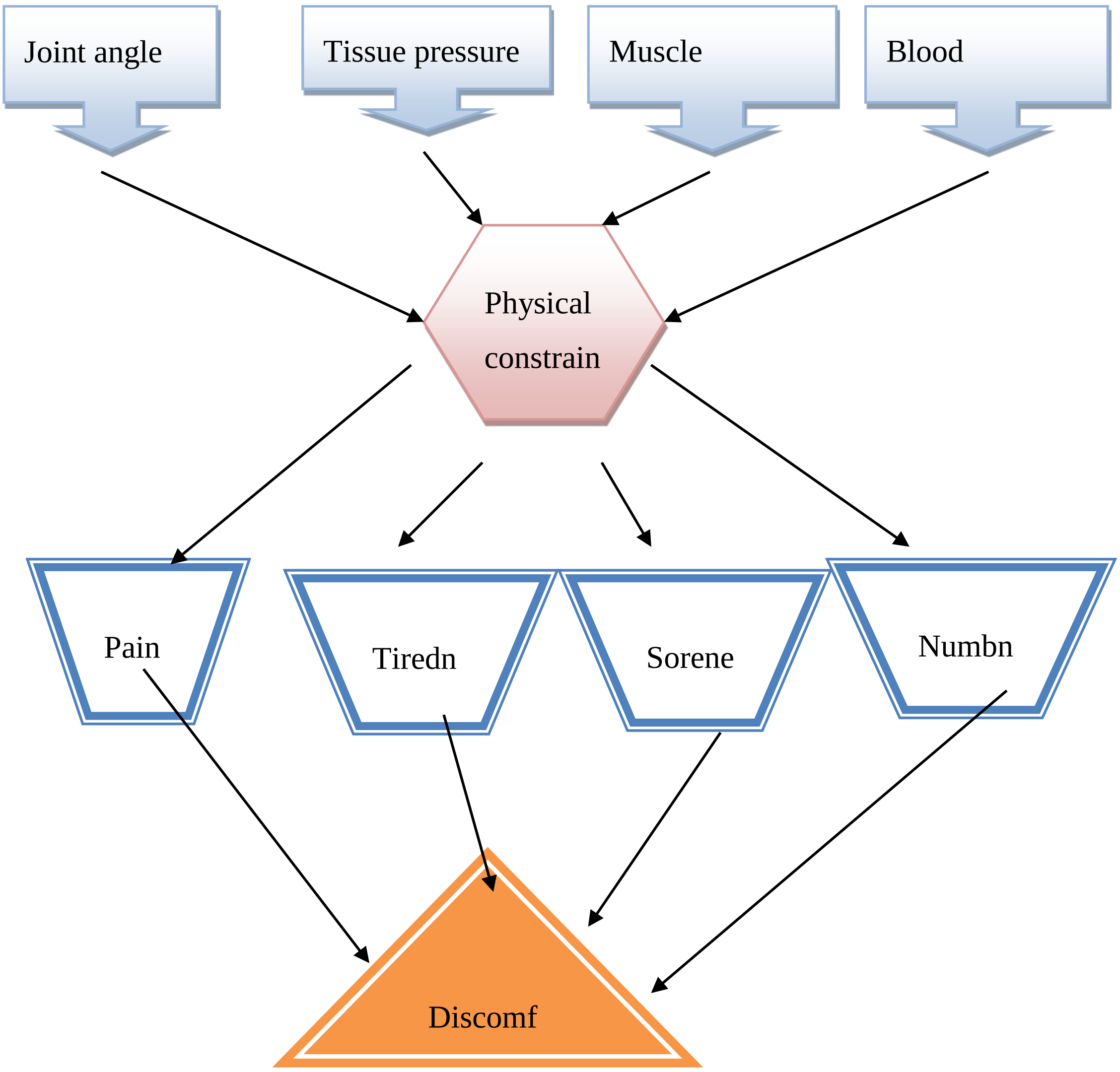


Figure 4. 1 Feelings of discomfort /comfort associated with pain, Tiredness, soreness and numbness imposed by physical constraints.

As can be seen in this figure, feelings of discomfort in a sitting task are associated with pain, tiredness, soreness and numbness resulting from physical constraints. Physical constraints play a link characteristic between these symptoms and biomechanical as well as physiological activities such as joint angles, tissue pressure, muscle contractions and blood pressure. The feeling of discomfort increases as the time of the workday proceeds.

This means that the exposure to fatigue in the form of pain, tiredness and other symptoms increases gradually. Therefore, it is essential to select a proper sitting posture in order to avoid or at least minimize the fatigue. This requires designers to provide proper seat feature and structure for the occupant or users.

The assessment of comfort in sitting on a seat, on the other hand, may be considered to be based on feelings of well-being and the aesthetic (plush and luxurious) impression of the seat. The assessment of comfort regarding the circumstances of the present study is judged by considering some specific characteristics and facilities of the seating device. These characteristics encompass either manual or power seat adjusters such as reclining seat backs, seat track travel, arm rests, lumbar supports and head restraints.

The illustration of this phenomenon is proposed by following figure.

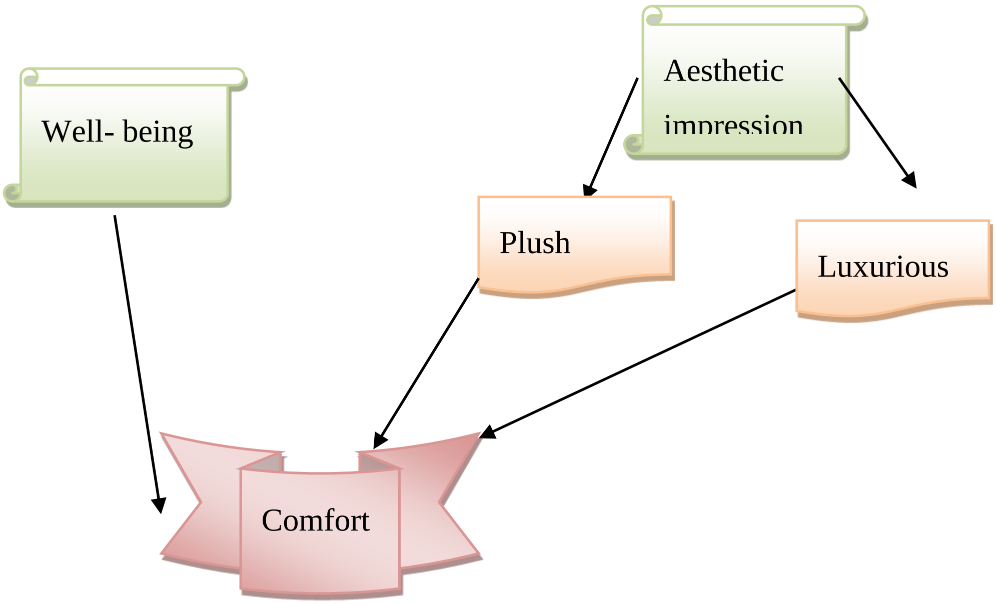


Figure 4. 2 Assessment of comfort in sitting on a seat based on the feelings of well-being and the aesthetic (plushness and luxurious).

The assessment of some selected parameter of analyse was stated as follow.

4.2.3.2 *Seat height feature assessment*

Seat height is the measured value of the seat from the floor of the vehicle to seat pan surfaces. Or the vertical distance measured from the floor to the midpoint of the front edge of the seat. The seat height of studied vehicle can be equipped with different height in the same model of vehicle. This is the result of manufacturing passenger seat without any reference or specification of vehicle ergonomic which result in discomfort of the users. These activities can bring different suggestion ideas in the assessment of the features from person to person.

Depending up on that the feature height assessment could be done by giving some grades rating 1to 5 which is indicating the length of that seat was compatible with the suggested person or not. The assessment of this feature is mentioned in data frequency table.

4.2.3.3 *Seat width feature assessment*

Seat width is the length measurement of the seat pan width or the distance measured horizontally between the lateral edges of the seat. From the assessment of this feature, local manufactured seat of studied vehicle can be equipped with different measured value which is not considering the specification of the vehicles. This feature can be evaluated according to the prepared open idea questionnaires each individuals participating in the assessment can give their grade for seat width according to their anthropometrical dimensions of their physical features. The assessment can be evaluated by rating its width grade from 1 to 5 which indicates the feeling of participant's width is too narrow or too wide

4.2.3.4 *Seat depth feature assessment*

Seat depth is the side length of seat or the horizontal distance measured from the front edge of the sitting surface of the seat to the back edge. Similar to the seat feature mentioned above this dimension of the seat also manufactured without consideration of human anthropometric measurement of popliteal lengths of individuals which leads o uncomfortable seat features.

4.2.3.5 *Seat Backrest width feature assessment*

Backrest is the feature of the seat which the passengers can incline their bodies to rest their spine or to rest back side of their bodies when they want to take some recreation and also it used to passengers as a support while the vehicle can accelerate. Back rest contains padding for the low back area that is curved to fit the shape of the back of the user. It must be of adjustable height and angle with locking mechanism, wide and high enough to fit the back of the user. It should be noted that, when seated, the back tends to lose some of its natural curvature. An effective lumber support of a chair is designed to help maintain the natural curvature of the spine when sitting. It is important to provide appropriate support for the spine so that there is no discomfort or pain.

4.2.3.6 *Seat Backrest height feature assessment*

Backrest height is the vertical distance measured from the upper edge of the backrest to the horizontal sitting surface. The height of back rest is designed by having some engineering consideration of anthropometrical data of the peoples for integrating headrest with it. This features sometimes it was built with headrest feature in some vehicles.

4.2.3.7 *Assessment of anthropometric Pain Perception in Body Parts*

For obtaining the ratings on the pain concentration in various affected regions of the human body while travelling for long hours, but in this study there is no high pain perception while travelling intercity transportation with concerning that the questionnaire helps to accurately rate the pain they would feel in their journey gives a more accurate data.

From this assessment the seat feature analysis for subjective evaluation was summarised depending up on their rating value from the respondents. This pain perception were evaluated using rating scale of 5 points numbered as 1 to 5; value of 3 is represent neutral value which is just nice. With value 1 and 5 represent both low and high ends which are far away from just nice. Treating the scale as continuous scale, mean standard deviation value for each seat feature evaluation is depicted from seat evaluation of the respondent's data sheet.

Table 4. 5 seat feature evaluation result for subjective analysis

1	2	3	4	5
Seat Dimensions				
Number Of Respondents				
Frequency (%)				
Seat Heights				
Very Short	Short	Just Nice	Long	Very Long
2	41	175	22	0
0.83	17.08	72.92	9.17	0
Seat Width				
Too Narrow	Narrow	Just Nice	Wide	Too Wide
0	43	161	28	8
0	17.91666667	67.08333333	11.66666667	3.333333333
Seat Depth				
Very Short	Short	Just Nice	Long	Very Long
0	4	108	121	7
0	1.666666667	45	50.41666667	2.916666667
Backrest Height				

Too Short	Short	Just Nice	Long	Too Long
0	6	163	51	20
0	2.5	67.91666667	21.25	8.333333333
Backrest Width				
Too Narrow	Narrow	Just Nice	Wide	Very Wide
0	43	161	28	8
0	17.91666667	67.08333333	11.66666667	3.333333333
Head Rest				
Very Short	Short	Just Nice	Long	Very Long
41	131	26	33	9
17.08333333	54.58333333	10.83333333	13.75	3.75
Gap Between Seats				
Too Narrow	Narrow	Just Nice	Wide	Too Wide
167	49	24	0	0
69.58333333	20.41666667	10	0	0
Inclination Of Backrest				
Too Small	Small	Just Nice	Large	Too Large
63	72	84	21	0
26.25	30	35	8.75	0
Stability				
Too Shaky	Shaky	Just Nice	Stable	Too Stable
0	16	119	81	24
0	6.666666667	49.58333333	33.75	10
Buttock Comfort				
Too Uncomfortable	Uncomfortable	Just Nice	Comfortable	Too Comfortable
7	86	98	49	0
2.916666667	35.83333333	40.83333333	20.41666667	0
Thigh Comfort				
Too Uncomfortable	Uncomfortable	Just Nice	Comfortable	Too Comfortable
8	85	103	44	0

3.333333333	35.41666667	42.91666667	18.33333333	0
Head Rest				
Too Uncomfortable	Uncomfortable	Just Nice	Comfortable	Too Comfortable
79	96	52	13	0
32.91666667	40	21.66666667	5.416666667	0
Overall Evaluation				
Too Uncomfortable	Uncomfortable	Just Nice	Comfortable	Too Comfortable
66	153	21	0	0
27.5	63.75	8.75	0	0

As each seat feature has its own independent value representation the mean value was calculated to determine the average concept perception of population.

Evaluations of seat height value which 1 represent the seat to be too short and the value 5 indicate too long from the reference frame. And the rest value indicate the perception of the people for the given value which is the average value of respondent idea is the representative value as number 3 which is just nice conclusion prom them. From this data analysis it is possible to express each seat feature analysis to express in graphical representation of perception of the respondents.

From sample data analysis of seat height features; it was found that most respondents did not complain on the seat height features. the result of this feature indicate that it is fall under just nice rating value which takes 72.92% of the respondent can agree with this rating value. The height of the seat can have short in context of their age and anthropometric measurements of the sample of the population indicate that as it was short with rating value 17.08% of the respondents and some of them respond as it was long for them in rating value of 9.17% which indicate that the height of the seat were not any pain perception for the respondents accordingly but it can be avail as it is very short for 0.8% of rating value which is described in figure 4.3

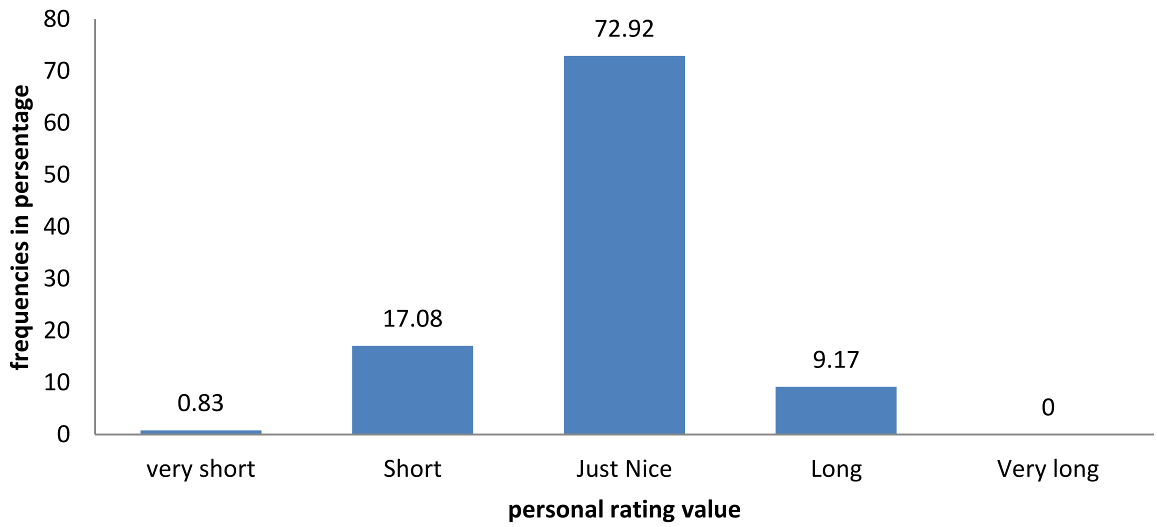


Figure 4. 3 seat height feature evaluation result of personal perception

From sample data analysis of seat width features; it was found that most respondents did not complain as similar to seat height on the seat width features. the result of this feature indicate that it is fall under just nice rating value which takes 67.08% of the respondent can agree with this rating value. The width of the seat can be narrow for 17.92% of respondents that wide thigh and it is wide for 11.67% of the respondents with slim body size. Like this there are 3.33% of the respondent can express as it is very wide which indicate that the width of the seat is not such much problem in their daily usage of the vehicles. The result of seat width feature analysis of with personal rating value of the respondents can be summarised and presented in figure 4.4

Figure 4. 4 seat width feature evaluation result of personal perception

The seat depth evaluation of passenger seat in the studied vehicle can be fall under good personal evaluation which is 45% of the sample population were rating as just nice and 50% of them can agree as it was long which is there is no problem in seat width features. Those their anthropometric measurement of them was long peoples also agree as it was short with 1.67% of the sample population.

Generally it was found that the other seat feature evaluation most respondents did complain much on their evaluation and it is summarised in figure 4.5

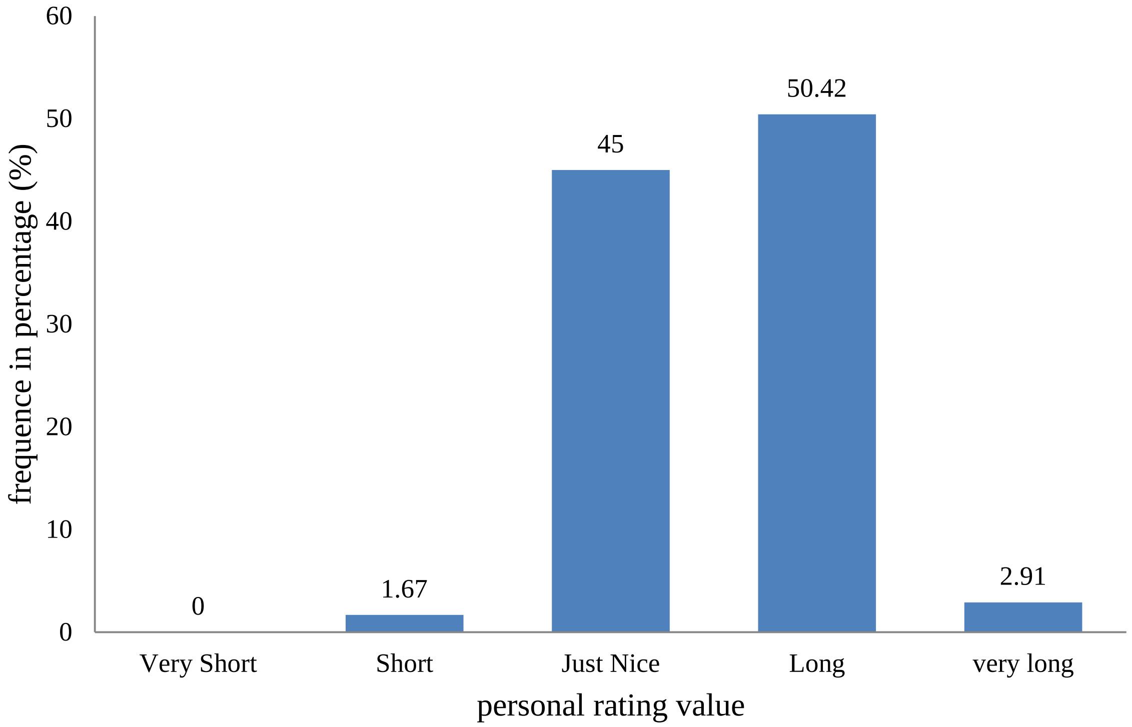


Figure 4. 5 seat depth feature evaluation result of personal perception

Figure 4. 6 Seat backrest height feature evaluation result of personal perception

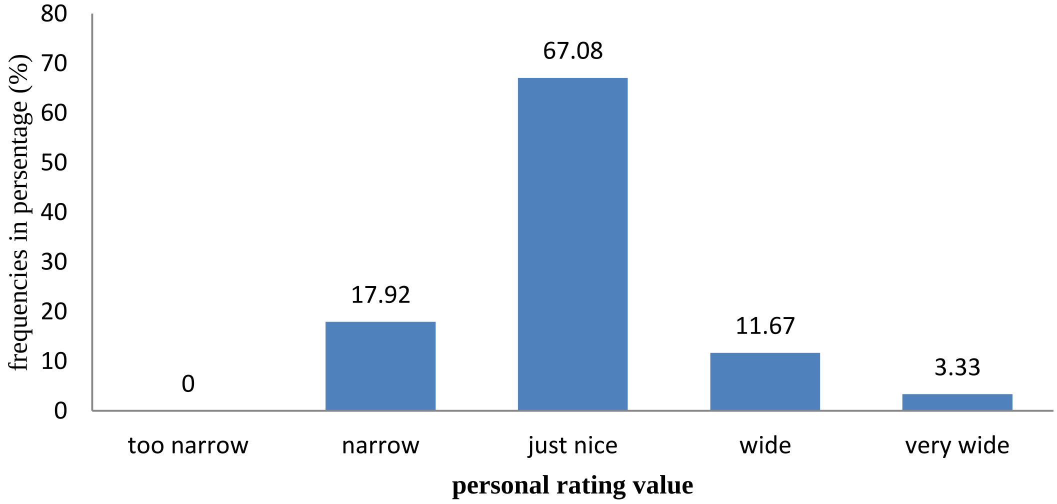


Figure 4. 7 backrest feature evaluation result of personal perception

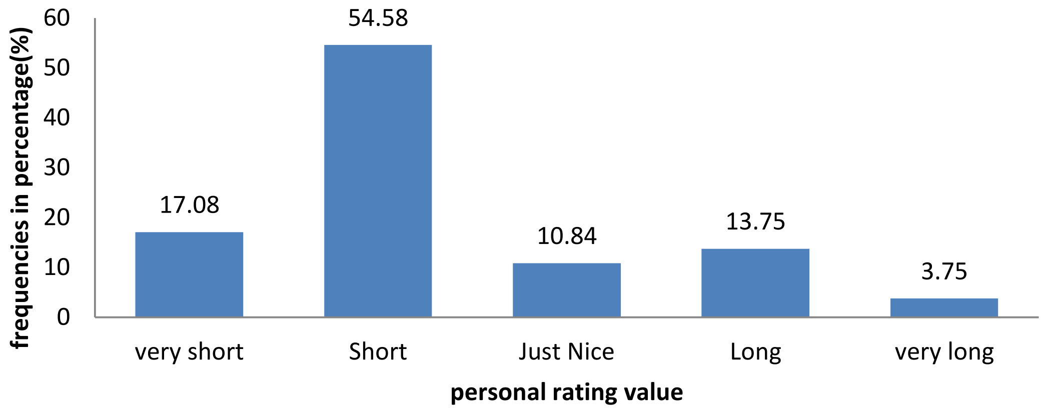


Figure 4. 8 head rest feature evaluation result of personal perception

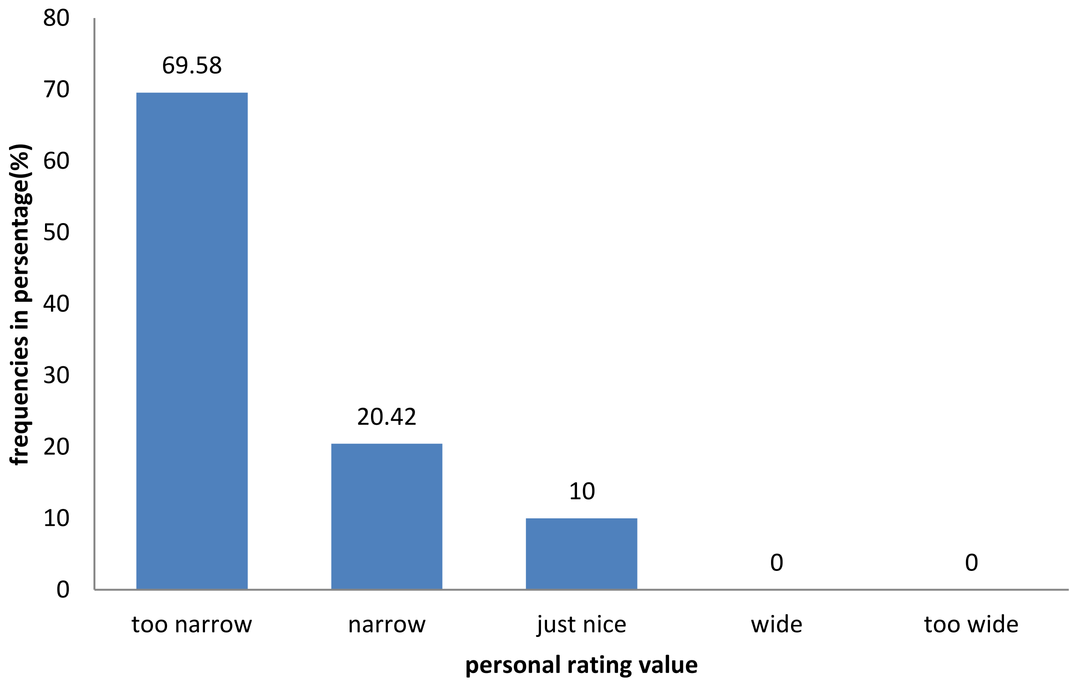


Figure 4. 9 gap between seat feature evaluation result of personal perception

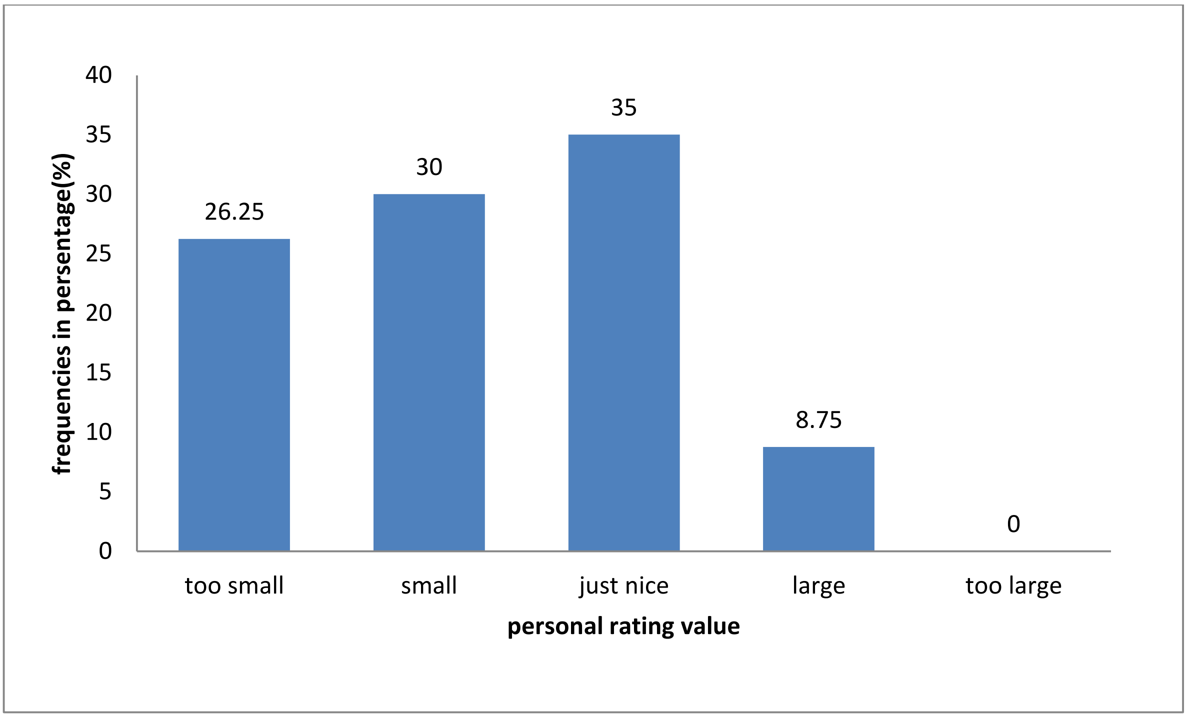


Figure 4. 10 inclination of backrest feature evaluation result of personal perception

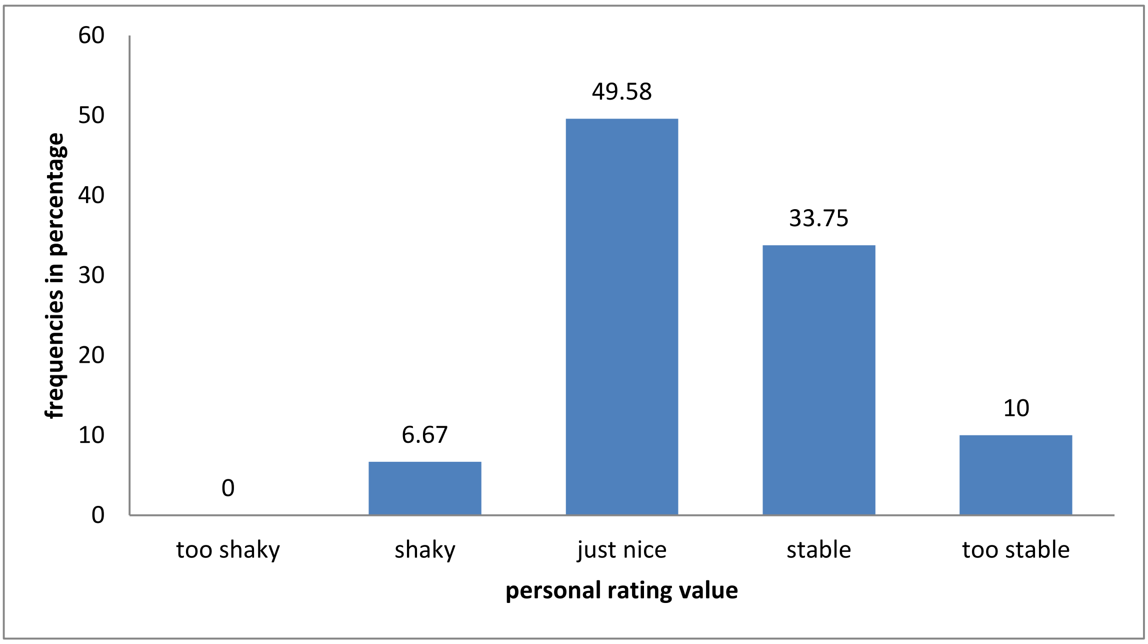


Figure 4. 11 stability feature evaluation result of personal perception

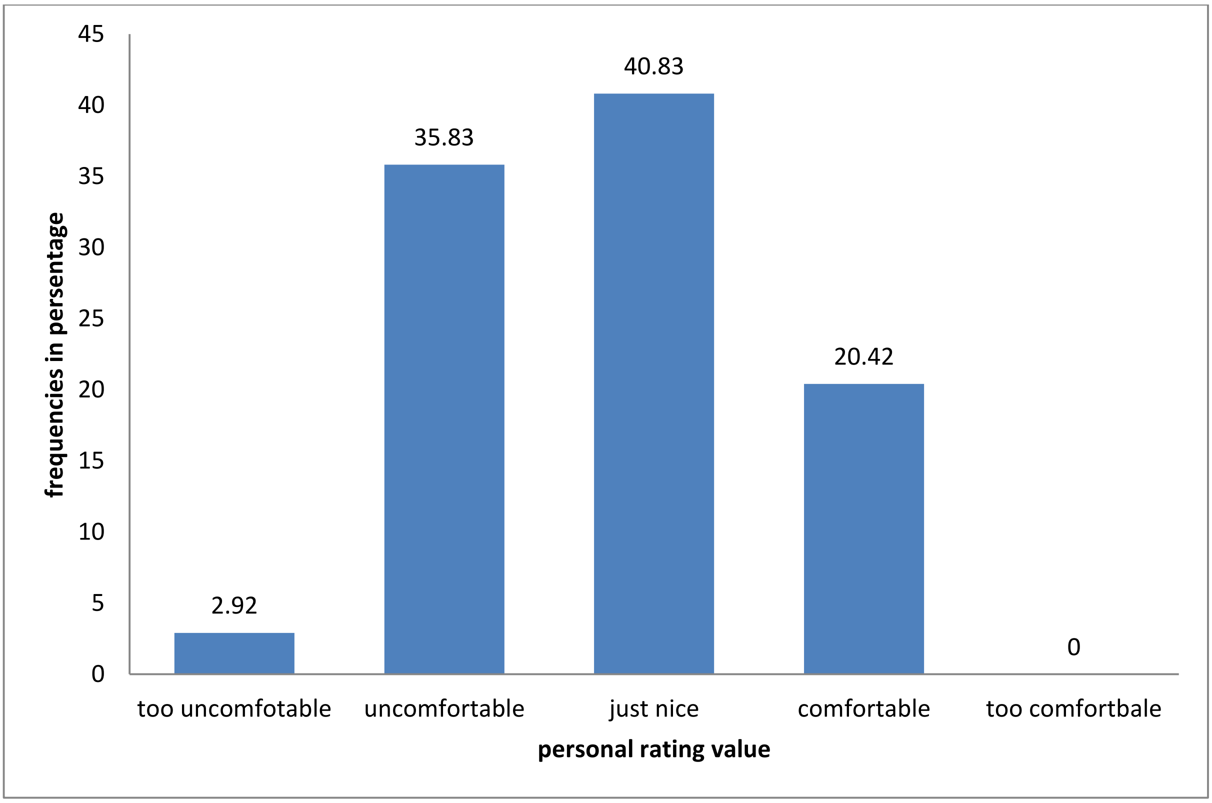


Figure 4. 12 buttock comfort feature evaluation result of personal perception

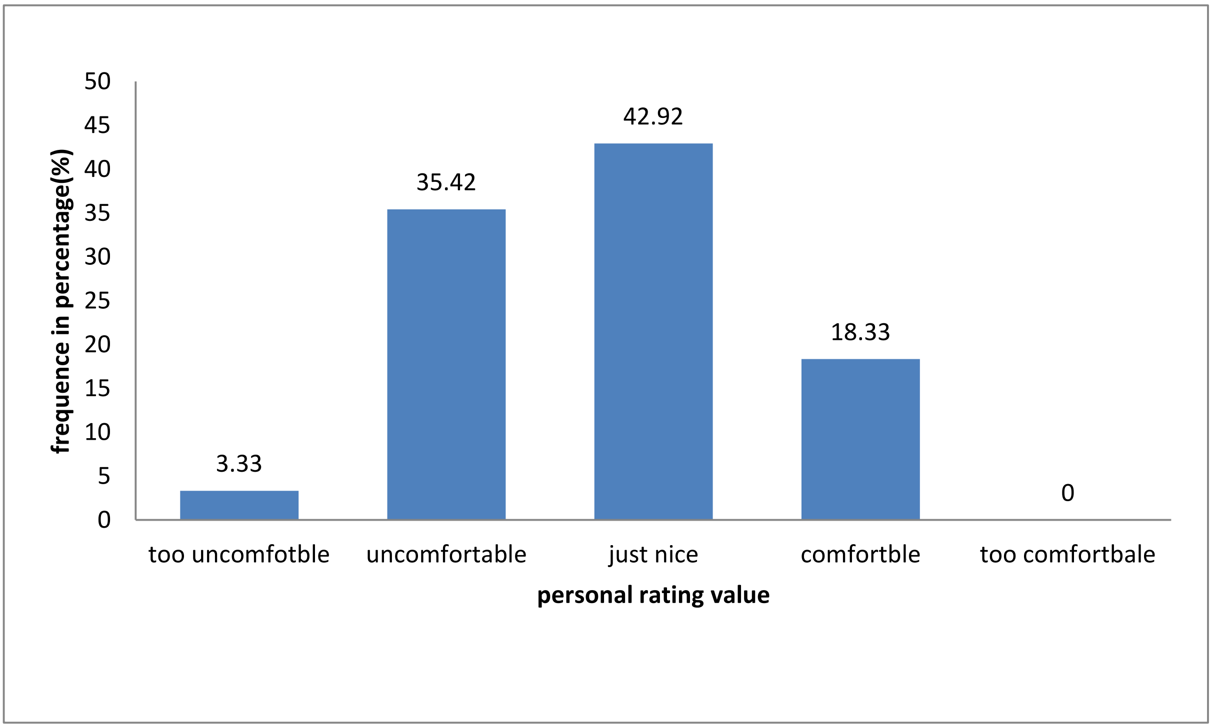


Figure 4. 13 thigh comfort feature evaluation result of personal perception

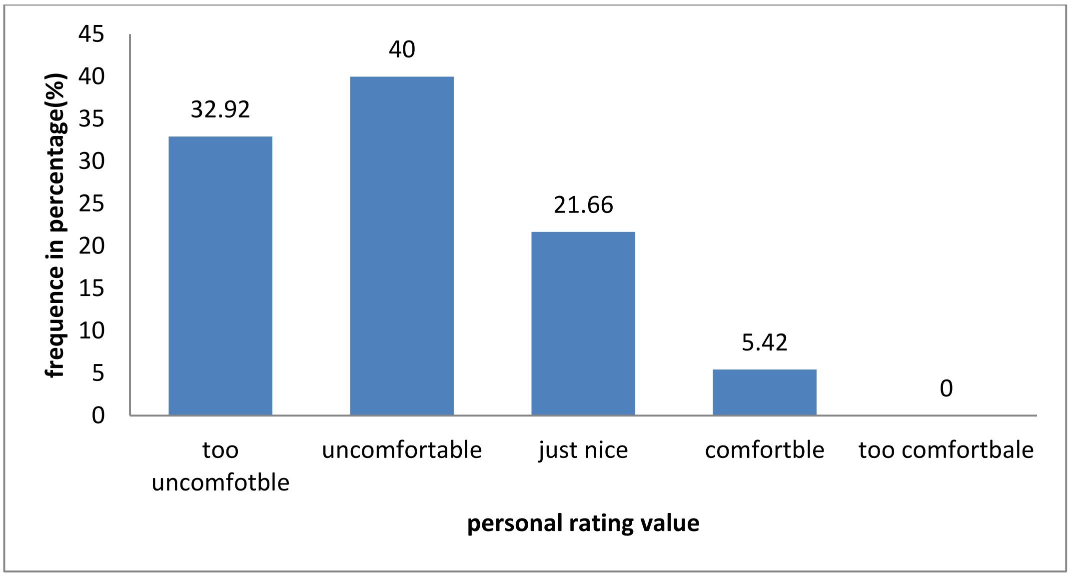


Figure 4. 14 head rest feature evaluation result of personal perception

4.2.4 **Overall Evaluation of Seat Features**

There was one part in the questionnaire which required the respondents to rate their overall evaluation towards the passenger seating they were sitting minibuses. Based on Figure 4.4, it is clearly revealed that 8.75% of the respondents rated overall evaluation of their ride comfort as just nice and no one rated their ride comfort as comfortable and no one rated the ride comfort as very comfortable. On the other hand, 27.5% of the respondents were not satisfied with their ride comfort and rated it as very uncomfortable and 63.75% rated their ride comfort as uncomfortable.

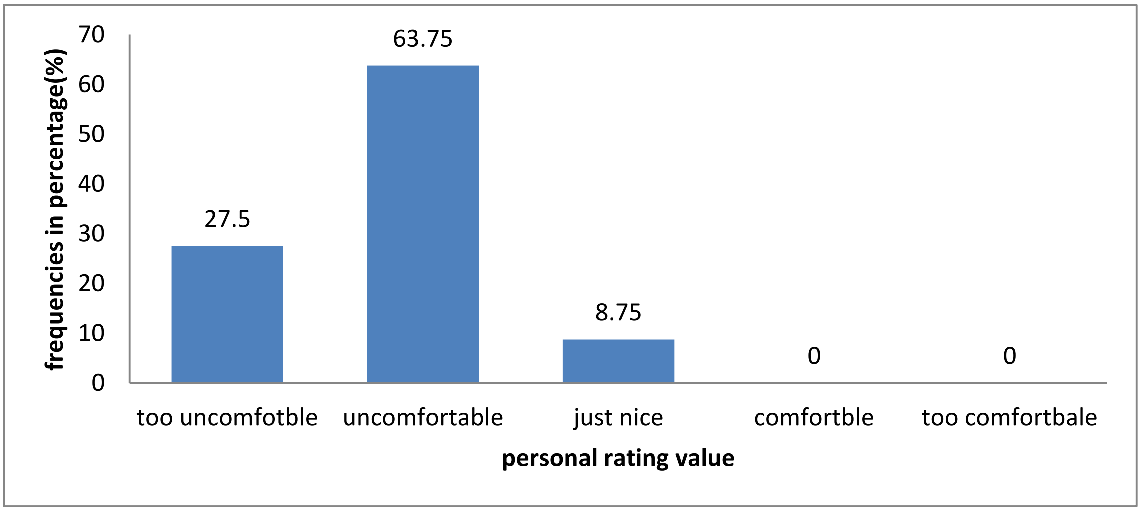


Figure 4. 15 overall evaluation of passenger seat

4.2.5 **Result of Evaluation of Minibus Seat features**

Minibus seat features were evaluated using a rating scale of 5 points numbered as 1 to 5; value of 3 represents neutral value, which is 'just nice' value, with value of 1 and 5 represent both low and high ends which are far away from 'just nice'. Mean and standard Deviation (SD) value for each seat dimensions' evaluation was calculated by using equation 4.2 and equation 4.7 by using frequencies data Table 4.5 respectively. The general evaluation of seat features depicted as in Table 4.6

Table 4. 6 mean and standard deviation value for seat feature evaluation

seat dimension	mean (n)	standard deviation (SD)
seat height	2.9043	0.537
seat width	3.004167	0.6584
seat depth	3.54583	0.5856
backrest height	3.354167	0.6707
backrest width	3.004167	0.6584
gap between seat	1.404167	0.66727
head rest height	2.325	1.0353
inclination of back rest	2.2625	0.95
stability	3.470833	0.767
buttock comfort	2.7875	0.8
thigh comfort	2.7625	0.7878
head rest comfort	1.995833	1.4127
head rest	2.325	1.0353
overall evaluation	1.8125	1.3463

As shown in table 4.4 mean value of evaluation on each seat feature is ranging from 1.404 (gap between seat) to 3.5 (backrest height). Mean value below 2.5 shows that the mentioned seat features was less than just nice in this category, except headrest height and inclination of backrest which are slightly more than 2.5.overall, no extreme mean value or larger standard deviation was not shown in this evaluation, showing that the probability of 5 point scale was not fully used by most of respondents. As each seat feature has its own independent value representation, mean value as depicted above corresponds to this independent value. For example, evaluation of seat height; value 1 represents the seat height to be too low and value 5 represents the seat height to be too long for respondents. While evaluation of seat width; value 1 represents the seat width to be too narrow and value 5 represents the seat width to be too wide for respondents.

It was found that most respondents did not complain much on their seat dimensions. Some of the seat dimensions were rated as 'just nice' such as seat height (72.92% rated their seat height as 'just nice'), seat width (67.08% rated their seat width as 'just nice'), back rest height (679% rated their back rest height as 'just nice') and seat depth (50.42%rated seat depth as 'just nice'). However, some of the seat dimensions (headrest height, inclination of backrest and gap between seats) are rated below 'just nice'. This shows that the overall size of the passenger seats of minibus nowadays is not suitable for the passengers. Summary of respondents' rating on every seat dimension is depicted in Table 4.3.

4.3 Objective Evaluation-Results and Discussion

In objective evaluation the compatibility of the existing passenger seat with the respondents for those selected from peoples as a sample is evaluated weather they are fitting ergonomically in acceptable or not acceptable condition. This can be evaluated by taking measurements of the seat parameter with the related compatible dimensions of the anthropometric measurements of the peoples and checking that weather in the recommended range. To understands how to test and to judge whether a sample fits a particular population well. The main objective of evaluation of passenger seat is whether it is fitting to the population of selected sample or ergonomically fitting to appropriate body's part of the users. From this analysis the locally manufactured passenger seat it is possible to decide to design new passenger seat which is designed by considering ergonomically with proper average value of anthropometric dimensions of the population.

4.3.1 Measurement of Existing Locally Manufactured Passenger Seats

For the objective evaluation dimensional measurements of existing locally manufactured seats of forty randomly selected minibuses were selected for evaluation of passenger seat dimension parameter. The measurement of seat dimensions was important tool in the development of minibus seat to fulfil the criteria of ride comfort and proper vehicle packaging. The dimensions of existing locally manufactured passenger seats of minibus are assessed by taking measurements on seat height, seat width, seat depth, back rest height and back rest width using meter. From the result of survey on locally manufactured seat dimension of passenger seat was summarised in frequencies data table 4.7, 4.8, 4.9and 4.10 Height of passenger seat measured value from forty different minibus taxis can be

Table 4. 7 measurement of existing seat height with number of vehicles

dimensions in cm	34	35	37	38	39	40	42	43	45
number of vehicles	2	3	5	3	8	6	9	1	3

Table 4. 8 measurement of existing seat pan depth with number of vehicles

dimensions in cm	33	34	35	36	37	38	40	41	42
number of vehicles	1	6	1	9	7	4	3	6	3

Table 4. 9 Measurement of existing seat width with number of vehicles

dimensions in cm	37	39	40	41	42	43	44	45
number of vehicles	5	6	8	4	8	4	3	2

Table 4. 10 Measurement of existing seat backrest height with number of vehicles

backrest height	65	66	67	68	69	70	71	73	75
number of vehicles	8	6	2	8	1	8	3	1	3

Generally, from frequency data table, measured value of seat features can be analysed by finding the mean and standard deviation of data by using equation of 4.2 and equation 4.7. percentile of seat features is the common practice to design with a minimum value of 5^{th} % and 95^{th} % of the highest seat feature measurement value rather than this the 50^{th} % value represent the average design value which is common for the smaller and larger measured value of the seat features. Depending up on this from the survey of data of seat feature measurement its percentile value can be calculated for the number of vehicle with the smallest diminution can be taken as the 5^{th} % and for the number of vehicle with maximum seat feature measurement can be taken as 95^{th} % the 50^{th} % can be represent median value of the vehicle seat feature parameters and can be presented in table 4.11

Table 4. 11 summaries of the seat dimensions in terms of means, standard deviations, 5th, 50th, and 95th percentiles

Seat dimensions			Percentile		
	Mean	SD	5th	50th	95th
Seat height	39.5	2.87	34	39	45
Seat width	40.825	2.229	37	41	45
Seat pan depth	37.475	2.66	34	36	42
Backrest height	68.35	2.887	65	68	75
Backrest width	40.825	2.229	37	41	45
Note: SD-Standard deviation					

4.3.2 Measurement of Passengers' Anthropometric Dimensions

In the use of anthropometric data for designing something, the data should be reasonably representative of the population that would use the item. In many instances the population of interest consists of people at large implying that the design features must accommodate a broad spectrum of people. When items are designed for specific groups (such as adult females, children, the elderly, the handicapped, etc.), the data used should be specific for such groups in the country or culture in question. (However, there are many specific groups for which appropriate data are not yet available.)

4.4 Principles in the Application of Anthropometric Data

There are three general principles for applying anthropometric data to specific design problems; each applies to a different type of situation. Design for Extreme Individuals In designing certain features of our built physical world, one should try to accommodate all (or virtually all) the population in question. In some circumstances a specific design dimension or feature is a limiting factor that might restrict the use of the facility for some people; that limiting factor can dictate either a maximum or minimum value of the population variable or characteristic in question. Designing for the maximum population value is the appropriate strategy if a given maximum (high) value of some design feature should accommodate all (or virtually all) people. Examples include heights of seat, and strength of supporting devices. In turn, designing for the minimum population value is the appropriate strategy if a given minimum (low) value of some design feature has to accommodate all (or virtually all) people.

Usually there are reasons for accommodating most, but not 100 percent, of the population. Thus, it frequently is the practice to use the 95th male and 5th female percentiles of the distributions of relevant population characteristics as the maximum and minimum design parameters. Designing for Adjustable Range Certain features of equipment or facilities can be designed so they can be adjusted to the individuals who use them. Some - examples are automobile seats, office chairs, desk heights, and footrests. In the design of such equipment, it frequently is the practice to provide for adjustments to cover the range from the 5th percentile female to the 95th percentile male of the relevant population characteristic (sitting height, arm reach, etc)

The use of such a range is especially relevant if there could be technical problems in trying to accommodate the very extreme cases (i.e., 100percent of the population); frequently the technical problems involved in accommodating the extreme cases are disproportionate to the advantages gained in doing so. using a range from the 5th percentile female's the 95th percentile male will result in accommodating 95 percent of a 50/50 male/female population, not 90 percent, because of the overlap between male and female body dimensions. Generally, designing for an adjustable range is the preferred method of design, but of course, it is not always possible. Designing for the Average First of all, there is no "average" individual. A person may be average on one or two body dimensions, but because there are no perfect correlations it is virtually impossible to find anyone who is average on more than a few dimensions. Often designers design for the average as a cope out so that they do not have to deal with the complexity of anthropometric data. This is not to say that one should never design for the average. On the contrary, a thorough analysis of the situation may prove that an average value is acceptable. Such a situation would probably involve noncritical work where it is not appropriate to design for an extreme and where adjustability is impractical. Designing for the average should only be done after careful consideration of the situation and never as an easy way out.

Discussion of Anthropometric Design Principles of the above principles refers to the application of anthropometric data for single dimensions (such as height or arm reach). The design problem becomes stickier when one needs to take into account combinations of several dimensions. For example, the setting of limits such as the 95th and 5th percentiles on each of several dimensions can eliminate a fairly high percentage of the population. For instance, Bittner (1974) found in one situation the 95^{th} and 5^{th} percentile limits on each of 13 dimensions would exclude *52* percent of the population instead of the 10 percent implied by the 95^{th} and 5^{th} percentile limits of the individual dimensions. This occurs because body dimensions are not perfectly correlated with each other. For example, people with short arms do not necessarily have short legs. Not all the people excluded because they are outside the 5^{th} to 95^{th} percentile range on one variable will be the same people who are excluded on another measure. It is important, therefore, to consider the relationships (correlations) between body dimensions in the design of things based on combinations of dimensions. Adding the 5^{th} or 95^{th} percentile values of body segments (e.g., fingertip to elbow and elbow to shoulder lengths) will not produce the corresponding percentile value for the combined dimension (e.g., fingertip to shoulder length). Once again this is because of the imperfect correlation between body dimensions. Robinette and McConville demonstrated this by building a 5^{th} percentile female out of 5^{th} percentile body segments (ankle height, ankle to crotch, crotch to buttock, etc.). The resulting female was 15.24 cm shorter than the actual 5^{th} percentile value for stature. To derive composite measures requires taking into account the imperfect correlations between the segments being added (or subtracted) by using regression analysis. In the application of anthropometric data to specific design problems, there can be no nicely honed set of procedures to follow, because of the variations in the circumstances in question and in the types of individuals for whom the facilities would be designed.

Using anthropometric data in design involves art as well as science. As a general approach, however, the following suggestions are offered. Determine the body dimensions important in the design (e.g., sitting height as a basic factor in seat-to-roof dimensions in automobiles).

- ✓ Define the population to use the equipment or facilities. This establishes the dimensional range that needs to be considered (e.g., children, women, different age groups, world populations, different races).
- ✓ Determine what principle should be applied (e.g., design for extreme individuals, for an adjustable range, or for the average).
- ✓ When relevant, select the percentage of the population to be accommodated (for example, 90 percent, 95 percent) or whatever is relevant to the problem.

  Locate anthropometric tables appropriate for the population, and extract relevant values.
- ✓ If special clothing is to be worn, add appropriate allowances (some of which are available in the anthropometric measurements).

- ✓ Build a full-scale mock-up of the equipment or facility being designed and, using the mock-up, have people representative of large and small users walk through representative tasks. All the anthropometric data in the world cannot substitute for a full-scale mock-up.

In the modern world it is impossible to design in terms of average dimensions. It is for that reason that anthropometry plays a capital role in the world of design. In terms of public transport, it is necessary to define the spaces of circulation, access and exit doors, as well as the dimensions of the seats considering the more corpulent people. On the other hand, the dimensions of the smaller people are used to define the height of the seats, height of the superior handles, height of the steps of the access and exit stairs, and finally the height of the last step of these stairs in relation to the road level The data collected was analyzed using descriptive statistics such as means, standard deviations, fifth, fiftieth and ninety-fifth percentiles using Excel Microsoft Package. The data obtained for the passengers was compared with the relevant dimensions of the seats features.

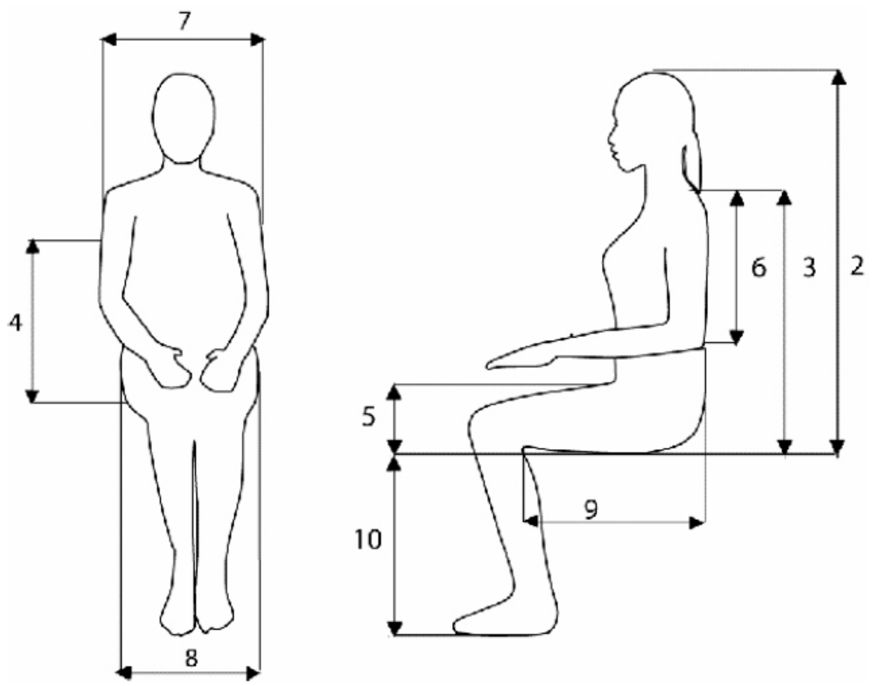


Figure 4. 16 Anthropometric dimensions measured parameters

2. Sitting height (SH)

3. Sitting to shoulder height (SSH)

4. Lowest point scapula to sitting

5. Thigh clearance height (TCH)

6. Shoulder-elbow length

7. Shoulder breadth (BB)

8. Hip breadth seated (HB)

9. Popliteal depth or buttocks to popliteal length (BPL)

10. Popliteal height (PH)

The summary of the anthropometric dimensions of the passengers in terms of means, standard deviations, fifth, fiftieth, and ninety fifth percentiles are presented in Table 4.12 While those of the seat dimensions are presented in Table 4.13, Table 4.14

Table 4. 12 Anthropometric data of passengers in cm

Anthropometric height	**mean**	**SD**	**5^{th} %**	**50^{th} %**	**95^{th} %**
Sitting height (SH)	79.48	5.57	68	80	88
Sitting to shoulder height (SSH)	56.69	4.55	46	54	62
Lowest point scapula to sitting	39.74	2.78	34	40	44
Thigh clearance height (TCH)	21.4	1.97	18	21	25
Shoulder-elbow length	37.93	3.18	31	38	43
Shoulder breadth (BB)	45.34	4.05	38	46	52
Hip breadth seated (HB)	37.26	3.8	30	36	46
buttocks to popliteal length (BPL)	47.53	3.08	42	46	52
Popliteal height (PH)	45.39	2.94	40	44	50
Note : SD standard deviation of the data					

Table 4. 13 Dimensions of existing locally manufactured passenger seats of minibus in cm

Seat dimensions			Percentile		
	Mean	SD	5^{th}	50^{th}	95^{th}
Seat height	39.5	2.87	34	39	45
Seat width	40.825	2.229	37	41	45
Seat pan depth	37.475	2.66	34	36	42
Backrest height	68.35	2.887	65	68	75
Backrest width	40.825	2.229	37	41	45
Note: SD-Standard deviation of the data					

Table 4. 14 Aanalysis of seat dimensions and passengers' anthropometric dimensions

Anthropometric dimensions			**Seat dimensions**			Difference	decision
	Mean	SD		Mean	SD		
Popliteal height (PH)	45.39	2.94	Seat height	39.5	2.87	5.89	Acceptable
Hip breadth seated (HB)	37.26	3.8	Seat width	40.82	2.23	3.565	Acceptable
buttocks to popliteal length (BPL)	47.53	3.08	Seat pan depth	37.47	2.66	10.05	mismatch
Sitting to shoulder height (SSH)	56.69	4.55	Backrest height	68.35	2.88	11.66	mismatch
Shoulder breadth (BB)	45.34	4.05	Backrest width	40.83	2.23	4.515	Acceptable

The anthropometric data of the passengers are presented in Table 4.12 as means, standard deviations (SD), and 5^{th}, 50^{th} and 95^{th} percentiles. Furthermore, the minimum, maximum, median of the dimensions and the body mass are included in appendix of anthropometric data. In anthropometry, percentiles of various body dimensions are used to determine design values for an application. For seat height, the 5th percentile (lower percentile) of the popliteal height of the population is usually recommended so that a larger number of the population is accommodated and thus allow a short person to use the seat. Similarly, 5^{th} percentile of: buttock-popliteal length is considered for seat depth; sitting shoulder height for upper back rest height; arm rest height for lower back rest height. However, the 95^{th} percentile (larger percentile) of the hip breadth is usually recommended in the design of the seat widths to accommodate as many people of the population as possible and thus allows a fat person to use the seat.

The seat surface height, seat depth, seat width, backrest height, and backrest width are the important dimensions for the design of passenger seat. The design of the seat for the use by passengers in the in vehicles was based on the following criteria:

Seat Height: The popliteal height should be considered in the design of seat height and for non-adjustable seats; the 5^{th} percentile may be used as the maximum allowable seat height [39]. The 5^{th} percentile in the present passenger is 34cm and if this is added to shoe heel allowance of 0.45 cm the seat height should be 34.45 cm.

Seat Depth: The anthropometric dimension to be considered in the design of the seat depth is the buttock-popliteal length. The seat depth should not exceed the buttock-popliteal length of the shortest user [40] and as such the 5^{th} percentile of the buttock-popliteal length should be used to determine the seat depth. In this study, the 5^{th} percentile of the buttock-popliteal and thus the seat depth is 42 cm.

Seat Width: The dimension of the seat width should be determined using the hip breadth of those with wide hips. The seat width should be wide enough not only to accommodate the user’s hips and clothing but also allow the use of arms comfortably [40]. The recommended 95^{th} percentile of hip breadth and allowance 0.40 cm for clothing while recommended a seat width that is equivalent to 95^{th} percentile hip breadth and 15percent allowance for clothing. In this study, the 95th percentile of hip breadth of 46 cm is used with an allowance of 15 percent of the value (6.9 cm) which translates to a seat width of 52.9 cm.

Generally, the seat feature with the seating height, seat depth and seat width of 34.45cm, 42cm and 52.9 cm respectively was expected for passenger seat. This dimension is space consuming inside the vehicle and bad packaging for the vehicle.

4.5 Proposed seat design

From current conventional seat, efforts have been made to improve the passenger ride comfort with ergonomically considered of the seat features. As mentioned in previous chapter, from most of the locally manufactured existing passenger seat, the common way to achieve comfort is through the cushion. Cushion properties such as material, thickness softness and contour will affect the passenger satisfaction of passenger. However, a seat design was proposed as sample in this research. The improvement and modification on this seat focused on the seat structure and features as well as on the seat layout of packaging in proposed vehicle. The parameter of seat feature can be fit with the anthropometric measurement taken from the sample of selected personnel with recommended interval. The proposed seat structure design is shown in figure 4.17

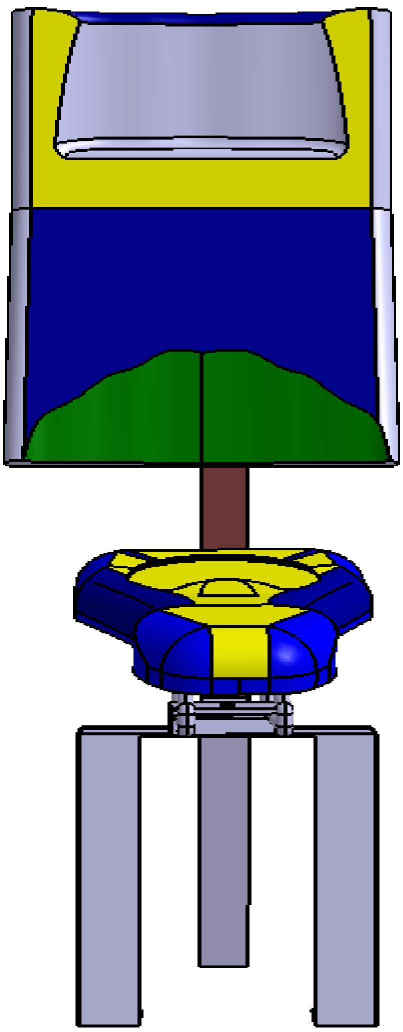


Figure 4. 17 Proposed seat design features

Besides improving the seat comfort, there are other advantages of improving the seat structure:

Simple design: the seat structure consists of few components

Low cost: the simple design will result in the low cost of producing the seat especially for a mass production. Furthermore, the cost of maintenance is low.

Safety: during emergencies (collision or sudden braking), the seat structure would be able to absorb the impact transmitted from the vehicle to the passenger.

Vibration: the discomfort caused because of vibration generated in different causes can be transmitted without magnification to the human body.

The proposed conceptual design in the form of 3D model which is developed using CATIA V5 for seat structure is shown in the figure 4.18. Bill of materials of seat backrest with their respective function is given in table 4.15 bill of materials for seat pan of developed model with their function are given in table 4.16.

Table 4. 15 Bill of material with components and their function of seat back rest

I/N	Part name	Qty	Material	Function
1	Backrest pan	1	Plastic	Support the lumbur of the occupant.
2	Backrest frame	1	Carbon steel	Support the load applied on the backrest.
3	pedestal	1	Angle iron	To support the overall weight of the occupant.

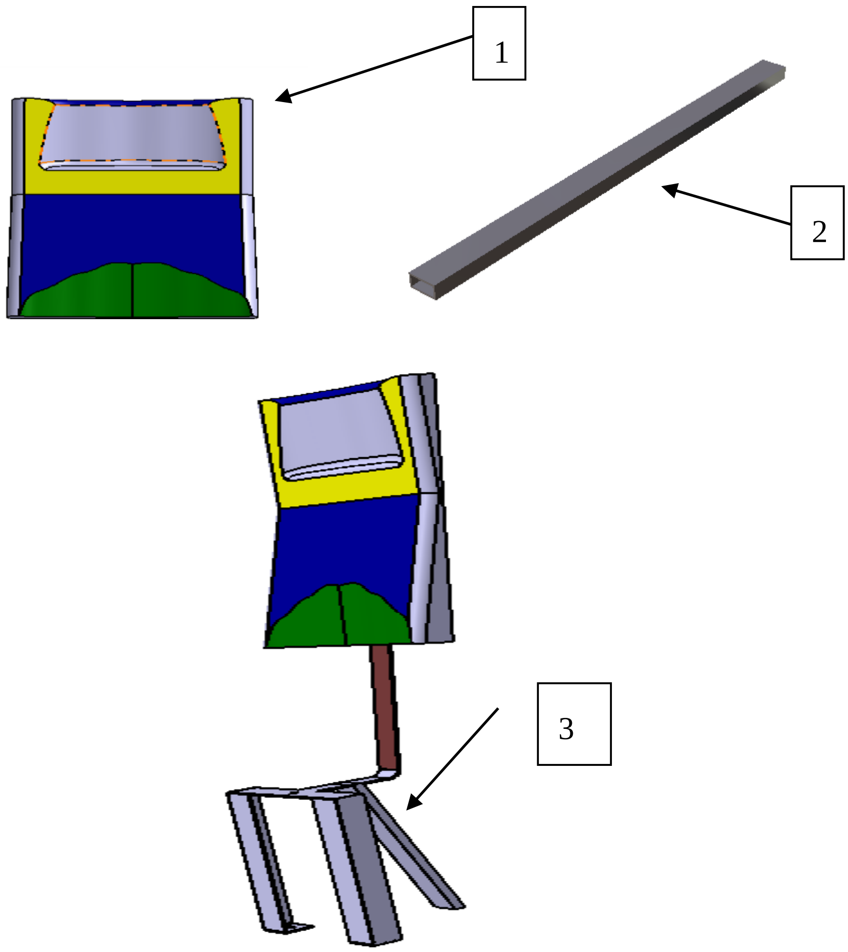
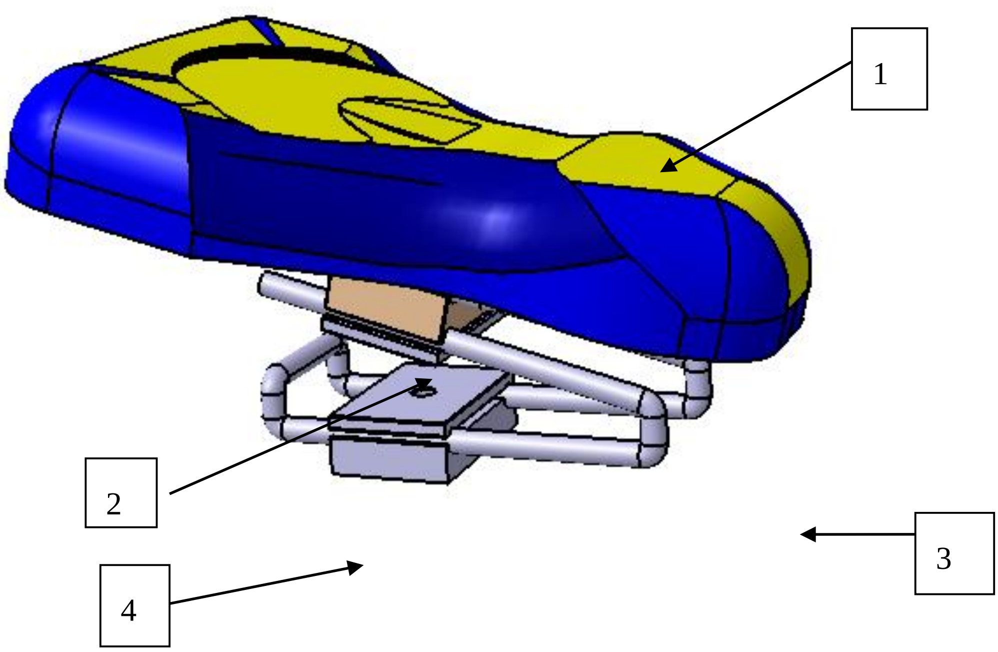


Figure 4. 18 new improved model frame of backrest with pedestal



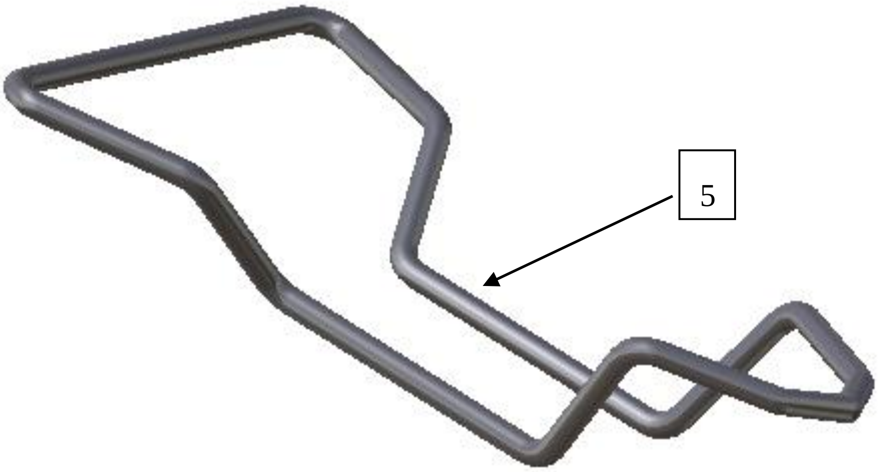


Figure 4. 19 Improved model of seat pan, frame with it suspension structure.

Table 4. 16 Bill of material with components and their function of seat pan

I/N	Part name	Qty.	material	function
1	Seat pan	1	Plastic	Support the buttock of occupant
2	Fixing plate	3	Flat iron steel	Connecting seat pan frame with suspension and pedestal
3	Suspension spring	1	Carbon steel	Support the load with dumping vibration transmitted to seat pan
4	Seat pan structure	1	Carbon steel	Support the weight of the occupant

4.5.1 **Static and dynamic strength analysis of passenger seat**

Static and dynamic strength analysis is done on improved seat to verify that the requirements of seat features weather they are handling the load or not for the required purposes. The purpose of static strength analysis is to verify that the seat structure and its component meet the various loading condition that are expected during the running of vehicle. In general, static strengths analysis can be performed on the structure parts of seat assembly of seat frame. Seat frame and components shall be designed to meet the individually applied static load requirements given below with no yielding force of structural materials, loss of function or change in appearance of seat component.

Automotive seats are physically tested for strength, deflection, and energy absorption in an event of vehicle rear end, front end, and side impact loads. Automotive vehicles driven in the European Union must satisfy the requirements of ECE R17 regarding seats [3]. The structural design of a complete seat is primarily driven by the strength requirement in an event of vehicle crashes. The seat has to support the weight of a person and also resist severe static and dynamic loading during an event of accident. During rear, frontal and side impacts of automobile, structural members are the load bearing components in a seat. The moment requirements of typical reference seats for rear impact of an automobile are often several times higher than the European Union standard ECE- R17.

4.5.1.1 ***Backrest frame strength***

The purpose of this calculation to know the strength of seat back against the effect of passenger sitting his/her body against the seatback or backrest. The load of exposing of this frame structure was the load of the occupant on the seat can apply over it not more than half of the weight of him/ herself. From that we can determine the maximum load acting on the backrest structure. Which is the maximum weight of the measured data can be taken as a design point with some safety factors which can compensate the variation of the weight and some other factors to resist with that design criteria. From anthropometric data collection and sample data selection of the peoples leaving in adama, the maximum weight of the recorded data was 92kg. For this design concept the load of individuals can be taken as 110kg for safe design of seat structure. This force can be acted on the backrest at the scapula the users. This parameter can taken as the minimum point of application of the load which acting as a bending load on the backrest stricture. The measurement can be taken from male anthropometric measurement value and it is measured from longest person as design reference point which is 48mm height form seat pan. The load applied on the structure is applied as distributed load on structure rather than point load. To determine maximum bending force and bending moment the reference point of acting can be taken as the length of the force acting on the structure from hinged (fixed) point.

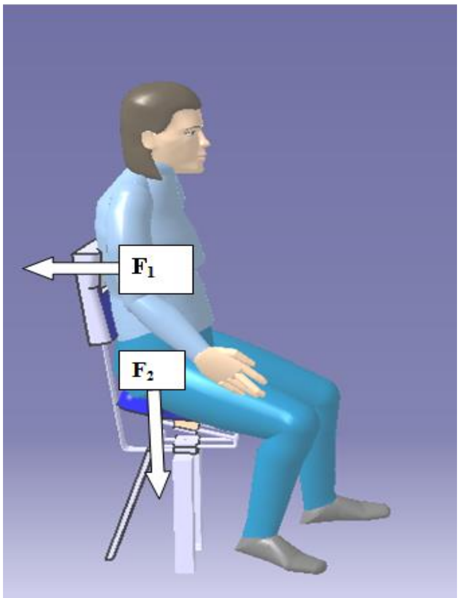


Figure 4. 20 Interactions of human being with seat structure in seating position

4.5.1.2 ***Backrest static loading***

Statics deals with equilibrium of bodies under action of forces (bodies may be either at rest or move with a constant velocity).

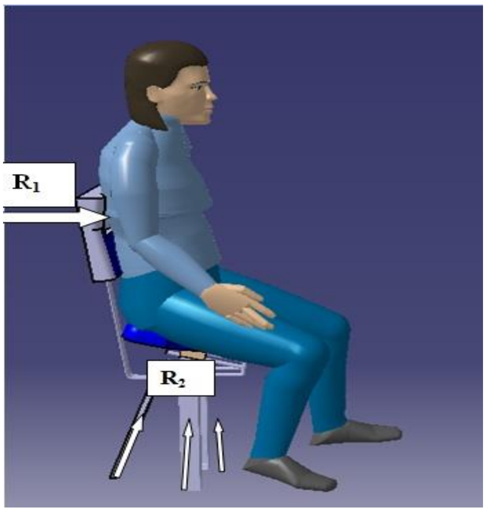


Figure 4. 21 Reaction forces from seat structure.

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. Static analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. When some external systems of forces or loads act on a body, the internal forces (equal and opposite) are set up at various sections of the body, which resist the external forces. This internal force per unit area at any section of the body is known as unit stress or simply a stress. It is denoted by a Greek letter sigma (σ) [41]. The load acting on the backrest can be determined from weight of 110kg person stated above. 18% of the weight of this person may act on structure. From this measured data it is possible to determine the load acting on structure from weight and force relationship.

$$F_1 = 15\%\ of\ the\ Weight\ occupant$$

$$F_1 = \frac{18}{100} * W * g$$

$$F_1 = \frac{18}{100} * 110\ kg * 9.81 \frac{m}{s^2}$$

$$F_1 = 194.24\ N$$

This force acting on the features to bend the structure and it is the initial condition to design the structure. This force is produce bending moment on the structure at pivot and it is the cause of bending of the structure. In order to determine bending moment of the structure, the position of the action of this force must be determined. From anthropometric data analysis the mass of the integrator on the seat can be selected as a man with the height of 95^{th} %. From this the length of scapula of the occupant at seating position from seat pan is the prerequisite for determination of bending moments. This bending moment and bending stress can be determined as follows. The bending equation is given by[41]

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ equation\ 4.$$

Where M = Bending moment acting at the given section,

σ_b= Bending stress,

I = Moment of inertia of the cross-section about the neutral axis,

y = Distance from the neutral axis to the extreme fibre,

E = Young’s modulus of the material of the beam, and

R = Radius of curvature of the beam.

From the above equation, the bending stress is given by

$$\sigma_b = \frac{M}{I} * y = \frac{M}{\frac{I}{y}} = \frac{M}{Z} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. equation\ 4.$$

The ratio *I/y* is known as ***section modulus*** and is denoted by *Z* which is stated in Appendix

Section of modulus for rectangular hallow section can be determined Appendixes

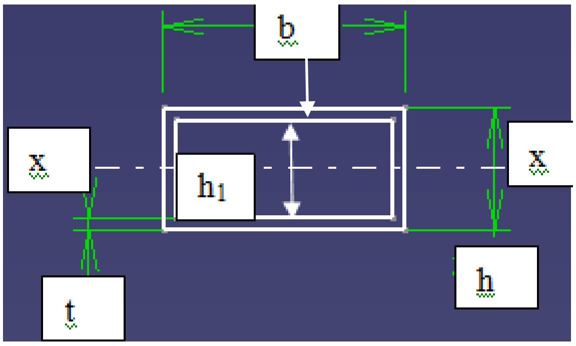


Figure 4. 22 cross sectional view of backrest structure

$$Z = \frac{I}{y} = \frac{b}{6}\left(\frac{h^3 - h_1^3}{h}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{equation 4.}$$

Bending moment (M)

$$M = F_1 * r$$

Where M bending moment

F_1 perpendicular applied force

r length of moment arm (Lowest point scapula to sitting)

$$M = 194.24\ N * 440mm$$

$$M = 85465.6\ N\ mm$$

$$M = 85.47 * 10^3 Nmm$$

Bending stress developed due to this bending force can be determined as;

$$\sigma_b = \frac{M}{Z}$$

Where σ_b bending stresses

M bending moment

Z Sectional modulus of the structure

Rectangular section of sectional modulus can be determined by equation 4.

$$Z = \frac{I}{y} = \frac{b}{6}\left(\frac{h^3 - h_1^3}{h}\right)$$

$$Z = \frac{25}{6}\left(\frac{12^3 - 8.8^3}{12}\right)$$

$$Z = 363.4\, mm^3$$

$$\sigma_b = \frac{85.47 * 10^3 Nmm}{363.4\, mm^3}$$

$$\sigma_b = 235 \frac{\mathrm{N}}{\mathrm{mm}^2}$$

For this bending stress the safe material of rectangular cross section of hallow Fe290 (carbon steel) with yield stress of 235N/mm^2. Appendix

4.5.1.3 *Backrest dynamic loading*

Load applied on the backrest structure due to occupant weight transfer when the bus accelerating is the other force. This load is may applied on the backrest due to inertia developed as a result of change of velocity of the vehicle. The mass of occupant was transferred to the backrest at contact point of scapula and backrest. The acceleration of developed due to change of velocity can be determined by equation of motion. The acceleration developed; for the change of velocity of vehicle from rest position to maximum velocity developed by 1st gear meshing condition. The other acceleration is hard acceleration during sudden change of gear meshing condition. Most of the time the change of velocity's ranging from zero initial velocity of the vehicle to 26m/s in 8.67s. Form this condition acceleration developed due to change of this velocity can be calculated as;

Mass of occupant (m) = 19.8 kg

Acceleration of the vehicle (a);

$$a = \frac{v - u}{t} \ldots\ldots\ldots\ldots\ldots .4.$$

Where v the maximum velocity of vehicle

u Initial velocity of the vehicle

t time taken arrive this final velocity

$$a = \frac{26.67m/s - 0m/s}{8.67}$$

$$a = 3.076\frac{m}{s^2}$$

Occupant weight transfer to the backrest during hard acceleration

$$F = 19.6 * 3.076$$

$$F = 60.29N$$

This load is applied to the backrest due to change of velocity during acceleration of the vehicle in specified velocity. Due to this load the backrest structure exposed to bending Moment.

Bending moment (M_b)

$$M_b = F * r$$

$$M_b = 60.29N * 440mm$$

$$M_b = 26.53 * 10^3\ Nmm$$

The total bending moment due to patronage and acceleration condition can calculated as

$$M_{b\ total} = (F_1 + F) * r$$

$$M_{b\ total} = (194.24 + 60.29) * 440$$

$$M_{b\ total} = 11.2 * 10^4 Nmm$$

Bending moment stress due to lean and acceleration of the vehicle can be calculated as;

$$\sigma_{b(max)} = \frac{M_{b\ total}}{Z}$$

$$\sigma_{b(max)} = \frac{11.2 * 10^4 Nmm}{363.4mm^3}$$

$$\sigma_{b(max)} = 308.2\frac{N}{mm^2}$$

The carbon steel with yielding strength 310N/mm^2 was selected from mechanical property of carbon steel structural with rectangular cross section of resisting 308.2 N/mm^2 of maximum yielding moment.

To calculate maximum deflection of rectangular hollow frame when load is applied near the middle of the backrest or at scapula;

The cross section area moment of inertia (I) of rectangular hallow structure can be determined by;

$$I = \frac{b}{12}(h^3 - h_1^3)$$

$$I = \frac{25}{12}(12^3 - 8.8^3)$$

$$I = 2.2 * 10^3 mm^4 = 0.22 cm^4 = 2.3 * 10^{-9} m^4$$

The young modulus of carbon steel (E)=207 GPa. Appendex A

From the Appendix, the deflection at the free end of cantilever beam structure

$$\delta = \frac{p * l^3}{3EI} \dots \dots \dots \dots . equation\ 4.$$

Where p load applied on the beam

l length of the beam from fixed point

E modulus of elasticity Carbon steel 207*10^9 pa

I Moment of inertia of rectangular cross section

$$\delta = \frac{(F_1 + F) * l^3}{3EI}$$

$$\delta = \frac{(192.24N + 60.29N) * (0.440m)^3}{3 * 207 * 10^9 Pa * 2.2 * 10^{-9} m^4}$$

$$\delta = \frac{21.51}{13662.7} m$$

$$\delta = 0.0016m = 1.6mm$$

The maximum deflection of the backrest beam (structure) when a force applied at the scapula will be 1.46mm which is small compared to the load applied from the weight of the occupant and load due to change of velocity. Thus the backrest is considered rigid when the load is applied over it.

4.5.1.4 ***Finite element method of determination of static strength analysis backrest***

In strength analysis, considering loads acting on the component, equivalent stresses are calculated and compared with allowable stresses to check if the dimensions of the component are adequate. Finite Element Method is a numerical calculation method used to analyze such problems

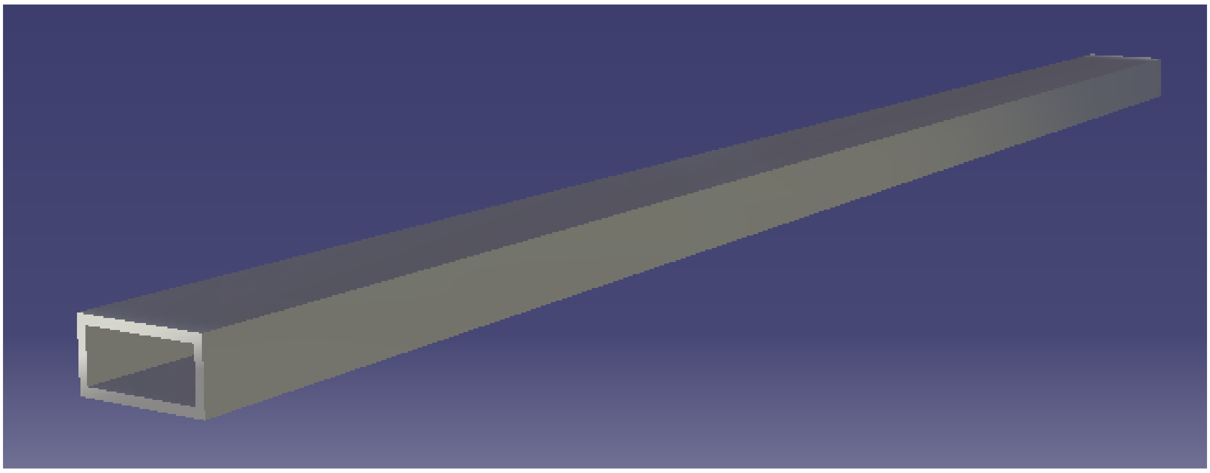


Figure 4. 23 The 3-Dimensional model in CATIA V5 of backrest structure

Figure 4.23 shows the 3-Dimensional model of backrest structure in CATIA V5 environment.

✓ Procedure of static Analysis

The procedure of using FEM usually consists of following steps.

a) modelling;

First, I prepare a model of backrest structure in CATIA V5 software and save as .IGS file format for Analysis of backrest in ANSYS WORKBENCH 16 import .IGS model in ANSYS Workbench simulation module

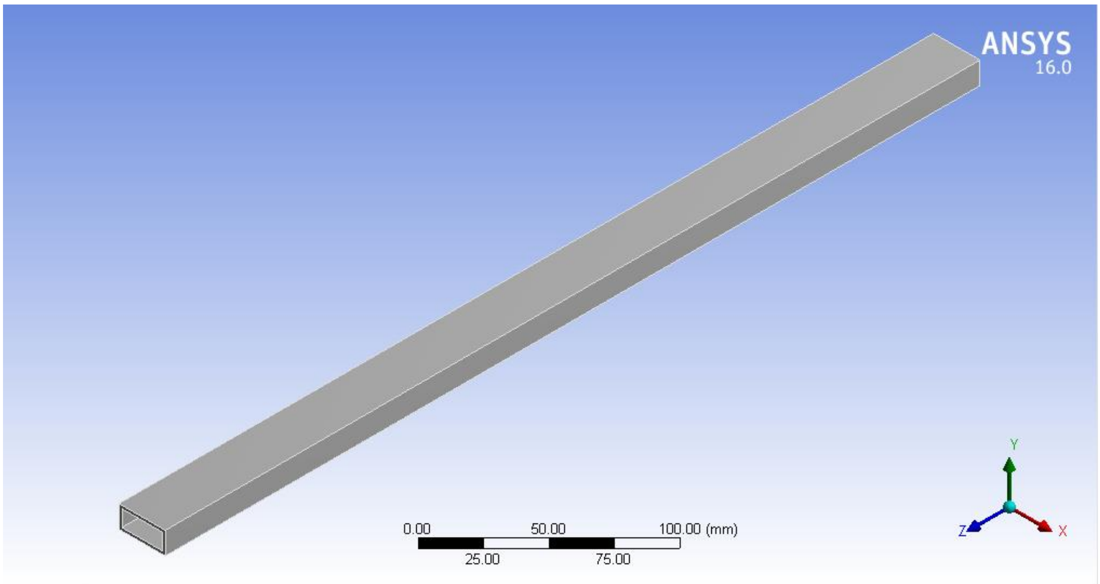


Figure 4. 24 model of backrest structure imported to ANSYS workbench

The ANSYS demands for material properties which are defined using module engineering data. The selected material used for backrest carbon steel Fe E310.The material properties are listed in Table 4 16.

Table 4. 17 the material properties of back rest

Density	7850kg/m^3
Young's Modulus	207GPa
Poisson's Ratio	0.3
Tensile Strength	410MPa
Yield stress	310MPa

(b) Meshing;

Greater the fineness of the mesh better the accuracy of the results and Fig. 4.25 shows the meshed model in ANSYS consisting of 13386 nodes and 2070 elements

Type of Element: rectangular
Number of nodes: 13386
Number of elements: 2070

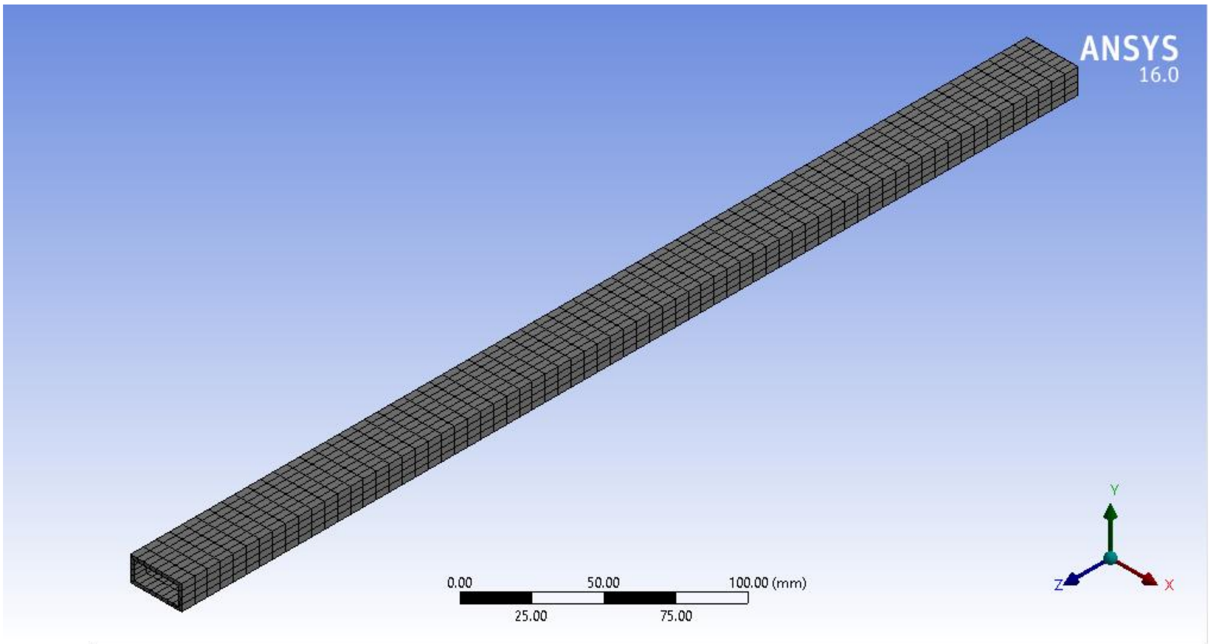


Figure 4. 25 back rest structure rectangular shape meshing element

(c) Determining and imposing loads and boundary conditions;

Boundary conditions play an important role in FEM. Therefore they must be carefully defined to resemble actual working condition of the component being analyzed. The backrest is subjected to two loads namely weight of the passenger and load due to shifting force result of variation of velocity of vehicles. Load applied on the component when the backrest is at the position of maximum bending moment load data were taken from the calculated result. Boundary condition is based on under supporting condition of backrest.

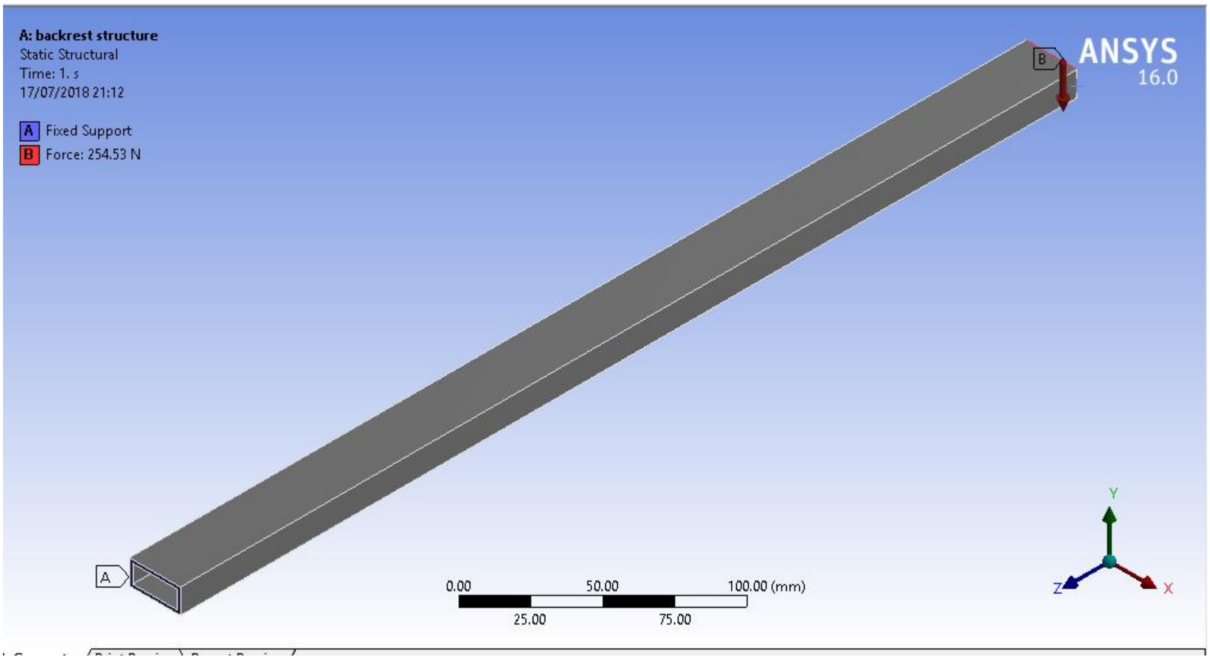


Figure 4. 26   backrest structure boundary conditions and input data

(d) Result analysis of finite element analysis

The backrest structure has the tendency to resist the load applied as the weight of occupant with maximum equivalent stress, bending stress and deflection of the structure is shown in figure of result output of ANSYS software for selected material.

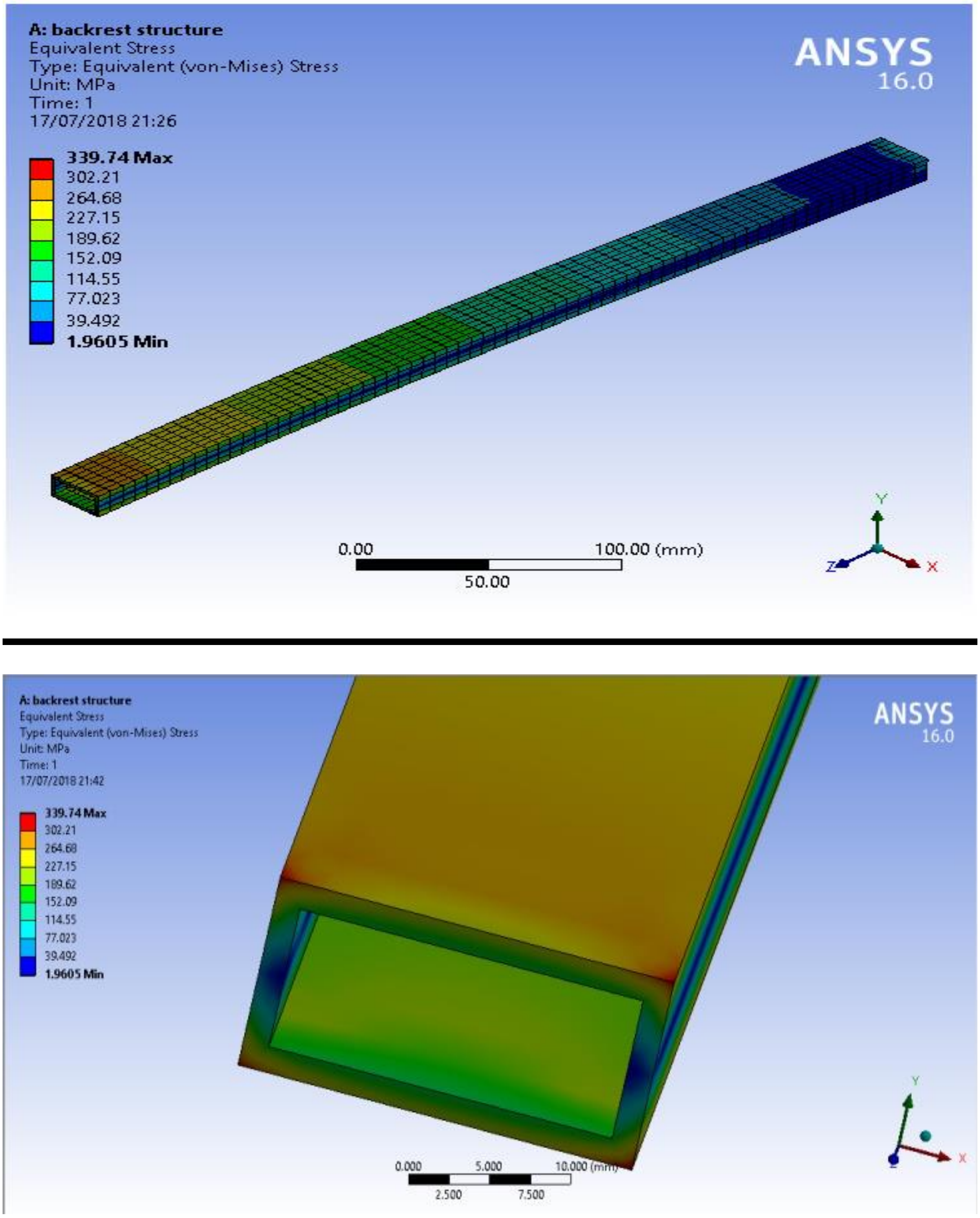


Figure 4. 27 Static structure of backrest with Equivalent (von-Mises) stress.

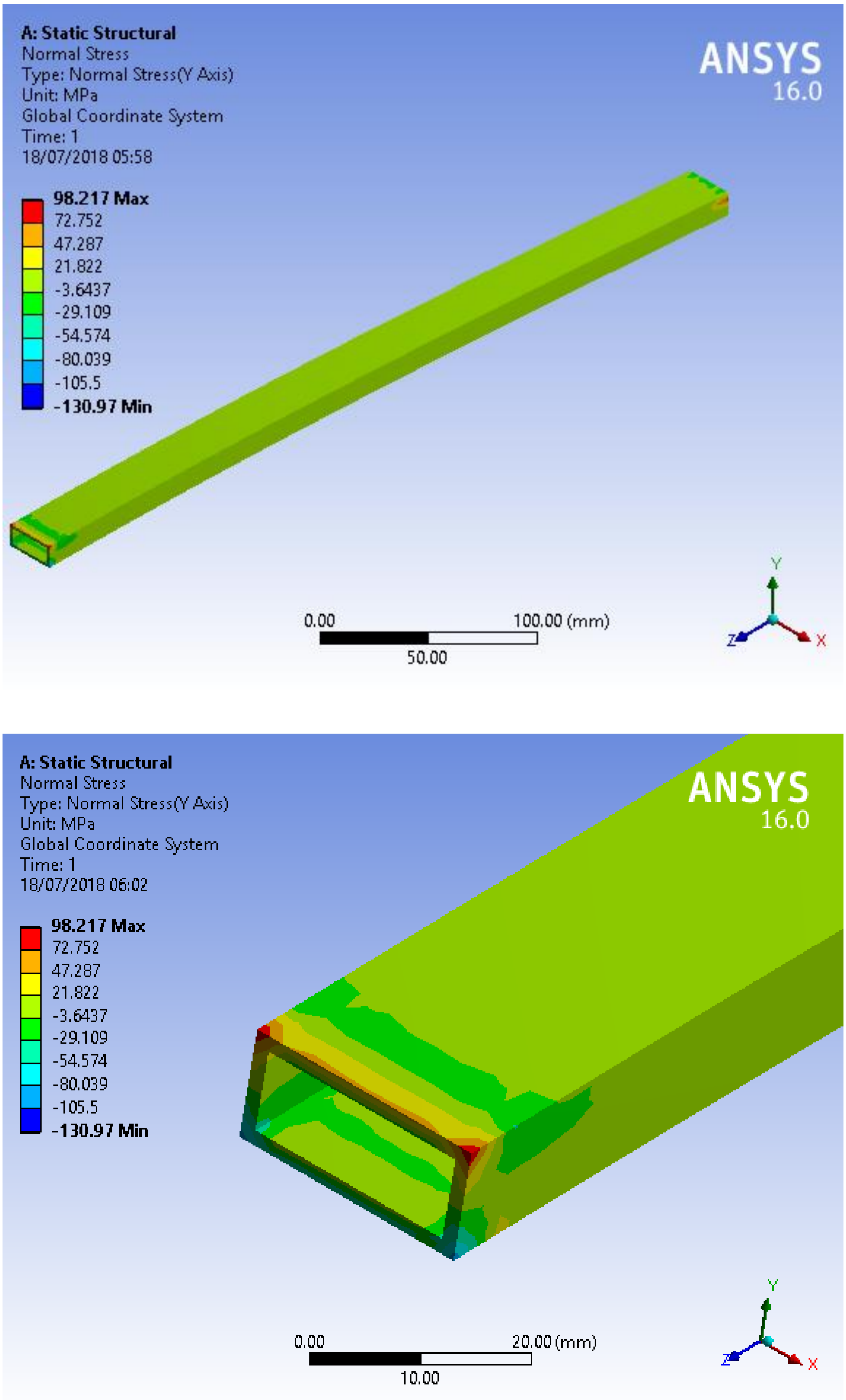


Figure 4. 28 static structure of Normal stress on backrest structure

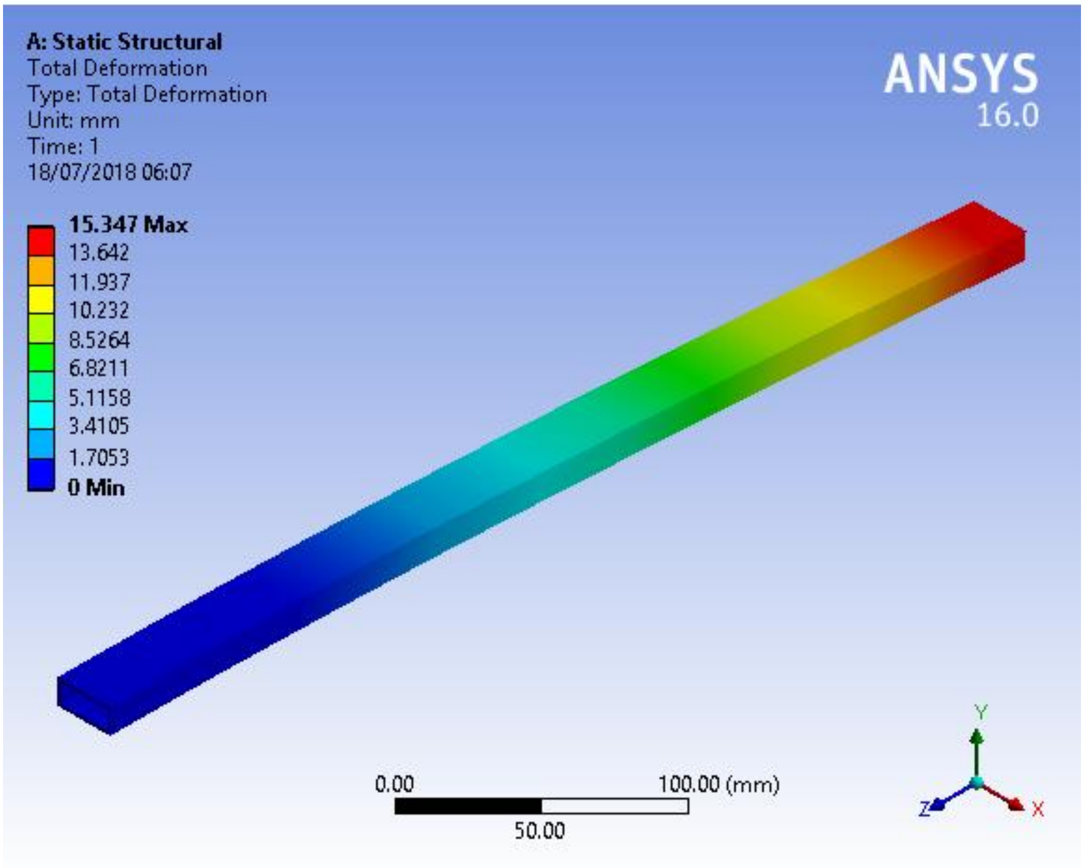
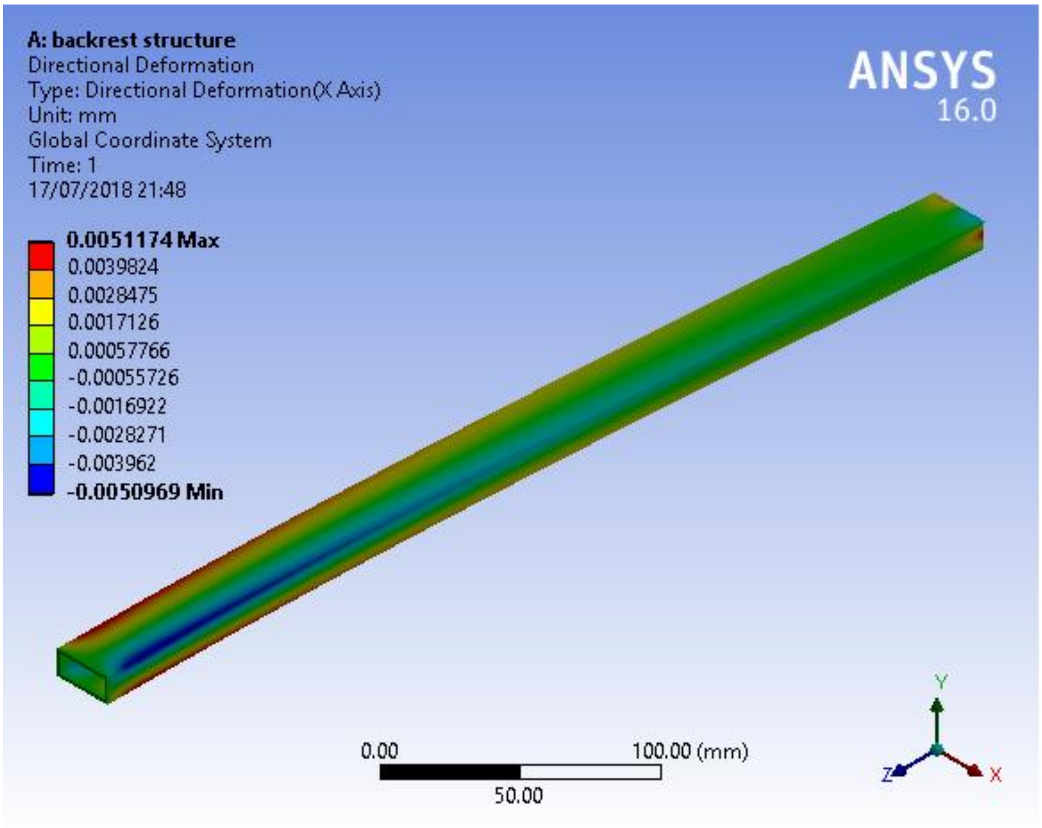


Figure 4. 29 Total deformation of backrest structure



4.5.2 **Strength analysis of Seat pan frame.**

The analysis is to ascertain that the steel frame located underneath the bus seat has the strength and durability to with stand the passenger's weight. A load of 110kg occupant shall be sited on the seat pan and the weight acting downward direction seat frame contact surface of seat pan frame with seat pan. The weight of occupant act downward as a distributed load acting Overhanging (mid supported) beam which is similar mathematical equation with simply supported beam. The seat pan frame which is contacting with seat pan can resist the weight of the occupant to be in static condition. If loading is perpendicular (transverse) to its axis so that the rod bends, then the rod is called a *beam*.

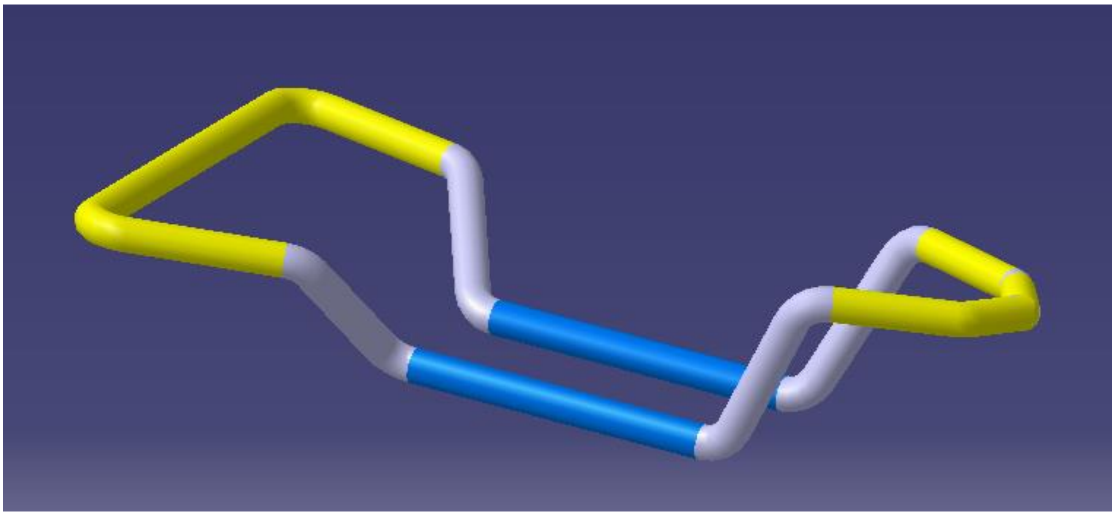


Figure 4. 30 3D designed seat pan structure

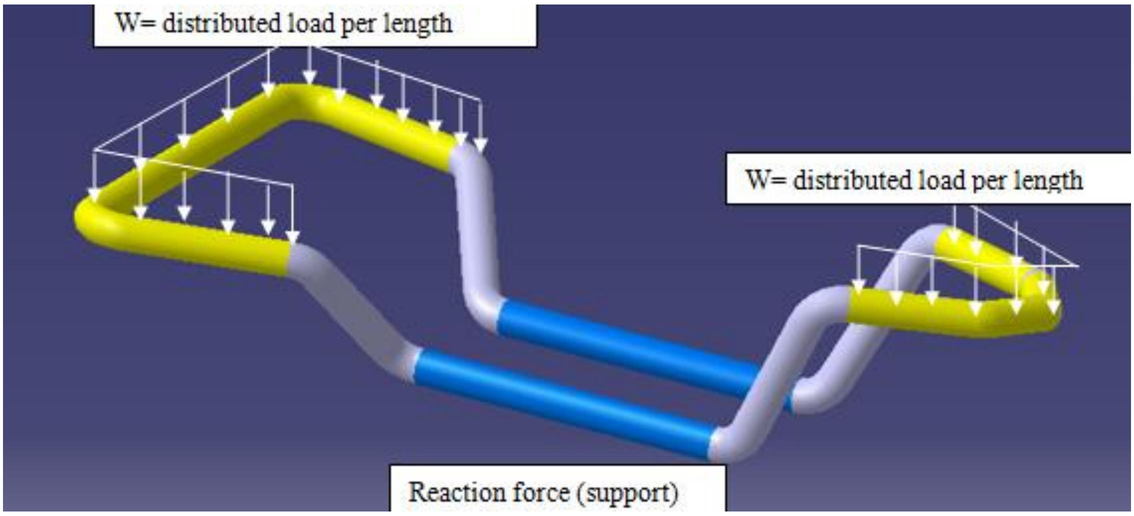


Figure 4. 31 Distributed load over seat pan structure

As figure 4.32 the frame of seat panel can have symmetric structure which is represents in simple supported beam with equivalent load acting on it. The load which is acting on the structure can be shared with this symmetric line.

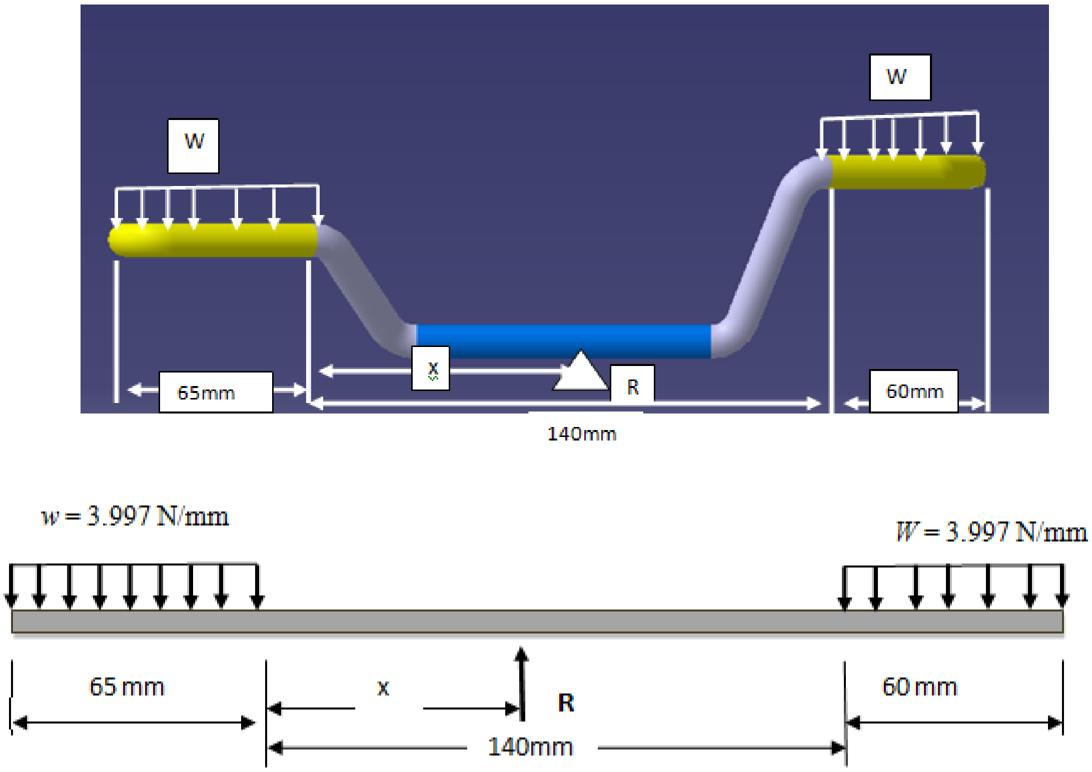


Figure 4. 32 Representation of loaded seat pan structure and position of load

If a uniformly distributed load is applied on the specified length, then we need to convert the distributed load into a point load equivalent to the total load W=w*L where L is the length of the distributed load of 65mm and 60mm. The equivalent point load is located at the centroid of the distributed load or the center of the rectangle. Then we have to use the equivalent load diagram for calculating the reaction forces.

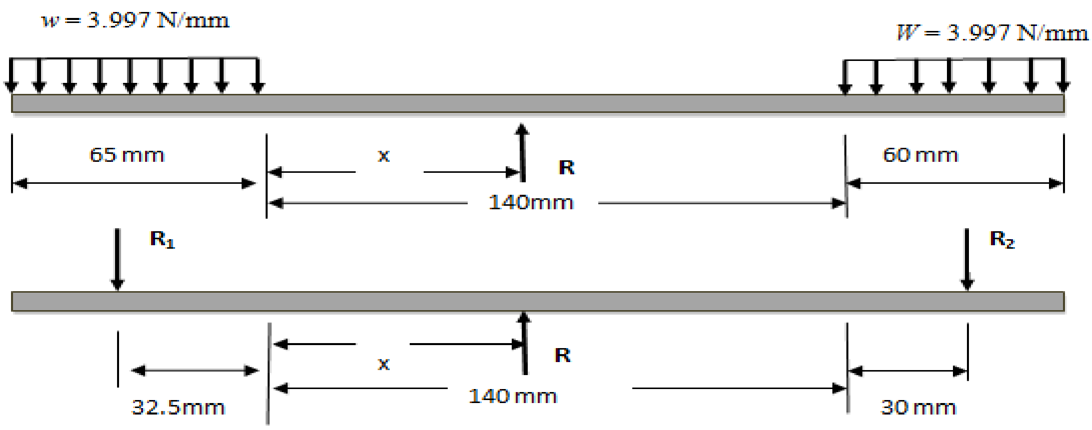


Figure 4. 33 Free body diagram of seat pan structure in beam structure representation

The distributed load runs for 65mm and 60mm, so the location of the equivalent load is 32.5mm and 30mm respectively from the left end and right end of the distributed load.

The equivalent load;

$$R_1 = w * l_1$$

$$R_1 = 3.997\frac{N}{mm} * 65mm$$

$$R_1 = 259.8\,N$$

$$R_2 = w * l_2$$

$$R_2 = 3.997\frac{N}{mm} * 60mm$$

$$R_2 = 239.82\,N$$

Now it is possible to calculate the reaction force at support in order to resist applied load or to be equilibrium condition whenever this load is applied over it. From Newton's 1st low of static condition;

$$+\uparrow\sum \mathrm{F_y} = 0$$

$$-\mathrm{R_1} - \mathrm{R_2} + \mathrm{R} = 0$$

$$-259.8\mathrm{N} - 239.82\mathrm{N} + \mathrm{R} = 0$$

$$\mathrm{R} = 499.62\ \mathrm{N}$$

To be in equilibrium condition the distance of reaction force from some convenient position can be determined by using momentum equation of static state of represented beam.

The moment about point $F_1$is

$$\curvearrowleft \sum M@F_1 = 0$$

$$R * (32.5 + x) - F_2 * 202.5 = 0$$

$$499.62 * 32.5 + 499.62\,N * x - 239.82\,N * 202.5mm = 0$$

$$x = \frac{(48{,}563.55 - 16237.65)\,Nmm}{499.62\,N}$$

$$x = \frac{32325.9}{499.62} mm$$

$$x = 64.7mm$$

This mean the reaction force for can react at a distance of 129.7mm from left side of the beam. Which mean that the position of fixing the seat frame structure with pedestal of the seat.

When we calculate reaction forces and we are calculating external forces we are going to select proper material which resist these external loads by developing internal loads. Beams in bending also develop internal forces to resist external forces. Since the external forces on beams are transverse (perpendicular to the axis of the beam), the internal resisting forces are also transverse forces.

With a shear diagram, we can identify the location and size of the largest shear load in a beam. Therefore, we know the location of the largest shear stress, and we can calculate the value of this stress. Once we know the actual stress in the material, we can compare this value with the shear strength of the material, and we can know whether the beam will fail in shear. The bending stresses that develop within beam are attaining maximum value at hinge. We can compare the actual bending stresses with the yield strength of the material, and we can know whether the beam will fail in bending.

From beam configuration the beam is fixed at 129.7 mm from left side of the rigid fixing position which is equivalently represented by a cantilever beam of caring 259.8 N at 97.2mm from left side and other cantilever beam of in the right side with 239.82N at the arm length of 105mm from hinged point. By assuming point C as reference it is possible to determine the bending moment of the beam

Moment at C for the left hand side applied force;

$$M_b = F_1 * r$$

$$M_{b\ at\ c} = 259.8\ N * 97.2mm$$

$$M_{b\ at\ c} = 25252.56\ Nmm$$

Moment at C for the right hand side applied force;

$$M_{b\ at\ c} = F_2 * r$$

$$M_{b\ at\ c} = 239.82\ N * 105.3mm$$

$$M_{b\ at\ c} = 25253Nmm$$

From these two results the beam can be exposed to bending moment of equal values. The bending stress formed by bending moment along the cross section area of the beam.

$$\sigma_{b(max)} = \frac{M_b}{Z}$$

Where $\sigma_{b(max)}$ maximum bending stress

M_b Maximum bending moment

Z Sectional modulus of the structure

The sectional modulus of round rod can be determined by

$$Z = \frac{I}{y}$$

Where *I* = Moment of inertia of the cross-section about the neutral axis,

y = Distance from the neutral axis to the extreme fibre,

$$Z = \frac{\pi d^3}{32}$$

$$Z = \frac{\pi * 8^3}{32}$$

$$Z = \frac{1{,}607.68mm^3}{32}$$

$$Z = 50.24mm^3$$

So bending moment

$$\sigma_{b(max)} = \frac{25253 \text{ Nmm}}{50.24 \text{ mm}^3}$$

$$\sigma_{b(max)} = 502.65 \frac{\text{N}}{\text{mm}^2}$$

The carbon steel with yielding strength 520 N/mm^2 was selected from mechanical property of carbon steel structural with round cross section of resisting 502.65 N/mm^2 of maximum yielding moment.

To calculate maximum deflection of round bar frame

$$\delta = \frac{p * l^3}{3EI}$$

$$\delta = \frac{259.8N * (0.0972)^3 m^3}{3 * 207 * 10^9 Pa * 20 * 10^{-11} mm^4}$$

$$\delta = 1.91 * 10^{-3} m = 1.91\ mm$$

The maximum deflection of the round bar (seat pan structure) when a force applied at the contact surface of the structure it will be deflect with 1.91mm which is small compared to the load applied from the weight of the occupant. Thus the seat pan is considered rigid when the load is applied over it.

4.5.2.1 ***Finite element method of determination of static strength analysis seat pan structure***

In strength analysis, considering loads acting on the component, equivalent stresses are calculated and compared with allowable stresses to check if the dimensions of the component are adequate. Finite Element Method is a numerical calculation method used to analyze such problems

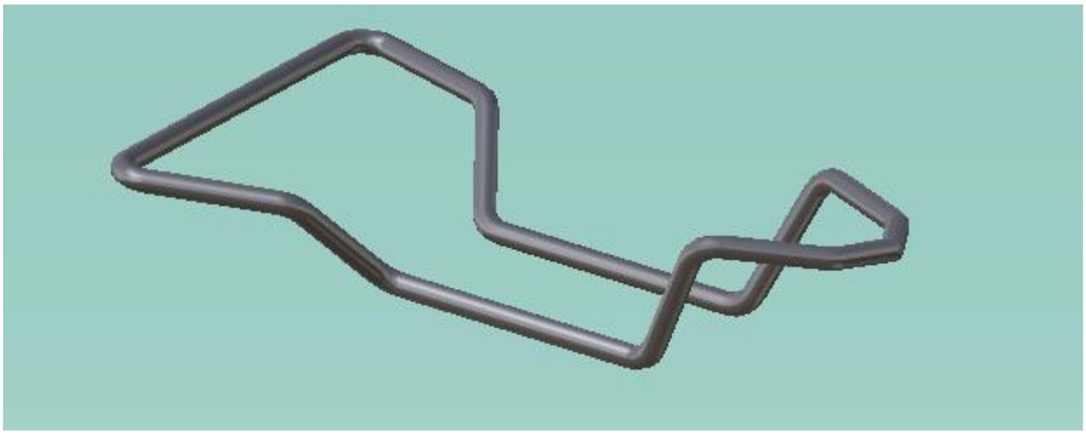


Figure 4. 34 Three dimensional model of seat pan structure in CATIA V5

Procedure of static Analysis

The procedure of using FEM usually consists of following steps.

a) **modelling;**

First, I prepare a model of seat pan structure in CATIA V5 software and save as. igs file format for Analysis of seat pan structure in ANSYS WORKBENCH 16 and import. igs file model in ANSYS Workbench simulation module

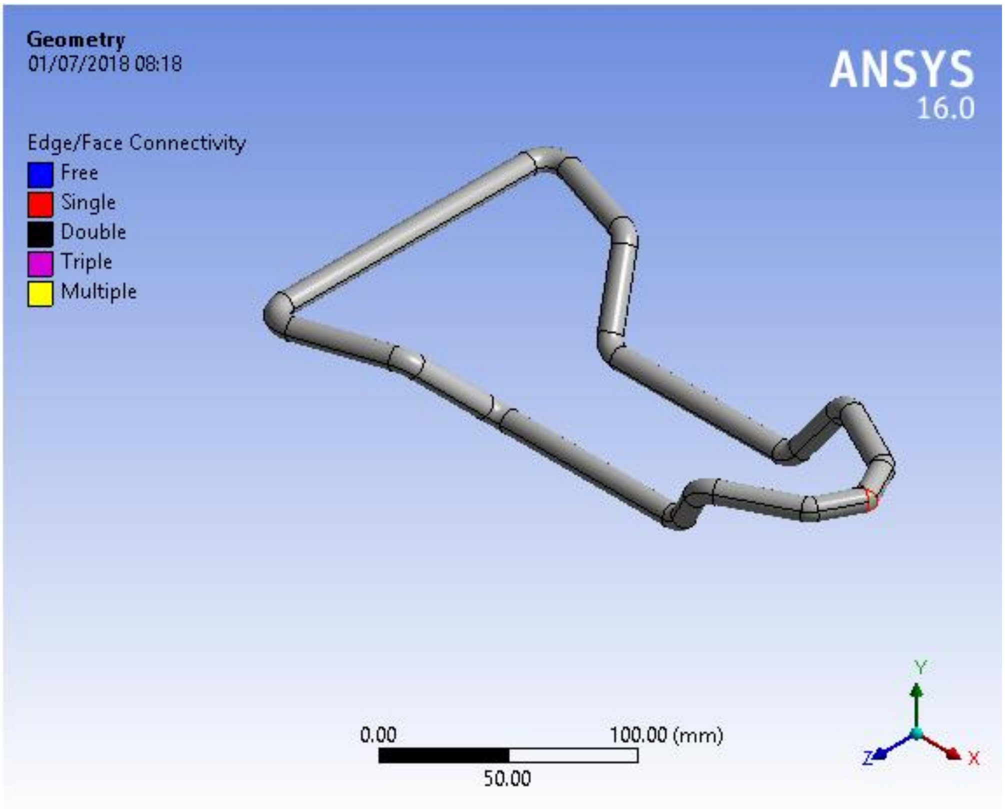


Figure 4. 35 model of seat pan structure imported to ANSYS workbench

The ANSYS demands for material properties which are defined using module engineering data. The material used for seat pan structure is carbon steel Fe E520 with mechanical properties of. The material properties are listed in Table 4.18

Table 4. 18 material properties of carbon steel Fe E 310

Mechanical properties of carbon steel Fe E 520	
Density	1780kg/m^3
Young's Modulus	207GPa
Poisson's Ratio	0.3
Tensile Strength	690MPa
Yield stress	520MPa

(b) Meshing;

Greater the fineness of the mesh better the accuracy of the results and Fig. 4.36 shows the meshed model in ANSYS consisting of 76783 nodes and 49566 elements

Type of Element: triangular

Number of nodes: 76783

Number of elements: 49566

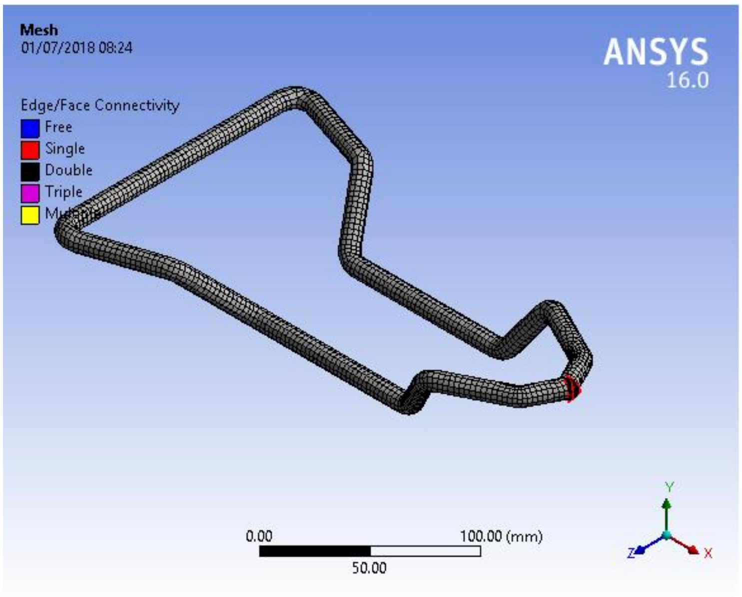


Figure 4. 36 seat pan structure triangular shape meshing element

(c) Determining and imposing loads and boundary conditions;

Boundary conditions play an important role in FEM. Therefore, they must be carefully defined to resemble actual working condition of the component being analysed. The seat pan structure is subjected to weight of the passenger. Load applied on the component when the seat pan is at the position of maximum bending moment load data were taken from the calculated result. Boundary condition is based on under supporting condition of seat pan.

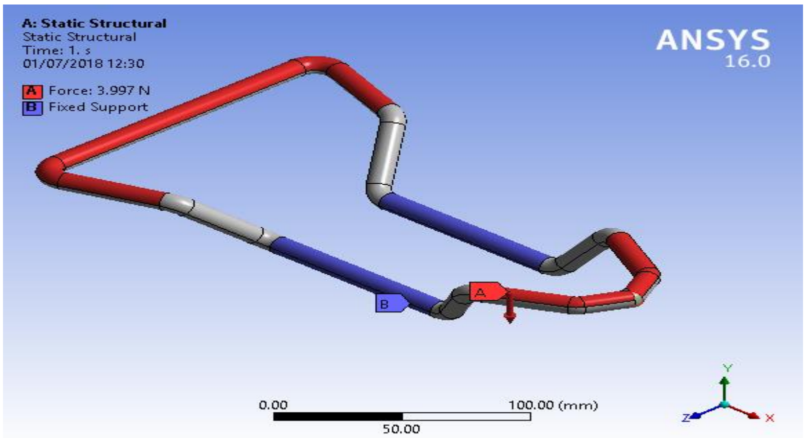
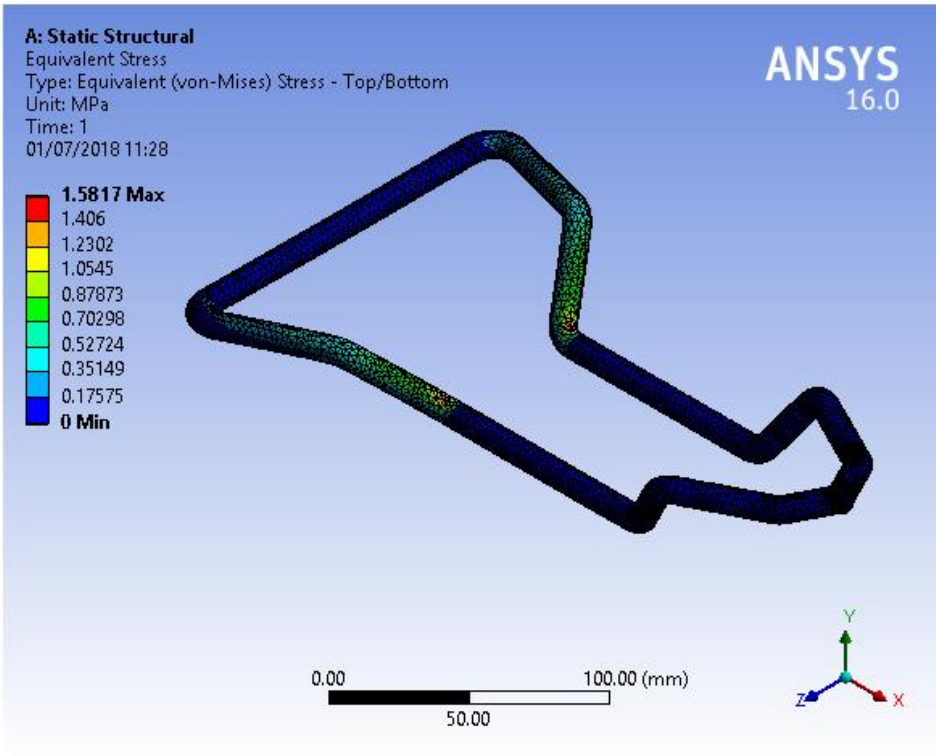
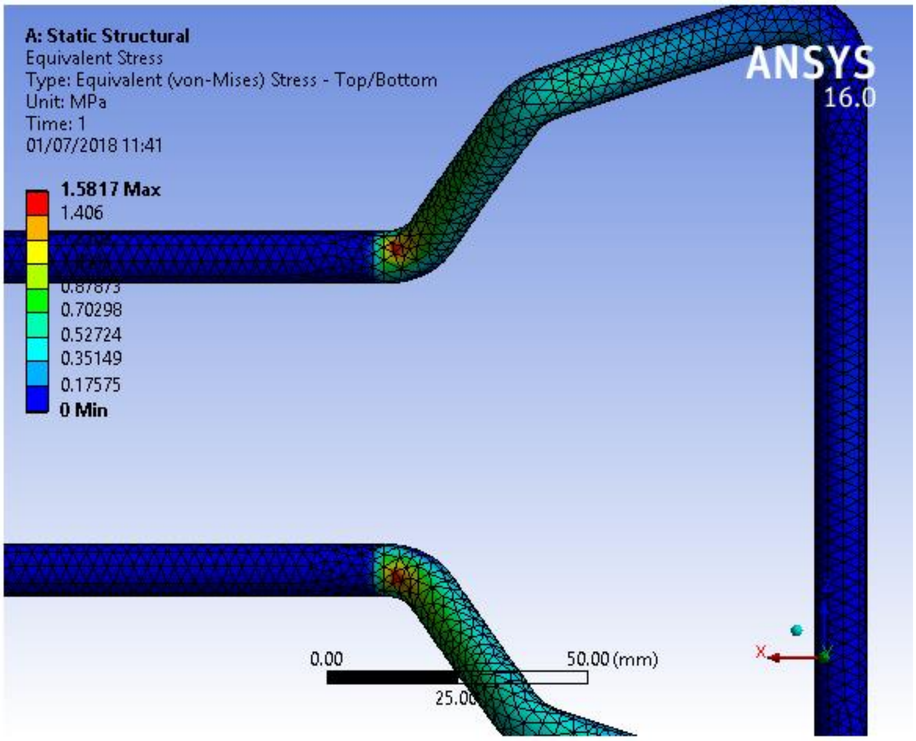


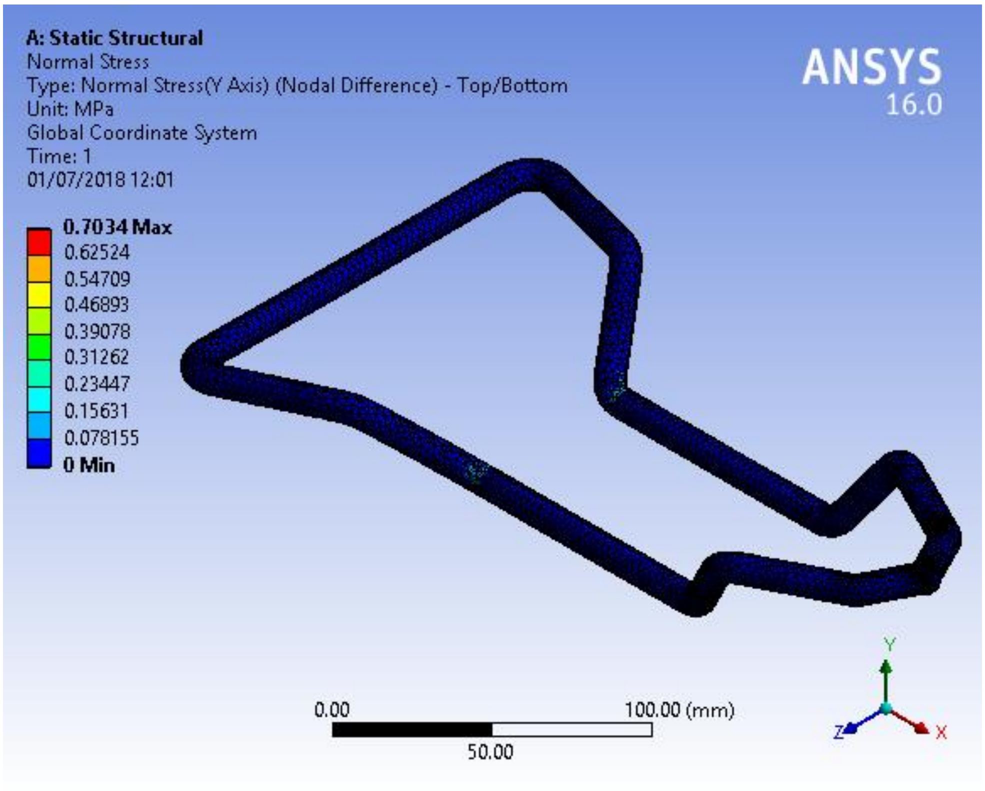
Figure 4. 37 seat pan structure boundary conditions and input data

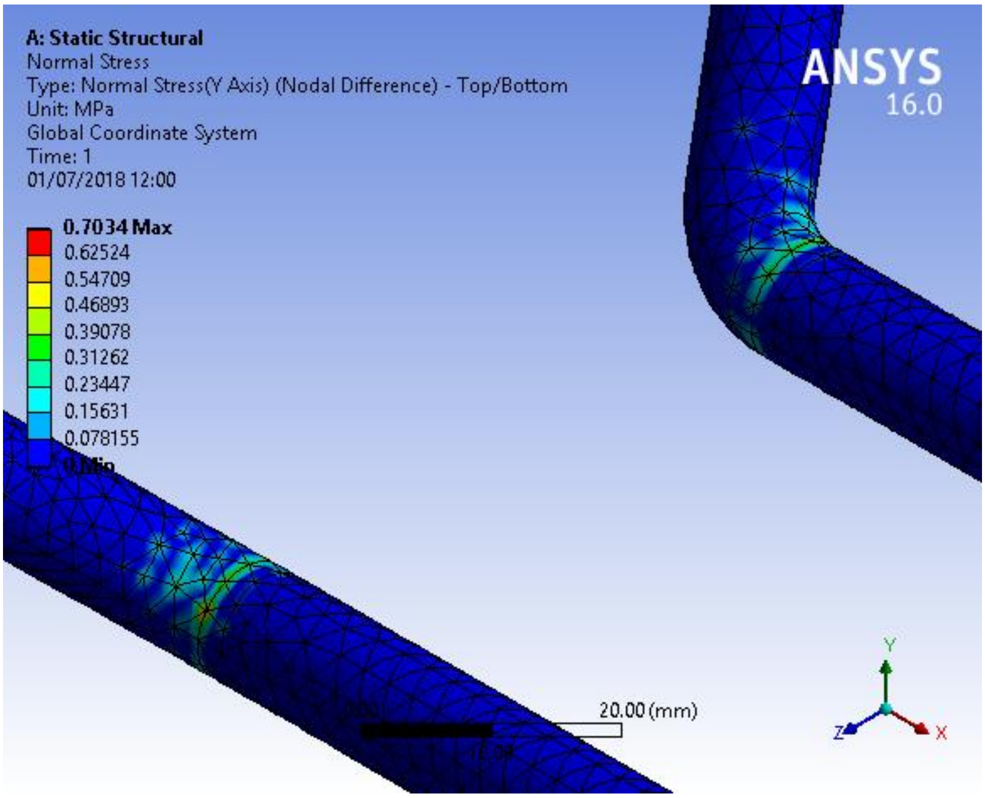
(d) Result analysis of finite element analysis

As the analysis of static structural analysis on seat pan structure, the weight of the occupant is the maximum load applied over the structure. While this load is applied over static structure the body is loaded for bending, shearing and deflecting from its structural position.






A: Static Structural
Normal Stress
Type: Normal Stress(Y Axis) (Nodal Difference) - Top/Bottom
Unit: MPa
Global Coordinate System
Time: 1
01/07/2018 12:01
0.7034 Max
0.62524
0.54709
0.46893
0.39078
0.31262
0.23447
0.15631
0.078155
0 Min
ANSYS
16.0
0.00
100.00 (mm)
50.00
Y
Z
X


A: Static Structural
Normal Stress
Type: Normal Stress(Y Axis) (Nodal Difference) - Top/Bottom
Unit: MPa
Global Coordinate System
Time: 1
01/07/2018 12:00
0.7034 Max
0.62524
0.54709
0.46893
0.39078
0.31262
0.23447
0.15631
0.078155
ANSYS
16.0
20.00 (mm)
Y
Z
X

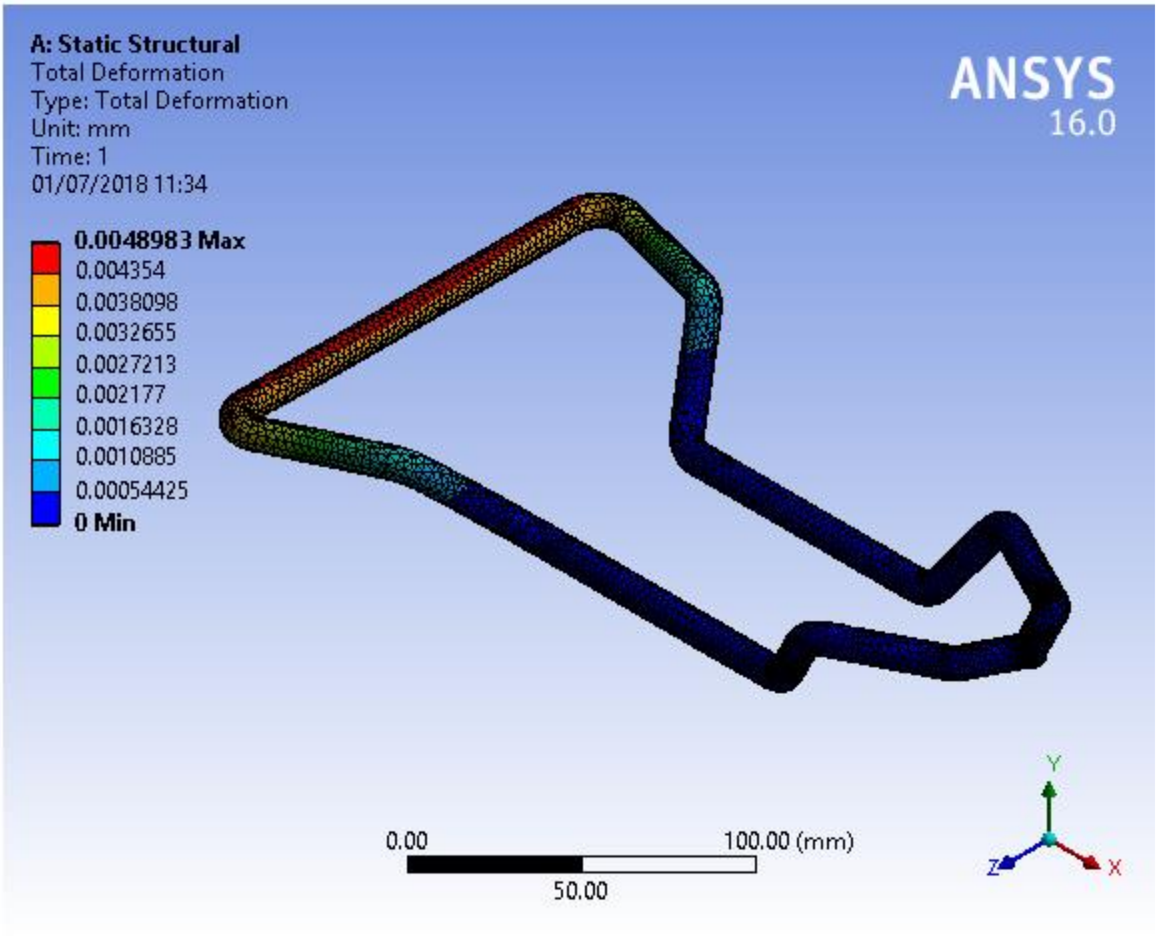


Figure 4. 38 FEA result analysis of seat pan frame

According to FE analysis result shown in Figure listed above in both parameters red location shows maximum stress which needs to be reinforcing the structure if its yield stress is approaching too and blue locations have low stresses during service life and have the potential for material removal for weight reduction.

4.6 Vehicle package geometry and passenger Seat distribution

4.6.1 Vehicle package geometry

Vehicle occupant packaging is the process of laying out the interior of a vehicle to achieve the desired levels of accommodation, comfort, and safety for the occupants. One important aspect in the vehicle industry is to design and manufacture the components of vehicle in respect to a specific coordinate system called the three-dimensional reference system. This system enables designers, engineers, constructors and other experts in production as well as assembly lines to easily identify the components and also to support the interaction and communication of these groups.

Vehicle Packaging in short is the organization of space for people and the parts of a vehicle to suite a specific need or transport. It is the first consideration for shaping the vehicle. At Vehicle Package stage, factors such as engine size, weight, width, height, luggage, number of passengers and their seating arrangement are targeted. Knowing all the said parameters plus more will help to establish a range of dimension within a category of vehicle types and cost, enabling the designer to target the shape of vehicle on a "family of dimensions" that will make it competitive.

Vehicle Packaging actually dictates of how a vehicle should be designed. It provides all the necessary information for the styling designers and part designers to proceed with at the following stage. Without vehicle packaging input, all the design engineers will not be able to proceed with the design concept in details. On the other hand, since Vehicle Packaging is meant to provide suitable space for people and parts in vehicle, human factor consideration is a must for the integration of the total design. In vehicle design, the term human factor is interchangeably called as automotive ergonomics.

In designing an automobile, there have to be certain dimensions that have been agreed for by the management, design, and manufacturing departments. As much as design attractiveness is important, so do the cost factor and manufacturing capability. Design has to be aligned with proper product positioning and budget as well as manufacturing line setup. To make sure all these factors merged in, vehicle packaging takes all this factors in drafting the total layout of the automobile. Ideally, a perfectly packaged automobile will definitely determine the number of sales. One must not misconstrue vehicle packaging as the total deciding factor for sales. Instead, Vehicle Packaging is the starting point of an automobile seat design processes.

4.6.2 **Passenger Seating Area**

The area of passenger seating was the section at which the users can be seated for transportation purpose. The surface area available for seated passenger's area will be calculated after deducting the following parameters from the total area of the internal floor area of the vehicle.

The area of driver compartment i.e. the space intended for deriver the steering wheel, instruments and other devices exclusive use and containing the driver seat,

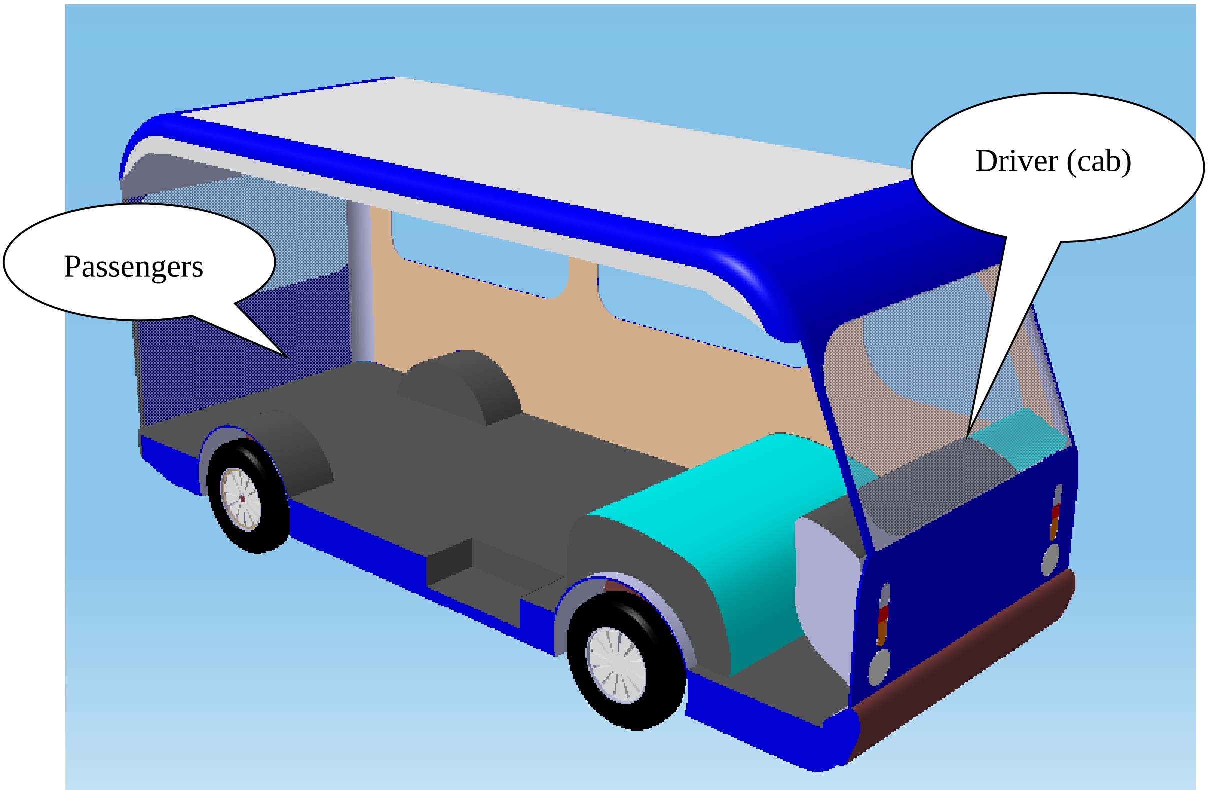


Figure 4. 39 Compartments of passengers and driver seating area in minibus.

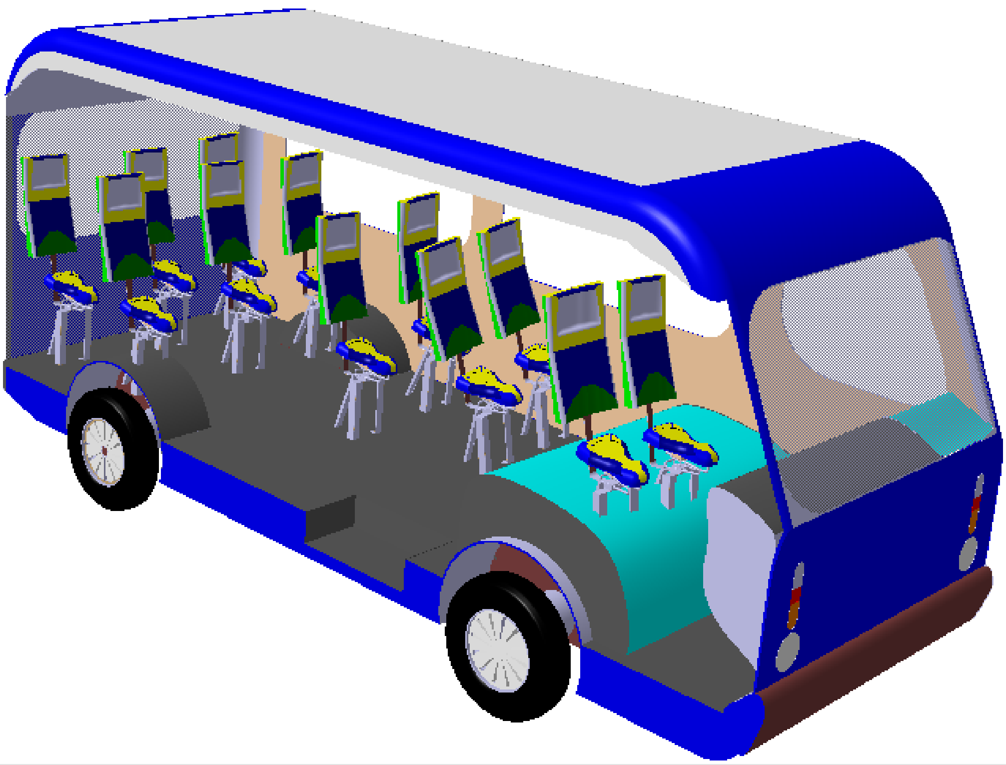


Figure 4. 40 Passenger seat layout in modelled minibus taxi

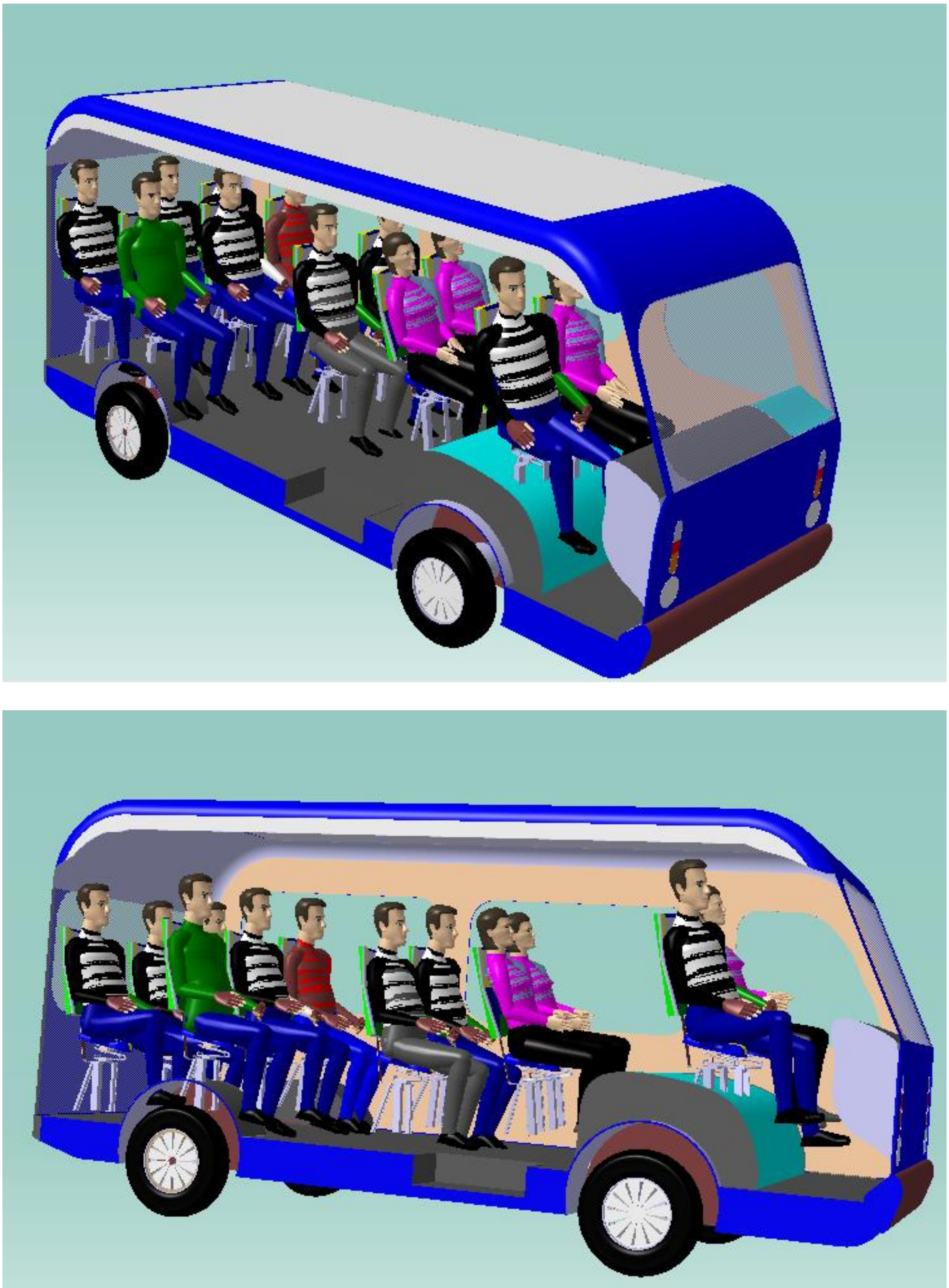


Figure 4. 41 Passenger seat layout with human body builder model

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Summery

This study immensely gives main comfort parameters as priority for human using commercial vehicle in their daily activities. The assessment can be accomplished in two systematic measuring evaluations. Those are subjective evaluations and objective evaluations. In the subjective evaluation questionnaires were prepared for comfort related in locally manufactured seat. In another term it is the way of need assessment of passenger seat comfort and improvement of locally manufactured seat. From the response of respondents parts to be modified can be identified. Form objective evaluations the mismatch of seat parameters and anthropometric measurements of the occupant can implies to re design passenger seat in modified condition. Depending up on this the new passenger seat was designed by considering anthropometric data of the occupant with some required strength for resisting the load applied over it.

5.2 Conclusions

This research consisted of subjective and objective evaluation methods to assess the comfort of passenger seat. Subjective evaluation method had been carried out in the form of questionnaire to approaches feeling of passengers and factors affecting seat discomfort had been determined. More than half of the respondents were not satisfied with current passenger seat and complain about certain parts of the seat; such as lateral support, back support, thigh comfort, gap between seat and seat width with respect to number of users.

Through subjective assessment, seat dimensions had been evaluated as:

- the respondents were satisfied with some of the dimensions of existing passenger seats and also they complained about certain dimensions of the seats features; such as seat depth and gap between seats. The results from survey would become one of guidelines to develop a better passenger seat design for intended personnel.
- The objective evaluation method had been carried out by measuring passenger Seat feature dimensions and anthropometric measurement of users which results (output) in the form of data reading from the measuring instrument. In this study it shows that a mismatch between the dimensions of existing locally manufactured passenger seats of minibus and the anthropometric dimensions of passengers observed.

- Therefore, the objectives of this study have been achieved and would definitely assist in an ergonomic passenger seat design of minibus. However, there are still spaces for development of the passenger seat design of minibus.
- Overall evaluation of existing seat has narrowed gab between seat and long seat depth result in 63% of discomfort condition, but in modified design the gap between seat can be decreased by changing the seat feature from chair style to saddle seat style.
- The seat pan depth of existing seat has been measured that 45cm which is too long which consume the space of the vehicle for occupant, but in modified seat the depth of seat is reduced to 30 cm and ridable features. This result in 40cm saved for occupant to freely move their legs between the seat;
- The existing seat width is measured that 40 cm wide for handling of hip breadth of 45cm which is represented this width in 13.5 cm which is enough to handle the weight of occupant in riding mode;
- A new proposed seat structure had been designed based on anthropometrical measurements and ergonomic consideration of the users. The features of this seat are not allowed to seat more than one person, which improve the comfort of the users in their journey;
- The strength of improved design model seat for the maximum weight of occupant of 110kg can be evaluated and the structure could be handle the load by selecting proper material;
- The new improved passenger seat design is illustrated in order to explain the conceptual design development. The structure, strength, function, comfort and shape of passenger seat design are parameters to be determined for improving a new conceptual design. In addition, analysis also employed to evaluate seat strength of seat pan structure and backrest structure in order to take account to car seat standards for ensuring safety.

The significance components of minibus seat are backrest and seat pan, which should be carefully designed. Consequently, backrest frame receives force occupant static loading and weight transfer during acceleration then it should be strong enough to resist load applied over it. Styling is also determined in design phase to meet the customer needs for attractive buyers.

It is possible to carry a great number of passengers in public transport units. But in attention to the users comfort and safety, it is necessary to limit the number of passengers in such way that provide the minimum comfort that the users deserve. The interior of NISSAN NV350 URVAN model minibuses should accommodate 12 seated passengers excluding driver if proper seat design and seat distribution are followed and well addressed.

5.3 Recommendations

As per the result of the study, it is possible to make certain recommendations in order to improve the passenger seat design of minibus. The overall notion of this study is not to give all in all a detailed prescription for the design of passenger seats in minibus. However, the suggestions that are forwarded herein are aimed at giving more general guidelines to better suit this seat design in its role toward improving seat design, manufacturing and reducing the level of discomfort currently observed. The following suggestions are forwarded as the result of the present study:

- ✓ In order to allow the passengers a sense of comfort, passenger seats of minibus should be ergonomically designed (the local manufacturers of passenger seats of minibus should use the anthropometric dimensions of passengers for the design and manufacturing of these seats).
- ✓ It is recommended that while designing seats, designers should use guidelines for seat dimensions proposed by the Society of Automotive Engineers (SAE).
- ✓ Local seat manufacturers usually design or redesign the seats to suit the expectations of their customers without due consideration for the comfort and safety of the passengers. Therefore, it is advisable if the Ethiopian road and transport authority control this case.

Generally,All seats shall meet the following minimum requirements;

- ✓ All applicable design materials and specification requirements for passenger seat
- ✓ Seat pan and cover shall be slip cover type, removable and replicable without removing the entire seat.
- ✓ All metal surfaces shall be covered and coated.
- ✓ All seats shall have not less than 600mm hip to knee room spacing between seats.
- ✓ All seat shall face forward

5.4 Future work

As this research was concentrating more on the seat comfort issues there was not much focusing on safety factors. Therefore, in future it is hoped that there will be more studies on the safety issues at the same time during the comfort analysis of passenger seat comfort.

As this research was concentrating more on the seat dimensions, there was not much focusing on other factors for ride comfort. Therefore, in the future, it is suggested that other interested investigators conduct more studies on other factors as well as seat dimensions.

In the modified seat feature there is spring which is used to dump vibration by absorbing energy transmitted to human body. Therefore, in the future, it suggested that to determine the amount of energy absorbed by spring and thinking for dumping the oscillation of the spring.

6 References

[1] Hiling, D. (1996).Transport and developing countries. London:Rontledge Publisher.

[2] Xiao, G., Lei, L., Dempsey, P.G., Lu, B., & Liang, Y. (2005). Isometric muscle strength and anthropometric characteristics of a Chinese sample. International Journal of Industrial Ergonomics, 35, 674-679.

[3] Bridger, R.S. (1995). Introduction to Ergonomics. New York: McGraw-Hill.

[4] Barroso, M.P., Arezes, P.M., Costa, L.G., & Miguel, A.S. (2005). Anthropometric study of Portuguese workers. International Journal of Industrial Ergonomics, 35(4), 401-410.

[5] Timothy, D.S. and M.M. Trivedi, 2003. Real-time stereo-based vehicle occupant posture determination for intelligent airbag deployment. In: Proceeding of the IEEE International Conference on Intelligent Vehicles, pp: 570-574.

[6] Gautama, S., S. Lacorix and M. Devy, 1999. Evaluation of stereo matching algorithms for occupant detection. In: Proceedings of the International Workshop on Recognition, Analysis and Tracking of Faces and Gestures in Real-Time System, pp: 177-184.

[7] Devy, M., A. Giralt and A. Marin-Hernandez, 2000. Detection and classification of passenger occupancy using stereovision. In: Proceeding of IEEE Intelligent Vehicles Symposium, pp: 714-719.

[8] Parcells, C., Stommel, M. and Hubbard, R. P. 1999, Mismatch of classroom furniture and student body dimensions – Empirical findings and health implications, Journal of Adolescent Health, 24, 265 – 273.

[9] Chaffin D.B,, Gunnar B.J., Bernard J.M. Occupational biomechanics, Ed Wiley Interscience, 1999 pgs 377-379

[10] ISO 9241-5:1998, Requisitos ergonómicos para trabajos de oficina con pantallas de visualización de datos, parte 5: disposición del puesto de trabajo y requisitos postulares.

[11] Grandjean, E. (1988). Fitting the Task to the Man. International Publications Service, New York.

[12] Schoberth, H. (1962). Sitzhaltung. Sitzschäden. Sitzmöbel. Springer, Berlin

[13] Chaffin, D. B. and Andersson, G. B. J. (1991). Occupational Biomechanics. 2nd Ed. John Wiley & Sons, Inc.

[14] Visser, B., de-Looze, M.P. and Vegger, D., (2003), "The effects of precision demands during a low intensity pinching task on muscle activation and load sharing of the fingers", Journal of Electromyography and Kinesiology, 13(2), 149-157.

[15] Nordin, B.E.C. and Morris, H.A., (2004), "Osteoporosis and Vitamin D", Journal of Cellular Biochemistry,49.

[16] Lueder, R., (2004), "Ergonomics of seated movement: A review of the scientific literature", Board of Certification of Professional Ergonomists, Humanics ErgoSystems, Inc.

[17] Mergl, C., Klendauer, M., Mangen, C., Bubb, H., (2006), "Predicting long term riding comfort in cars by contact forces between human and seat", SAE 100, 2005-01-2690.

[18] Porter, D., Rassenti, S., Roopnarine, A., Smith, V., 2003, "Combinatorial auction design",Proceedings of the National Academy of Sciences,100, 11153–11157.

[19] Ariens, G., Bongers, P., Douwes, M., Miedema, M., Hoogendoorn, W., van der Wal, G., Bouter, L. & van Mechelen, W. (2001), "Are neck flexion, neck rotation, and sitting at work risk factors for neck pain? Results of a prospective cohort study", Occupational and Environmental Medicine, 58; 200-207.

[20] Kolich, M., (2003), "Automobile Comfort: occupant preferences vs. Anthropometric accommodation", Applied Ergonomics, 34; 177-184.

[21] Chateauroux, E., Wang, X., (2010), "Car egress analysis of younger and older drivers for motion simulation", Applied Ergonomics, 42; 169-177.

[22] Fazlollahtabar, H., (2010), "A subjective framework for seat comfort based on a heuristic multi criteria decision making technique and anthropometry", Applied Ergonomics, 42; 16-28.

[23] Siefert, A.,Pankoke,S.,Wolfel,H.P., 2008, "Virtual optimisation of car passenger seats: Simulation of static and dynamic effects on drivers' seating comfort", International Journal of Industrial Ergonomics,38;410–424.

[24] Yanga,J., Kim,J.H., Abdel-Malek,K., Marler, T., Beck,S., Kopp, G.R., (2007), "A new digital human environment and assessment of vehicle interior design", Computer-Aided Design, 39; 548-558.

[25] Gragg, J.,Yang, J. & Howard, B., (2012), "Hybrid method for driver accommodation using optimization-based digital human models", Computer-Aided Design 44; 29–39.

[26] Fazlollahtabar, H., (2010), "A subjective framework for seat comfort based on a heuristic multi criteria decision making technique and anthropometry", Applied Ergonomics, 42; 16-28.

[27] Diebschlag, W., Heidinger, F., Dupuis, H., Hartung, E. and Meiller, H. (1995). Seat Ergonomics. Aspects of Industrial Medicine and Technology Relating to Seat Design. Germany, verlag moderne industrie, D-86895 Landsberg.

[28] Jonsson, B. and Andersson, G. B. J. (1978). Functional Anatomical and Biomechanical Aspects on Sitting, In B. Jonsson, Ed., Sitting Work Postures, National Board of Occupational Safety and Health (Sweden) No. 12, pp. 6-17 (in Swedish).

[29] Nachemson, A. and Morris, J. M. (1964). In vivo measurements of intradiscal pressure. J. Bone Joint Surg., 46A, 1077.

[30] Roebuck, J. A. (1993). Anthropometric Methods: Designing to Fit theHuman Body. Human Factors and Ergonomics Society.

[31] Lehto, M. R. and Foley, J. P. (1990). The Effect of Law and Training on All-Terrain Vehicles Riders' Safety-Related Behaviors. Proceedings of the Human Society-34th Annual Meeting, Orlando, FL, pp. 966-969.

[32] Knight, I. (1984). The Heights and Weights of Adults in Grat Britain, London: HMSO.

[33] http://WWW.saylor.org .

[34] Webster's Ninth New collegiate Dictionary, 1998 Merriam-Webster

[35] Oborne, D,J., Clarke, M.J., (1973), "The development of questionnaire surveys for the investigations of passenger comfort", Ergonomics, 16,855-869

[36] Griffin, M.J.,(1995), "The ergonomics of vehicle comfort", Proceedings of the 3rd International Conference on Vehicle Comfort and Ergonomics. March 29-31, Bologna, Italy, Paper No.95A1026, 213-221

[37] Reynolds,H.M., (1993), “Automotive Seat Design for Sitting Comfort”, Automotive Ergonomics (Edited by Peacock, B and Karwoski, W), 99-116, London: Taylor and Francis.

[38] Branton, P., (1969) Behaiviour, body mechanics and discomfort. Ergonomics, 12, 316 327

[39] Parcells, C.; Stommel, M.; and Hubbard, R.P. (1999). Mismatch of classroom furniture and student body dimensions. Journal of Adolescent Health, 24(4), 265-273.

[40] Troussier, B.; Tesniere, C.; Fauconnier, J.; Grison, J.; Juvin, R.; and Phelip, X. (1999). Comparative study of two different kinds of school furniture among children. Ergonomics, 42(3), 516-526.

[41] R.S. KHURMI, J. G. (2005). A text book of machine design. india: EURASIA PUBLISHING HOUSE.

7 Appendix A: check list for data collection

Adama science and Technology University

Department of mechanical and vehicle engineering

Questionnaire

The objective of this questioner: **-** This paper is prepared for the purpose of gathering information regarding the evaluation of locally built passenger seat features, so as to forward some achievable solutions that may help for development of new design and cost effective passenger seat locally built for different vehicles. However, the success of this study largely depends on your genuine, frank and time response; hence you are very kindly requested to reply to the questions faith fully.

General description

- In any part of the questionnaires, you are not required to write your name.
- Put '**X** or **√**' mark against the most appropriate answer.

Thank you in advance for taking time to participate in this study.

Part Ⅰ. General information

- Gender

  Male ☐ ☐ female

- Please indicate the Range of your Age by placing **X** or √ in space provided for it:
  - less than 15 ☐
  - 15-25 ☐
  - 26-34 ☐
  - 35-45 ☐
  - 46-54 ☐
  - 55-65 ☐
  - 65-74 ☐
  - 75-85 ☐
  - above 85 ☐
- Your weight range:
  - 25- 35 ☐
  - 36-44 ☐
  - 45-55 ☐
  - 55-65 ☐
  - 66-74 ☐
  - 75-85 ☐
  - 86-94 ☐
  - above 95 ☐

Part II. Passenger Evaluation data sheet.

Rate the following seat features experiences in combination with the task you performed and in relation to seat design aspects. Put '**X** or √' marks against the list you consider is existing situation of seat feature in public transportation of minibus taxi. On a 5-point scale (1 = low, 5= high), the passengers were asked about:

s/n	**description**	**1**	**2**	**3**	**4**	**5**	**declare**
1	seat height						1-very short 2- short 3-just nice, 4-long, 5-very long
2	backrest height						
3	head rest						
4	seat depth						
5	seat width						1-too narrow 2-narrow 3-just nice 4-wide 5-very wide
6	backrest width						
7	gap between seats						
11	inclination of backrest						1-too small 2-small, 3-just nice, 4-larg , 5-very large
8	stability						1-too shaky, 2-shaky, 3-just nice, 4-stable, 5-very stable

9	buttock comfort	☐ ☐ ☐ ☐ ☐	1very uncomfortable 2-uncomfortable 3-just nice 4-comfertable 5-very comfortable
10	thigh comfort	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	
12	neck support	☐ ☐ ☐ ☐ ☐	
13	overall evaluation		

Part Ⅲ. Anthropometric measurement data sheet

S/N	Body parts	Anthropometric measurements in cm
1	stature	
2	Sitting height	
3	Sitting to shoulder height	
4	Lowest point scapula to sitting	
5	Thigh clearance height (TCH)	
6	Shoulder-elbow length	
7	Shoulder breadth (BB)	
8	Hip breadth seated (HB)	
9	buttocks to popliteal length (BPL)	
10	Popliteal height (PH)	

Part IV. Dimensions of Passenger seat data sheet

S/N	Seat Features	Length In Mm
1	Seat Height	
2	Seat Width	
3	Seat Depth	
4	Backrest Height	
5	Backrest Width	
6	Gap Between Seat	
7	Head Rest Height	
8	Inclination Of Back Rest	
9	Stability	
10	Buttock Comfort	
11	Thigh Comfort	
12	Head Rest Comfort	
13	Head Rest	

8 Appendexis B: Materials Properties

Table B1: Materials Properties at Room Temperature [41].

Table 2.1. Physical properties of metals.

Metal	*Density* (*kg/m³*)	*Melting point* (*°C*)	*Thermal conductivity* (*W/m°C*)	*Coefficient of linear expansion at 20°C* (*μm/m/°C*)
Aluminium	2700	660	220	23.0
Brass	8450	950	130	16.7
Bronze	8730	1040	67	17.3
Cast iron	7250	1300	54.5	9.0
Copper	8900	1083	393.5	16.7
Lead	11 400	327	33.5	29.1
Monel metal	8600	1350	25.2	14.0
Nickel	8900	1453	63.2	12.8
Silver	10 500	960	420	18.9
Steel	7850	1510	50.2	11.1
Tin	7400	232	67	21.4
Tungsten	19 300	3410	201	4.5
Zinc	7200	419	113	33.0
Cobalt	8850	1490	69.2	12.4
Molybdenum	10 200	2650	13	4.8
Vanadium	6000	1750	—	7.75

Table B2. tensile and yield properties of standard steels with their uses according to IS : 1570 (Part I)-1978 (Reaffirmed 1993).[41]

Table 2.5. Indian standard designation of steel according to IS : 1570 (Part I)-1978 (Reaffirmed 1993).

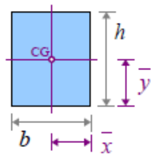
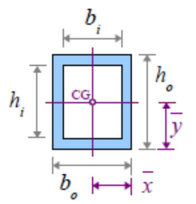
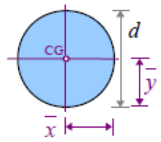
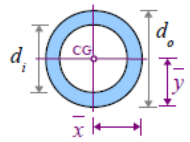
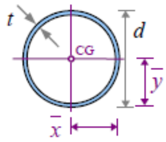
Indian standard designation	*Tensile strength (Minimum) N/mm^2*	*Yield stress (Minimum) N/mm^2*	*Minimum percentage elongation*	*Uses as per IS : 1871 (Part I)–1987 (Reaffirmed 1993)*
Fe 290	290	170	27	It is used for plain drawn or enamelled parts, tubes for oil well casing, steam, water and air passage, cycle, motor cycle and automobile tubes, rivet bars and wire.
Fe E 220	290	220	27	
Fe 310	310	180	26	These steels are used for locomotive carriages and car structures, screw stock and other general engineering purposes.
Fe E 230	310	230	26	
Fe 330	330	200	26	
Fe E 250	330	250	26	
Fe 360	360	220	25	It is used for chemical pressure vessels and other general engineering purposes.
Fe E 270	360	270	25	
Fe 410	410	250	23	It is used for bridges and building construction, railway rolling stock, screw spikes, oil well casing, tube piles, and other general engineering purposes.
Fe E 310	410	310	23	
Fe 490	490	290	21	It is used for mines, forgings for marine engines, sheet piling and machine parts.
Fe E 370	490	370	21	
Fe 540	540	320	20	It is used for locomotive, carriage, wagon and tramway axles, arches for mines, bolts, seamless and welded tubes.
Fe E 400	540	400	20	
Fe 620	620	380	15	It is used for tramway axles and seamless tubes.
Fe E 460	620	460	15	
Fe 690	690	410	12	It is used for locomotive, carriage and wagon wheels and tyres, arches for mines, seamless oil well casing and drill tubes, and machine parts for heavy loading.
Fe E 520	690	520	12	
Fe 770	770	460	10	It is used for locomotive, carriage and wagon wheels and tyres, and machine parts for heavy loading.
Fe E 580	770	580	10	
Fe 870	870	520	8	It is used for locomotive, carriage and wagon wheels and tyres.
Fe E 650	870	650	8	

9 Appendix C: Properties of Areas

Center of Gravity, Area, Moment of Inertia, and Radius of Gyration

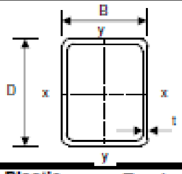
In these diagrams, the polar moment of inertia, *J*, is about the center of gravity (the small circle marked “CG”).

The moments of inertia, *Ix* and *Iy*, and radii of gyration, *rGx* and *rGy*, are about the x-x and y-y neutral axes (horizontal and vertical magenta lines).

Rectangle	Hollow rectangle	Circle	Hollow circle	Thin-walled hollow circle
				
$\bar{x}=\frac{b}{2}$, $\bar{y}=\frac{h}{2}$ $A=b\,h$ $I_x=\frac{b\,h^3}{12}$ $I_y=\frac{h\,b^3}{12}$ $J=\frac{b\,h}{12}(h^2+b^2)$ $r_{Gx}=\frac{h}{\sqrt{12}}$	$\bar{x}=\frac{b_o}{2}$, $\bar{y}=\frac{h_o}{2}$ $A=b_o h_o-b_i h_i$ $I_x=\frac{b_o h_o^3-b_i h_i^3}{12}$ $I_y=\frac{h_o b_o^3-h_i b_i^3}{12}$ $J=I_x+I_y$ $r_{Gx}=\sqrt{\frac{b_o h_o^3-b_i h_i^3}{12\,A}}$	$\bar{x}=\bar{y}=\frac{d}{2}$ $A=\frac{\pi d^2}{4}$ $I_x=I_y=\frac{\pi d^4}{64}$ $J=\frac{\pi d^4}{32}$ $r_{Gx}=r_{Gy}=\frac{d}{4}$	$\bar{x}=\bar{y}=\frac{d_o}{2}$ $A=\frac{\pi(d_o^2-d_i^2)}{4}$ $I_x=I_y=\frac{\pi(d_o^4-d_i^4)}{64}$ $J=\frac{\pi(d_o^4-d_i^4)}{32}$ $r_{Gx}=r_{Gy}=\frac{\sqrt{d_o^2-d_i^2}}{4}$	If a hollow circle has a thin wall of thickness *t*, then the area is equal to the circumference times the wall thickness. The cross-section of a copper water pipe is a good example of thin-walled hollow circle. $\bar{x}=\bar{y}=\frac{d}{2}$ $A=\pi\,d\,t$

10 Appendix D: standard of carbon steel

Rectangular



Designation Size	Designation Thickness		Mass Per Metre	Area Of Section	Second Moment Of Area Axis x-x	Second Moment Of Area Axis y-y	Radius Of Gyration Axis x-x	Radius Of Gyration Axis y-y	Elastic Modulus Axis x-x	Elastic Modulus Axis y-y	Plastic Modulus Axis x-x	Plastic Modulus Axis y-y	Torsional Constants J	Torsional Constants C	Surface Area Per Metre
DxB	t			A											
mm	mm		kg/m	cm^2	cm^4	cm^4	cm	cm	cm^3	cm^3	cm^3	cm^3	cm^4	cm^3	m^2/m
19x9	1.0	*	0.411	0.494	0.206	0.0621	0.645	0.354	0.216	0.138	0.283	0.165	0.165	0.244	0.0526
	1.2	*	0.421	0.577	0.231	0.0689	0.633	0.346	0.243	0.153	0.323	0.188	0.187	0.273	0.0519
	1.6	*	0.540	0.728	0.268	0.0783	0.607	0.328	0.282	0.174	0.390	0.224	0.222	0.315	0.0505
25x12	1.0	*	0.555	0.674	0.510	0.160	0.869	0.487	0.408	0.266	0.521	0.310	0.410	0.467	0.0706
	1.2	*	0.659	0.793	0.583	0.181	0.857	0.478	0.467	0.302	0.604	0.358	0.473	0.532	0.0699
	1.6	*	0.859	1.02	0.705	0.215	0.833	0.460	0.564	0.358	0.749	0.440	0.582	0.638	0.0685
25x13	1.2	*	0.670	0.817	0.617	0.219	0.869	0.517	0.494	0.337	0.632	0.398	0.549	0.586	0.0719
	1.6	*	0.860	1.05	0.749	0.262	0.845	0.500	0.599	0.402	0.786	0.492	0.679	0.707	0.0705
32x16	1.0	*	0.707	0.894	1.15	0.391	1.14	0.661	0.722	0.488	0.905	0.558	0.962	0.847	0.0926
	1.2	*	0.838	1.06	1.34	0.449	1.12	0.652	0.836	0.562	1.06	0.650	1.12	0.978	0.0919
	1.6	*	1.10	1.37	1.66	0.550	1.10	0.634	1.04	0.688	1.34	0.818	1.41	1.21	0.0905
38x19	1.0	*	0.858	1.07	1.99	0.676	1.36	0.793	1.05	0.711	1.30	0.805	1.65	1.23	0.111
	1.2	*	1.02	1.27	2.32	0.783	1.35	0.784	1.22	0.824	1.53	0.943	1.93	1.43	0.110
	1.6	*	1.34	1.66	2.91	0.973	1.33	0.766	1.53	1.02	1.95	1.20	2.46	1.79	0.109
38x25	1.0	*	0.949	1.19	2.40	1.26	1.42	1.03	1.26	1.01	1.52	1.14	2.63	1.66	0.123
	1.2	*	1.13	1.42	2.80	1.47	1.41	1.02	1.48	1.17	1.79	1.35	3.10	1.94	0.122
	1.6	*	1.50	1.85	3.55	1.85	1.39	1.00	1.87	1.48	2.30	1.72	3.99	2.45	0.121
50x25	1.0	*	1.15	1.43	4.69	1.60	1.81	1.06	1.87	1.28	2.31	1.43	3.85	2.22	0.147
	1.2	*	1.37	1.71	5.50	1.88	1.80	1.05	2.20	1.50	2.73	1.69	4.54	2.59	0.146
	1.6	*	1.81	2.23	7.02	2.37	1.77	1.03	2.81	1.90	3.53	2.17	5.85	3.29	0.145
	2.0	*	2.15	2.74	8.38	2.81	1.75	1.01	3.35	2.25	4.26	2.62	7.06	3.92	0.143
	2.3	*	2.48	3.10	9.31	3.10	1.73	1.00	3.72	2.48	4.78	2.92	7.90	4.34	0.142
	2.5	*	2.62	3.34	9.89	3.28	1.72	0.991	3.95	2.62	5.11	3.12	8.43	4.60	0.141
	3.0	*	3.07	3.91	11.2	3.67	1.69	0.969	4.47	2.93	5.86	3.56	9.64	5.18	0.140
	3.2	*	3.41	4.13	11.6	3.80	1.68	0.960	4.65	3.04	6.14	3.73	10.1	5.38	0.139
50x30	2.0		2.31	2.94	9.54	4.29	1.80	1.21	3.81	2.86	4.74	3.33	9.77	4.84	0.153
	2.5		2.82	3.59	11.3	5.05	1.77	1.19	4.52	3.37	5.70	3.98	11.7	5.72	0.151
	3.0		3.30	4.21	12.8	5.70	1.75	1.16	5.13	3.80	6.57	4.58	13.5	6.49	0.150
	4.0		4.20	5.35	15.3	6.69	1.69	1.12	6.10	4.46	8.05	5.58	16.5	7.71	0.146
60x40	1.6	*	2.37	3.03	15.2	8.16	2.24	1.64	5.07	4.08	6.12	4.64	16.9	6.72	0.195
	2.3	*	3.33	4.25	20.7	11.0	2.20	1.61	6.88	5.50	8.44	6.38	23.4	9.10	0.192

Appendix E: vehicle body specification.

11 Appendix F: Engineering drawings