Seating comfort analysis: a virtual ergonomics study of bus drivers in private transportation

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Abstract. Background: Seating comfort is one of the most important indicators of the performance of automotive seats. Seat is one of the places in the vehicle where most of the drivers spent driving. A good seat can prevent a lot of painful disorders including low back pain, which is typical of bad posture. Driver posture is one of the most important issues that need to be considered in the vehicle seat design process. Research Gap: Around the world, there have been many studies on seating comfort including car seats, truck seats, bus seats, train seats, etc. However, in India there are not many studies focusing on bus drivers seating comfort. Objective: This study aimed at investigating bus drivers seating comfort in private transportation using virtual ergonomics. Methods: We have considered a group of male bus drivers with different percentiles. And, we have selected a bus seat typically used in private transportation. The anthropometry of drivers and dimensions of the seat has been measured and modelled in the virtual environment (CATIA V6). For the seating comfort analysis, RULA (Rapid Upper Limb Assessment) analysis was performed. Results and Discussion: The RULA score revealed that the drivers with 77th to 94th percentile felt comfortable with the seat. The rest had higher RULA scores and felt discomfort. Conclusion: The bus seat design needs to be changed by considering Indian anthropometry. Also, this study only examined a few subjects; hence, further investigation would give better recommendations. Application: The benefit of virtual ergonomics is used in this project. The methodology used in this study could be used for other seat studies.

1. Introduction
Drivers face a lot of medical issues such as cramping, muscle fatigue, impeded circulation, spinal ache, depression, stiffness, aches, numbness in spine and other musculoskeletal issues that are even chronic. One of the factors influencing these issues is the posture in which they sit. Specifically, in India the ergonomics of the driver is given least importance and the drivers end up using pillows, towels and other materials to provide the cushioning and make their drive little comfortable. A seat that is comfortable in static conditions may have poor dynamic characteristics that make it uncomfortable on the road. A considered comfortable seat by a user also depends on the seating posture and how long it has been used. The optimum seat for one vehicle may not be the optimum seat for another vehicle and the sitting posture of one person may not fit another. It is therefore important to consider the person utilizing the seat while designing it. Until now, there are scarcely any local studies on seat comfort for the average population in Indian sub-continent for Buses. Most of the automotive seats, especially bus driver seats in India, are not designed according to the Indian anthropometry neither automakers are willing to invest resources in designing components appeasing human ergonomics [1].
Park S J has compared actual seating comfort position with respect to recommendations in the literature. Gender correlations and comparisons were also made to conclude their results [2]. Park S J further studied ergonomic comforts on most widely used sedan and compact cars with pressure measurements and 3D scanner with ANOVA statistical analysis [3, 4]. Jianghong developed a fuzzy set model of a multistage comfort scale (MCS) and assessed seating comfort, coupled with the techniques of human back shape, EMG measurements and posture analysis. The study concluded that MCS is a rapid but comprehensive evaluation method for single chair evaluation [5]. Mergl worked on a relationship between contact force distribution and discomfort in human-seat interaction was studied using pressure distribution and validation [6].

Organizations undertaking public transports are concerned about IPK (Index of Passengers per Kilometre travelled) operation which ultimately generates funds for investment, leading to improvement of the service provision quality indicators. The application of ergonomic principles shall not only help increasing machine performance and productivity, but also aid human operators to be comfortable and secure [7,8]. Lower back pain, ease of manual materials handling and whole body vibration caused while driving various bus models of public transport were studied and most of the drivers are likely to get chronic lower back pain [9]. Moreover, unavailability of updated standard Indian human anthropometry data has limited the ergonomic studies for Indian drivers and passengers [10]. Seating comfort analysis can be performed using vibration evaluation, electromyography, electroencephalography, oxygen saturation, posture-image analysis, spinal loading, CAE, pressure, temperature and humidity monitoring, etc. [11, 12 & 13]. This study has made an effort to evaluate the bus driver seat comfort through CAE method to analyse seating comfort by measuring the seat, driver cabin dimensions and the anthropometry of various people falling under certain range of population. The measured data were used to study the comfort levels in a virtual environment for an individual inside the driver cabin.

2. Method
Human anthropometry data were recorded and obtained for drivers of different range of heights and body mass. Measured anthropometry data were compared with existing data to facilitate validation. Data are tabulated for the software inputs. Bus driver’s seat dimensions were measured. Bus seat dimensional values are given as input in CATIA V5 modelling software. Human anthropology data were used to model manikin of the specified data for the human ergonomics analysis under static condition. Human CAD model is posturized with the bus seat dimension. The posturized model is adjusted according to real-time driving position. RULA is performed for the human model in the driving position. Results obtained are compared with the standard RULA chart. Conclusions are made according to stress levels and RULA scores obtained from the software.

![Figure 1. Methodology to conduct virtual ergonomic study.](image-url)
2.1. Measurement of driver anthropometry data

Figure 2. Driver anthropometry CAD data representation.
(Source: Dassault Systemes CATIA)

A: Total height from head to toe
B: Vertical height from chest to toe
C: Vertical height from waist to toe
D: Vertical height from abdomen to toe
E: Total length of the arm
F: Total length of the upper arm
G: Total length of the forearm
H: Chest width
I: Waist width
J: Abdomen width
K: Ankle width
Table 1: Driver anthropometry data (mm).

| Parameters | Driver A | Driver B | Driver C | Driver D | Driver E |
|------------|----------|----------|----------|----------|----------|
| A          | 1730     | 1660     | 1770     | 1620     | 1890     |
| B          | 1370     | 1370     | 1400     | 1350     | 1480     |
| C          | 980      | 970      | 1000     | 952      | 1150     |
| D          | 580      | 510      | 590      | 500      | 690      |
| E          | 750      | 690      | 800      | 650      | 890      |
| F          | 240      | 250      | 230      | 230      | 340      |
| G          | 300      | 270      | 320      | 250      | 350      |
| H          | 350      | 290      | 380      | 280      | 340      |
| I          | 400      | 250      | 420      | 240      | 330      |
| J          | 410      | 280      | 430      | 260      | 350      |
| K          | 90       | 90       | 110      | 85       | 100      |

2.2. Driver cabin dimensions

Driver cabin dimensions were measured by obtaining seat, steering wheel section, foot rest and accelerator pedal section dimensions (refer Figure 3, 4, 5, 6). Mean average values were taken for three iterations data values for every parameter.

2.2.1 Seat dimensions

Driver’s seat and position dimensions were measured as per CATIA V5 software dimensional requirements as depicted in Figure 3. Figure 3. A represents mean dimensional values measured from the driver cabin seat. Figure 3. B represents dimensional parameters measured from the seat.

Figure 3. (A)Table representing mean value of measured seat dimensions (B)Representation of seat dimensions, Source: Dassault systemes.
L31: Distance between Seat Rest Point (SgRP) and vertical axis
W20: Distance between Seat Rest Point (SgRP) and vehicle center line
H30: Distance between Seat Rest Point (SgRP) and horizontal axis
A19: Angle between H-point travel path and horizontal
A40: Angle of inclination of trunk with respect to vertical
A27: Angle formed due to thigh support cushioning

2.2.2. Steering Wheel Section Dimensions

Figure 4 depicts steering wheel position and dimensional parameters within the driver's cabin. All measured mean values are tabulated in Figure 4.A. Steering wheel section is displayed in Figure 4.B

| Parameters | Dimensions   |
|------------|-------------|
| L11        | 290 mm      |
| W7         | -550 mm     |
| H17        | 790 mm      |
| W9         | 430 mm      |
| A18        | 31°         |
| GD         | 28.66 mm    |

Figure 4. (A) Table representing mean value of steering wheel section dimensions
(B) Representation of steering wheel section, Source: Dassault systemes.

L11: Distance between Ankle Hinge Point (AHP) and center of steering wheel
W7: Distance between center of steering wheel and vehicle center line
H17: Vertical distance between center of steering wheel and ground level of driver cabin
W9: Outer diameter of steering wheel
A18: Angle of inclination of steering wheel with respect to vertical
GD: Grip diameter of steering wheel

2.2.3. Foot Rest Section Dimensions

Foot rest section is measured as per the RULA standards (refer Figure 5.B) and the mean dimensional values are tabulated (refer Figure 5.A).
Figure 5. (A) Table representing mean value of footrest section dimensions (B) Representation of foot rest section, Source: Dassault systemes. L98-1: Distance between Foot Resting Point (FRP) and zero grid vertical axis W98-1: Distance between Foot Resting Point (FRP) and vehicle center line H98-1: Distance between Foot Resting Point (FRP) and zero grid horizontal axis A48-1: Angle of inclination of foot with respect to horizontal

2.2.4. Accelerator Pedal Section Dimensions
Dimensions bus driver cabin acceleration pedal sections were measured as per RULA standards (refer Figure 6. B) And mean values are tabulated in Figure 6. A

| Parameters | Dimensions |
|------------|------------|
| L98-1      | 350 mm     |
| W98-1      | -530 mm    |
| H98-1      | 400 mm     |
| A48-1      | 48.01 mm   |
2.3. Posture Modelling of Manikin

The seat dimension data and human anthropometry data are fed to the CATIA V5 software (refer Figure7) under ‘Ergonomics Design and Analysis’ modelling.

Posture modelling is performed by selecting the package tool and selecting the modelled manikin and seat dimensions.

2.4. Posture Analysis

RULA (Rapid Upper Limb Assessment) analysis is performed in CATIA with modelled posture and the manikin. The upper limbs of posture were assessed using the RULA score sheet. In Rapid Upper Limb
Assessment, the range of movement for each body part is divided into segments [5] (refer Figure 8). These sections are valued indicating the score 1 is valued to the range of movement or working posture having minimum risk. Higher scores are valued to the range of the movement with more extreme postures indicating an increasing risk factors causing stress on the body segments. The exposure RULA levels were divided into four categories (0, 1, 2, and 3) indicating negligible, low, medium and high risk levels (refer Table 2).

Figure 8: RULA analysis chart [5].
Table 2: RULA analysis chart.

| RULA Level | 0   | 1   | 2   | 3   |
|------------|-----|-----|-----|-----|
| RULA Score | 1-2 | 3-4 | 5-6 | 7   |
| Risk Level | Negligible | Low | Medium | High |

Table 3: Final RULA scores.

| Parameters      | A   | B   | C   | D   | E   |
|-----------------|-----|-----|-----|-----|-----|
| UPPER ARM       | 2   | 2   | 3   | 2   | 2   |
| FOREARM         | 1   | 2   | 2   | 3   | 3   |
| WRIST           | 2   | 3   | 3   | 3   | 4   |
| WRIST TWIST     | 1   | 1   | 1   | 1   | 1   |
| NECK            | 1   | 4   | 1   | 1   | 1   |
| TRUNK           | 3   | 3   | 3   | 3   | 3   |
| LEG             | 1   | 1   | 1   | 2   | 2   |
| FINAL RULA SCORE| 4   | 6   | 5   | 6   | 6   |

3. Results and Discussions
The RULA result for the various drivers are tabulated (refer Table.3) driver A, B, D and E scored 2 points in upper arm score indicating their working range is between 20° to 45° whereas person C has to extend his upper arm working range to 45° to 50° for his comfortable driving posture but could be subjected to muscular stresses upon prolonged driving. Person A works with his forearm in the range of 60° to 100° while driver B and C have to bend their forearm greater than 100° to fit his driving posture. Drivers D and E have to perform lateral forearm movements as well to position their driver seating so, +1 is added to their RULA score. Driver A is observed to have his wrist position within 0° to 15°. Driver B, C and D are found to turn their wrist more than 15° thus scoring 3 points whereas driver E is observed to have lateral movements so, +1 is added to the score. Wrist twist is observed to be in the mid-range for all drivers thus, 1 RULA point is evaluated. Drivers A, C, D and E are to bend their neck less than 10° securing 1 RULA point whereas driver B is observed to bend his neck more than 20° and scores 4 points. All drivers of various anthropometry are likely to bend their trunk 20° to 60° and score 3 points. Thus, final RULA score is calculated according to RULA weightage method as per the description in Figure.8 to analyze the overall seating comfort for the drivers. Driver A scores the least and is likely to suffer from muscular ailments when staying in the same posture compared to that of other drivers. Drivers B, D and E score the highest and might face severe muscular stresses in the long term. Seats of the buses are thus not universally promising comfort to all the drivers of various range of anthropometry. Thus the ergonomic analysis performed through Rapid Upper Limb Assessment helps us to conclude that the bus seat is more comfortable for people closer to the range of 28th percentile of SAE anthropometry and its neither suitable for tall nor short drivers.

4. Future scope
The ergonomic analysis can be performed through RUBA analysis coupled with Vibration measuring methods, Pressure measurement methods, Temperature and Humidity measuring methods and driver posture method using 3D scanner for more accurate results. The SEAT value (Seat Effective Amplitude Transmissibility) is the ratio of the vibration experienced on top of the seat and the vibration exposed while sitting directly on the vibrating floor. Such SEAT values can also be taken into consideration for cushioning effects. Moreover, psychological factors [25] do affect driver’s stress level during driving conditions. Hence, coupling all such results can yield more accurate results in determining the seating comfort for drivers in both static and dynamic conditions. Absence of standard Indian Anthropometry data for various populations remains unavailable which makes ergonomic study and product development into the halt [26]. This study can further be developed to evaluate seating comfort for all passengers travelling in different modes of transport, office and other workstation chairs.
physically disabled aiding machines, etc. and could improvise the comfort zone preventing unforeseen physical and mental illness.

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