DEVELOPMENT OF MATHEMATICAL MODELS FOR EFFECTIVE PLACEMENT OF STEERING WHEEL AND PEDALS IN THE BUS DRIVERS' WORKSTATIONS

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Abstract: **E**rgonomic design of driver's workstation is a necessary component of drivers' safety and health protection. It was discovered that majority of the drivers of public transport suffers a great deal of injuries and labour absenteeism. This study developed the mathematical models for design of bus drivers' workstations in Nigeria. Fifty urban buses selected from 10 brands were investigated by direct measurement. The buses were brands of urban small buses with various capacities and common brands of luxury buses categorized as A and B. Vertical and horizontal distances of the seat reference point to the pedal and steering wheel with the seat dimensions were considered. Anthropometric dimensions of 150 male urban bus drivers were taken from Southwest Nigeria. Data collected were analyzed using descriptive statistics. Four models were derived using a typical link-joint biomechanical line. The modeled values obtained for both horizontal and vertical distances of the steering wheel were 54.15 - 69.10cm and 52.16 - 57.83cm and foot pedal from the seat reference point (SRP) 72.49 - 80.59cm and 39.82 - 47.11cm for A buses; while horizontal and vertical distances of the steering wheel for B buses were 52.45 - 56.70cm and 22.15 - 26.40cm and foot pedal from the SRP were 82.35 - 91.70cm and 40.30 - 46.25cm respective1y. It was concluded that the driver's workstations in the urban buses are not ergonomically comfortable for optimum performance of the Nigerian drivers.

Keywords: Bus, Drivers, Anthropometric, Workstation, Model, Steering

Introduction

Most of the automotive seats, especially bus driver seats, were not designed according to the anthropometric data of Nigerians (Ajayeoba and Adekoya, 2010). This could be one of the major reasons why the drivers of public transport suffer a great deal of injuries and labour absenteeism higher than other professionals. Considering the special requirements of the transit bus operator function, the cabin can become an inconvenient environment to work effectively, especially for huge (male) operators. Hence, ergonomic design of the driver's workstation is a necessary component of drivers' safety and health protection. Ajayeoba and Adekoya (2010) further explained that the standard driving posture should ensure that a bus operator is able to conduct all driving tasks within a comfortable reach. Regarding the instrument panel, there are many recommendations for choosing proper controls, but universal design principles are applicable to all or any of them. Really, recommendations about manual controls are done based on direct observation of human interaction. (Berquist- Ullyman and Larsson, 2007)

The traditional configuration of a bus was an engine within the front and an entrance at the rear. With the transition to one-man operation, buses in the developed world have taken the form of mid or rear-engine designs, having a single door at the front and multiple doors at the sides. The articulated bus has two connected passenger coaches (Fondo-Norma, 1992), A steering wheel (also referred to as a driving wheel or hand wheel) is a type of hand control device in vehicles and vessels like ships and boats. Steering wheels are used in most modern road vehicles, as well as all automobiles including light and heavy trucks. The steering wheel is the part of the steering system that is controlled by the driver's hand; while the rest of the steering system responds to such driver command. This is done via some direct mechanical contacts, such as in re-circulating ball or rack and pinion steering gears, through or without the assistance of Hydraulic Power Steering, (HPS); or as in some modern cars with the assistance of computer-controlled motors, known as Electric Power Steering (EPS). Steering wheels are generally circular particularly for passenger automobiles. They are mounted on the steering column by a hub somewhat connected to the outer ring of the steering wheel by one or more spokes. Other types of vehicles like tricycle may use a butterfly shape, or some other shapes. Placement of the steering wheel depends on driving hand. The steering wheel is typically placed on the right side of the car in countries where cars are driven on the left side of the road, (i.e., right-hand drive or RHD); Conversely, applies in countries where cars must drive on the right side of the road (i.e., left-hand drive or LHD).

Apart from turning the vehicle, steering wheel also carries the car horn. Steering wheels of some modern automobiles have other controls, such as cruise control, audio system and telephone controls, as well as paddle shifters, to minimize the extent to which the drivers must take their hands off the steering wheel (Markovich, 2011). Soudatti et al., 2015 stressed that the seat life cycle is mainly developed to design seats that may adequately fit in variety of automotive environments. Many transit bus manufacturers, however, viewed the operator's seat as a supplementary or after thought device. However, to maximize profits, the commercial bus interior is designed to optimize the number of passenger seats. However, the small driver's workplace is cramped with dashboard, a firebox and the operator's seat.

The Seat-Reference-Point (SRP), the Heel-Reference-Point (HRP), Seat-Index-Point (SIP) and the Design-Eye-Point (DEP) are part of the several techniques for describing driver's workstation. However, the use of HRP, SIP, and DEP do not permit measurements to be made readily in the field without special equipment. The SRP approach assumes that various size operators have a common point for the placement of the operator's seat. Although this concept required large adjustment ranges for the seat in order to accommodate the various sizes and shapes within the driver population, it provided a readily identifiable reference point from which to compare existing seats against the new recommended guidelines (Gilmore *et al.*, 1997).

The anthropometric measurements suggest the evaluation of the physical elements inside the cabin (Ismaila *et al*., 2021). The evaluation revealed the geometric location, dimension, angle, and position of every element, in relation to one another and in relation to the Seat Reference Point (SRP). Moreso, the study evaluates the geometric location of all controls (foot and hand), and displays, inside the cabin, to best fit the operators' anthropometry. It also evaluates the controls for their location with the use of force (Byran *et al.*, 2013). The aim of this study is to derive suitable mathematical models for effective placement of the steering wheels and pedals in the bus drivers' workstations.

Materials and Methods

Collection of anthropometric and workstation variables

In this study, 30 anthropometric variables of 150 professional male drivers, randomly selected from seven urban centers (Abeokuta, Ilaro, Sagamu, Ijebu-ode, Oshodi, Yaba, Ibadan and Oyo) in three states (Lagos, Ogun and Oyo states) in South -West Nigeria were collected.

Similarly, 50 urban buses in two categories were considered. Category 'A' comprises of 6 common brands of urban small buses with various capacities (MITSUBISHI (a)-14 seaters, TOYOTA-COASTER- 30 seaters, MAZDA – 10seaters, HONDA –ODDYSEY 10-seater, NISSAN–URVAN 14-seaters; and MITSUBISHI(b)- 10 seaters). Category 'B' consists of 4 common brands of luxury buses (FOTON- 42 seaters, ASHOK - 42 seaters, TATA- 42 seaters and COMIL - 54 seaters). Measurement of the workstation parameters and the seat dimensions in all selected buses were done.

Measuring Instruments used are:Digital Stadiometer, PD 300M (DETECTO); Manufactured by Cardinal Scale Manufacturing Company, UK, Digital Vernier Caliper - 600mm manufactured by Mitutoyo Corporation, Japan. A 3.5m Steel tape; manufactured by Komelon, U.K was also used for this work and Protractor. The Universal Bevel Protractor was manufactured by Mitutoyo Corporation, Japan.

Measurement of the Driver's Seat Variables:

Preliminary search was conducted to identify the available brands of urban buses found to be commonly used in South-west Nigeria. They include: Toyota, Mazda, Mitsubishi, Nissan, and Honda. Observations together with direct linear and angular measurement were also carried out on the sampled drivers' seats.

The physical measurements of seat variables that were carried out on the sampled busesinclude: Seat height, Seat depth, Seat width, Headrest height, Headrest width, Backrest height, Backrest width (Lumber level), Backrest width (Thoracic level). Headrest angle, Backrest angle, Armrest height/length (where available)

Statistical Data Analysis

Microsoft Excel Starter 2010 and SPSS 21 version were used to perform the statistical analysis of the collected data to obtain the mean, standard deviation. The results were used in the four mathematical models derived in this study to get viable dimensional inputs for the placement of steering wheels and pedals in urban buses.

Figure 1 is a typical line-diagram / biomechanical link-joint representing a seated bus driver used to derive the four mathematical models; while Figure 2 also shows the relative placement of the two major controls (steering wheel and pedal) to the Seat Reference Point.

Derivation of the Mathematical Models for Calculating the Placement of the Steering Wheel and the Pedal from SRP

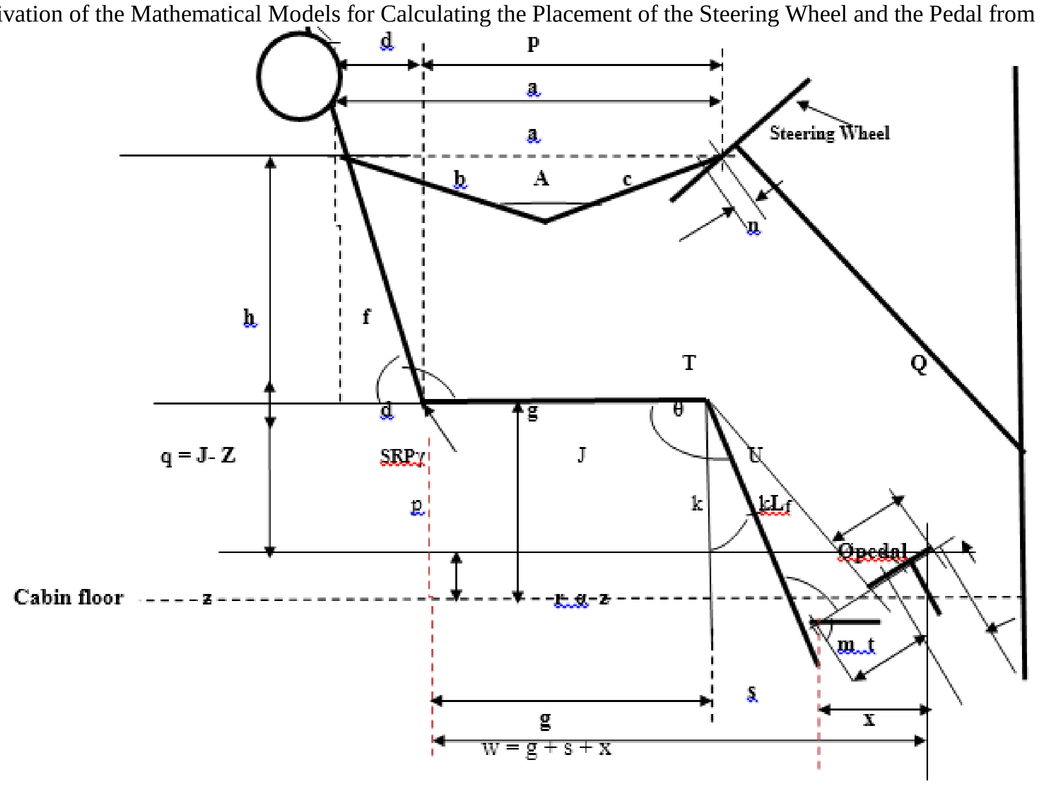


Figure. 1: Typical link-joint biomechanical model of seated urban bus driver

p = Horizontal Distance of Steering Wheel (**SW_H**)
h = Vertical Distance of Steering Wheel (**SW_V**))
w = Horizontal Distance of Foot Pedal (**FP_H**)

q = Vertical Distance of Foot Pedal (**FP_V**)

To derive the mathematical Models for the placement of the controls:

From figure 1

The horizontal Distance of Steering Wheel from SRP; SW_h= $p = a - d$-------- 1

Where SRP = Seat Reference Point

Applying Cosine rule, $a = (b^2 + c^2 - 2bc\ CosA)^{\frac{1}{2}}$ --------- 2

$CosT = \frac{d}{f}$--- 3

$d = fCosT$;-- ---- 4

$p = a - d = (b^2 + c^2 - 2bc * CosA)^{\frac{1}{2}} - f(Cos\ T)$……………………………… 5

$b = Lse$; $c = Lew + n = Lew + 0.5\ Lh$; ------------- 6

$f = Lsb$; $Angle\ T = 180 - Q$, $n = 0.5L_h$

$Sw_h = p = a - d$

Where

$Lse = Shoulder\ to\ Elbow\ Length$

$Lew = Elbow\ to\ Wrist\ Length$;

$Lh = Hand\ Length$; $Lf = Foot\ Length$

$Lsb = ShoulderHeight$

n = Half of hand Length

The horizontal Distance of Steering Wheel from SRP; SW_h $= [(Lse)^2 + (Lew + 0.5Lh)^2 - 2(Lse)(Lew + 0.5Lh)\ COs\ A]^{\frac{1}{2}} - [Lsb * Cos\ (180 - Q)]$….Model 1

Vertical Distance of steering wheel from SRP= h

$$Angle\ T = 180 - Q; Sin\ T = \frac{h}{f} = \frac{SW_v}{Lsb}$$

, $SW_v = Lsb\ Sin\ (180 - Q)$ ------------ 7

$Q = Back\ Angle\ (with\ the\ thigh)$

Vertical Distance of steering wheel from SRP, $SW_v = Lsb\ Sin\ (180 - Q)$ -----Model 2

Horizontal Distance of foot pedal from SRP, $FP_h = w = g + s + x$ -------- 8

$g = L_{bp}$

$Sin\ U = \frac{s}{k}$ --- 9

$s = k\ Sin\ U$ $where\ angle\ U = (\theta - 90^0)$

$Lbp = Length\ of\ Buttock\ to\ Popliteal$

k= Popliteal Height

$\theta = Popliteal\ Angle\ (with\ foot\ on\ the\ floor)$;

$\emptyset = Foot/Ankle\ angle\ (with\ Foot\ on\ pedal)$

$s = Lph\ Sin\ (\theta - 90^0)$ ………………………………………… 10

$Cos\ \alpha = \frac{x}{(m + t)}$

$x = (m + t)\ Cos\ \alpha$ ……………………………………………..11

where:

$Lph = Length\ of\ Popliteal\ to\ Heel$

L_{bp} = Popliteal length

$\alpha = \theta - r$ -- -----12

$2r + \gamma = 180$

$r = 0.5\ (180 - \gamma$)-- ----- 13

$also,$ $r = 180 - \emptyset$

$\alpha = \theta - (180 - \emptyset\ )$ ………………………………………… ……..14

$\gamma = 180 - 2r$

$\gamma = 180 - 2\ (180 - \emptyset\ )$

$= 180 - 360 + 2\emptyset$

$\gamma = (2\emptyset - 180)$…………………………………………….………… ……15

Applying Sine Rule;$\frac{m}{Sin\ \gamma} = \frac{k}{\text{Sin r}}$---------------------------------- -----16

$m = \frac{k\ Sin\ \gamma}{\text{Sin r}}$

where$k = Lph$

$M = \frac{Lph\ Sin\ (2\emptyset - 180)}{\text{Sin}\ (180 - \emptyset)}$……………………………………………… 17

$t = 0.75\ Lf$ (i.e = foot pressure point) ; Lf = Foot Length

$m + t = \frac{L_{ph}\sin(2\emptyset - 180)}{(Sin\ 180 - \emptyset)} + 0.75\ Lf$ … … … … … … … ….……………..18

$Cos\ U = \frac{J}{k}$

$J = k\ Cos\ U$

$J = Lph\ Cos\ (\ \theta - 90)$ ……………………………19

$Sin\alpha = \frac{Z}{(m + t)}$

$Z = (m + t)\ Sin\ \alpha$

$Z = \left[\frac{[Lph\ Sin(2\emptyset - 180)]}{\sin(180 - \emptyset)} + (0.75\ Lf)\right] Sin\ [\theta - (180 - \emptyset)]$..................... 20

Vertical Distance of Foot Pedal, FPv = $q = J - Z$

$q = Lph\ Cos\ (\theta - 90^0) - \left[(\frac{Lph\sin(2\emptyset - 180)]}{Sin\ (180 - \emptyset)} + (0.75\ Lf)\right] Sin\ [\theta - (180 - \emptyset)]$... Model 3

Horizontal Distance of Foot Pedal from SRP= $w = g + s + x$

$g = Lbp$

$s = Lph\ Sin\ (\theta - 90^0)$

$x = (m + t)\ Cos\ \alpha$

$x = (m + t)\ Cos\ \alpha$

$$= \left[\frac{Lph\ Sin(2\emptyset - 180)}{sin\ (180 - \emptyset)} + (0.75\ Lf)\right] cos[\theta - (180 - \emptyset)]$$

$w = Lbp + Lph\ Sin(\theta - 90^0) + \left[\frac{LPh\ Sin\ (2\emptyset - 180)}{Sin(180 - \emptyset)} + (0.755\ Lf)\right] Cos\ [\theta - (180 - \emptyset)]$…….Model 4

Therefore, the summary of the models is as written below

Model 1

The horizontal Distance of Steering Wheel from SRP; = SW_h

$$= [(Lse)^2 + (Lew + 0.5Lh)^2 - 2(Lse)(Lew + 0.5Lh)\ COs\ A]^{\frac{1}{2}} - [Lsb * Cos\ (180 - Q)]$$

Model2

Vertical Distance of steering wheel from SRP, $SW_v = Lsb\ Sin\ (180 - Q)$

Model 3

Vertical Distance of Foot Pedal from SRP, FPv

$$q = Lph\ Cos\ (\theta - 90^0) - \left[(\frac{Lph\sin(2\emptyset - 180)]}{Sin\ (180 - \emptyset)} + (0.75\ Lf)\right] Sin\ [\theta - (180 - \emptyset)]$$

Model 4

Horizontal Distance of Foot Pedal from SRP, FP_h

$$w = Lbp + Lph\,Sin(\theta - 90^0) + \left[\frac{LPh\,Sin\,(2\emptyset - 180)}{Sin(180 - \emptyset)} + (0.755\,Lf)\right] Cos\,[\theta - (180 - \emptyset)]$$

L_{bp} = Popliteal length

Where:

$Lse =$ *Shoulder to Elbow Length*
$Lew =$ *Elbow to Wrist Length*;
$Lh =$ *Hand Length*; $Lf =$ *Foot Length*
$Lsb =$ *ShoulderHeight*
n = *Half of hand Length*
k= *Popliteal Height*
$\theta =$ *Popliteal Angle (with foot on the floor)*;
$\emptyset =$ *Foot/Ankle angle (with Foot on pedal)*
$Lph =$ *Length of Popliteal to Heel*

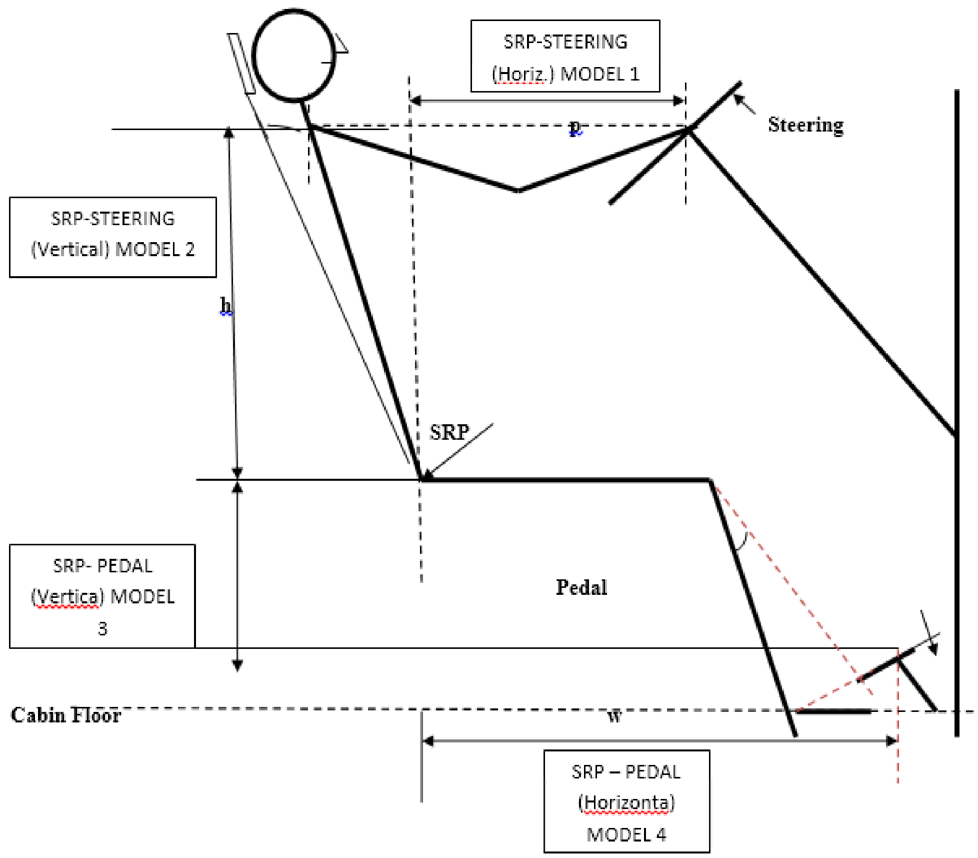


Figure. 2: Placement of controls on a link-joint biomechanical model of aseated urban bus driver

Results and Discussion

Data Obtained from Workstations

The Seat Reference Point (SRP) was used for the placement of the two controls.The following tables present the results of the statistical analysis of the raw data collected during the field work

Table 1: Summary of data obtained from mini bus workstations (Category A)

S/N	VARIABLE	No.	STD. DEV	MEAN	5^{th} Percentile	50^{th} Percentile	75^{th} Percentile	95^{th} Percentile
1	Cabin Height	30	13.39278	142.1667	122	148	149.5	150.75
2	Cabin width	30	6.531973	92.66667	90	90	90	102
3	Cabin Length	30	2.316607	90.16667	87.25	90.5	91.75	92.75
4	Seat to Door dist.	30	3.444803	5.333333	3	4	5.5	10.5
5	Cabin floor to road	30	16.54086	59	36.5	61.5	67.5	77.25
6	Pedal to Seat	30	4.490731	42.83333	38.5	41.5	45.25	49
7	Steering to Floor	30	4.119061	66.83333	61	68.5	70	70
8	Dashboard-backrest	30	10.65364	77.5	62.5	79.5	81.5	88
9	Steering to backrest	30	3.577709	45	40.5	45.5	46.75	49.25
10	dashboard width	30	6.531973	92.66667	90	90	90	102
11	Dashboard height	30	7.339391	41.66667	32	42.5	44.5	50.25
12	Steering wheel Dia.	30	4.722288	40.5	38	38.5	39.75	47.5
13	Steering rim thickness	30	0.917424	3.583333	2.625	3.5	4	4.75
14	Pedal angle	30	2.581989	46.66667	45	45	48.75	50
15	Steering rack angle	30	2	64	61	65	65	65
16	Door width	30	9.287985	113.3333	101.25	116	120	122.25
17	Door height	30	5.776389	134.8333	127	135	139	140.75
18	Dashboard to Seat	30	8.140434	26.33333	14.5	29	30	31.5
19	Gear lever to Seat	30	5.329165	16	10	16.5	19.5	22.25
20	Bus total Height	30	30.06271	194.1667	162	190	197.5	235.25
21	Steering rack to Seat	30	13.60392	23.33333	9.5	21.5	24.25	42.25
23	SRP-STR(H)	30	5.785038	50.66667	42.5	51.5	54.5	55.75
24	SRP-STR(V)	30	2.44949	32	30	31	34.25	35
25	SRP-PDL(H)	30	3.32666	91.66667	87.25	93	93.75	94.75
26	SRP-PDL(V)	30	2.316607	27.16667	25	26.5	29.25	30

Table 2: Summary of data obtained from mini bus Drivers' Seats (Category A)

S/N	VARIABLE	No.	STD. DEV	MEAN	5^{th}ile	50^{th}ile	75^{th}ile	95^{th}ile
1	Floor to Seat	30	6.09	32.7	25.5	33.5	34.75	40.25
2	Seat front width	30	1.97	50.3	48.5	50	50	53
3	Seat back width	30	2.76	41	38	41	43.5	44
4	Seatpan depth	30	0.52	49.7	49	50	50	50
5	Backrest width(Lumbar)	30	2	49	47	49	50	51.5
6	Backrest width(thoracic)	30	2.26	44.5	42.3	44	45.8	47.5
7	Backrest Height	30	3.14	53.7	50	54.5	55	57.25
8	Headrest width	30	4.09	26.5	22	25.5	28.3	32
9	Headrest height	30	8.44	23	16	22	22.8	35
10	Armrest Length	30		30	30	30	30	30
11	Armrest width	30		7	7	7	7	7
12	Armrest thickness	30		8	8	8	8	8

Table 3: Summary of data obtained from midi bus workstations (category B)

S/N	Variable	No.	Std. Dev	Mean(cm)	5^{th}ile(cm)	50^{th}ile(cm)	75th ile(cm)	95thile(cm)
1	Cabin Height	20	5.74	198.75	192.6	199.5	203.25	203.85
2	Cabin width	20	23.39	104.5	80.25	105	120.25	128.05
3	Cabin Length	20	10.62	122.75	109.85	127	128.5	129.7
4	Seat to Door distance	20	8.81	17.25	10.15	15	21.5	27.5
5	Cabin Floor to Ground	20	8.02	103.75	94.1	106.5	107.75	109.55
6	Pedal to Seat distance	20	7.33	30.5	23.6	29.5	34	38.8
7	Steering to Floor	20	3.32	72.5	70	71.5	74	76.4
8	Dashboard to backrest.	20	12.53	81.75	69.6	82.5	92.25	92.85
9	Steering to Backrest dist.	20	6.53	42	35.2	42	44	48.8
10	Steering Wheel Diameter	20	9.80	54.7	49.49	50	54.85	66.49
11	Steering rim thickness	20	1.37	3.525	2.475	3.1	3.85	5.17
12	Pedal Angle	20	7.47	133.125	124.375	135	136.25	139.25
13	Steerg rack angle	20	2.95	76.125	73.3	75.75	77.375	79.475
14	Door width	20	0.71	79.5	79.05	79.5	79.75	79.95
15	Door height	20	12.73	165	156.9	165	169.5	173.1
16	Dashboard to Seat distance	20	2.83	28	24.6	29	30	30
17	Gear lever to Seat distance	20	10.79	20.5	8.25	22	25.25	30.65
18	Total Height from ground	20	0	310	310	310	310	310
19	Steering rack to Seat dist.	20	14.84	30.5	13.95	33.5	42.25	42.85
20	Pedal to seat distance	20	21	50.5	28.1	54	68	68
21	SRP to Steering (Horiz.)	20	2.06	54.75	52.45	55	55.5	56.7
22	SRP to Steering (Vertical)	20	2.22	23.75	22.15	23	24	26.4
23	SRP to Pedal (Horizontal)	20	4.92	88.25	82.35	90	90.5	91.7
24	SRP to Pedal (Vertical)	20	2.99	42.75	40.3	42	43.25	46.25

Table 4: Summary of data obtained from midi bus Drivers' Seats (category B)

S/N	VARIABLE	No.	STDEV	MEAN(cm)	5^{th} Percentile	50^{th} Percentile	75^{th} Percentile	95^{th} Percentile
1	Floor to seat Height	20	2.061553	41.25	39.15	41.5	43	43
2	Seatpan thickness	20	2.362908	11.75	10	11	12.75	14.55
4	Seatpan back width	20	4.358899	41.5	38	40.5	44	46.4
5	Backrest Angle	20	7.371115	102.5	95.2	102	104.5	110.5
6	Backrest thickness	20	2.629956	10.25	8	10	12.25	12.85
7	Backrest width (lowback level)	20	3.855161	48.67	47.5	50.25	53.25	
8	Backrest width (Shoulder level)	20	4.391001	39.4675	34.6	40	42.4675	43.5895
9	Headrest Angle	15	28.30783	127.3333	110.2	112	136	155.2
10	Headrest width	15	1.921909	27.78667	26.568	26.82	28.41	29.682
11	Headrest height (with stand)	15	1.732051	37	35.3	38	38	38
12	Headrest height(no stand)	15	2	22	20.2	22	23	23.8
16	Seat Depth	20	5	47.5	41.5	50	50	50
17	Backrest Height	20	5.057997	44.25	38.75	44.5	47	49.4

18	SRP to Steering (Horizontal)	20	2.061553	54.75	52.45	55	55.5	56.7
19	SRP to Steering (Vertical)	20	2.217356	23.75	22.15	23	24	26.4
20	SRP to Pedal (Horizontal)	20	4.924429	88.25	82.35	90	90.5	91.7
21	SRP to Pedal (Vertical)	20	2.986079	42.75	40.3	42	43.25	46.25

Table 5: Summary of Specific Relevant Parameters for Application of the Models

Parameters	No.	Shoulder – Elbow L_{SE}	Elbow -wrist L_{EW}	Hand Length L_H	Popliteal-Height L_{PH}	Popliteal Length L_{BP}	Foot Length L_F	Shoulder Height L_{SB}	Elbow Angle A	Back/Hip Angle Sitting Q	Knee Angle with Leg on Floor θ	Ankle Angle with foot on Pedal Ø
STDEV	150	1.62	1.79	0.95	1.53	1.32	0.88	2.06	3.16	3.42	0.46	0.58
5th Percentile	150	31.48	28	19	43.95	46	25	53	139.975	96	94	93
50th Percentile	150	34	31	22	46	47	27	54	142.8	101.5	96	94
75th Percentile	150	35	33	23	47	50	27	56	144.25	103	95	93
95th Percentile	150	38.05	32.1	22.5	49.02	50	27.31	59.1	147	107.25	95	95

Table 6: Summary of the Model Application Results

Parameters	**No.**	**MODEL 1**	**MODEL 2**	**MODEL 3**	**MODEL 4**
		SW_H(cm)	SW_V (cm)	FP_V (cm)	FP_H (cm)
STDEV	150	4.12948	2.45774	1.783319	2.180912
5th Percentile	150	54.14957	52.1593	39.82145	72.49236
50th Percentile	150	62.40154	54.36274	43.45816	75.66254
75th Percentile	150	64.79303	55.80452	43.98762	79.18733
95th Percentile	150	69.10232	57.53072	45.83481	80.58612

Table 7: Comparison between current study models results and the summaries of workstations data for the two bus Categories (A and B)

S/N	**PARAMETER**	**BUS CATEGORY A Percentile Range (cm) 5TH- 95TH**	**BUS CATEGORY -B Percentile Range (cm) 5TH - 95TH**	**CURRENT STUDY MODELS Percentile Range (cm) 5TH - 95TH**
1	HORIZONTAL DIST. OF SRP TOSTEERING	42.5 - 55.75	52.45 - 56.7	54.15 - 69.10
2	VERTICAL DIST.OF SRP TO STEERING	30.00 - 35.00	22.15 - 26.40	52.16 - 57.83
3	HORIZONTAL DIST. OF SRP TO PEDAL	87.25 - 94.75	82.35 - 91.7	72.49 - 80.59
4	VERTICAL DIST.OF SRP TO PEDAL	25.00 - 30.00	40.30 - 46.25	39.82 - 47.11

Table 8: Summary of the Anthropometric Dimensions of 150 Nigerian Male Urban Bus Drivers

	VARIABLE	NO.	MEAN	STD.DEV.	5^{th} Percentile	50^{th} Percentile	75^{th} Percentile	95^{th} Percentile	MIN.	MAX.
P1	Stature	150	173.15	3.32473	168.8	173	175.5	179.1	166	180
P2	Sitting Height	150	83.175	4.51713	76.9	83	86.25	90	74	91
P3	Eye-Floor height	150	73.4	5.2315	60	77	81	83.15	50	88
P4	Shoulder Width	150	44.5	3.25458	40	44	46.2	50	39	51
P5	Shoulder Height	150	55.395	1.96898	53	55	56	58.15	53	62
P6	Shoulder-Elbow	150	34.6125	1.90642	31.475	35	36	37.05	31	38
P7	Knee Height	150	59.25	1.48497	56.95	59	60	61.05	55	62
P8	Elbow-Wrist	150	30.2875	1.34873	28	30	31	33	28	33
P9	Knee Length	150	60.7125	1.67901	57.95	61	62	63	57	63
P10	Popliteal Length	150	48.75	-1.4456	49.95	49	50	50	45	51
P11	Hip Breadth	150	37.0175	1.97975	34.7	37	38	40.145	32.4	41
P12	Tommy Depth	150	20.3325	3.06171	14.93	21	22.4	25	11.7	25
P13	Popliteal-Height	150	47.4625	1.21628	46	47.5	48	50	45.5	50
P14	Foot Length	150	26.5275	0.83297	25	26.4	27.1	28	25	28
P15	Foot Breadth	150	9.5175	0.73794	8.395	9.7	10	10525	8.2	11.2
P16	Hand Length	150	20.0575	0.70234	19	20	20.625	21	18.8	21
P17	Hand Breadth	150	9.745	0.57466	8.99	10	10	10.505	8.7	11
P18	Shoulder - Wrist	150	64.8	2.93258	60.475	65	67	70	60	70
P19	Head Breadth	150	14.975	0.73441	13.895	14.95	15.525	16	13.8	16.1
P20	Head Length	150	20.2075	0.98668	19	19.9	21	22	19	22
P21	Tommy - Steering	150	19.7	3.18812	15.95	19.5	22	24.1	15	26
P22	Chest – Steering	150	32.2	2.94566	27	33	34	36	26	38
P23	Right knee - Dash Board	150	12.45	2.26399	9	12	15	16	9	16
P24	Left knee - Dash Board	150	12.95	2.34193	10	12	15	16.05	10	17
P25	Knee-Steering Rack	150	8.275	1.88431	5.5	8	10	11	5.5	11
P26	Elbow Angle, with Steering	150	144.188	3.88073	140	144.25	146	147.15	139.5	162
P27	Elbow Angle with Gear	150	165.3	3.37563	160	166	168	171	158	171
P28	Knee Angle foot on Floor	150	123.075	1.91669	120.95	123	123.25	126.025	120	130
P29	Ankle Angle foot on Pedal	150	95.675	4.74686	91	94	98	104.25	91	110
P30	Back angle Sitting	150	100.975	4.02229	96	101	102.25	111.05	96	112

Table 1 shows the summary of data obtained from bus workstation (category A), while Table 3 shows the summary of data obtained from bus workstation (category B). In the tables, the 5th, 50th, 75thand 95th percentiles of the horizontal and vertical distances of the steering wheel/pedal from the seat reference point (SRP) were stated. The percentile value was in the range 42.50 - 55.75cm for the horizontal distance of the centre of steering wheel to the seat reference point for category 'A' buses. For category B, the range was 52.45 - 56.70cm. As recorded in Table 1, the percentile value range of the vertical distance of the steering wheel from the SRP for buses in category A was given as 30 - 35cm while, for the luxury buses in category B (as in Table 3) wasbetween 22.15 and 26.40cm. Table 1 again gives the value range of the vertical distance of the pedal from the SRP for small buses (A) as 25 – 30cm; whereas, in Table 3, the range for luxury buses (B) was 40.30 –46.25cm.For category A buses as in Table 1, the horizontal distance of the SRP to the pedal was within the range of 87.25 – 94.75cm while that of category B in Table 3 is 82.35 – 91.7cm.

Tables 2 and 4 showthe results obtained from the driver's seat data analysis for the two categories A and B of buses considered in this research work respectively. They reveal that the 5th and 95th percentiles value range for the seat height from the cabin floor is 25.5 - 40.25 cm for category A in Table 2 and 39.15 – 43cm for category B in Table 4; while the results obtained for the popliteal height of range 46 – 50cm from the anthropometric data analysis of the drivers is in Table 5. The value range of the seat pan depth in Table 2 for category A is 49 - 50cm; while the range for category B in Table 4 is 41.5 – 50cm.Meanwhile, the results stated in Table 2 give the back width range of 38 – 44 cm, while Table 4 depicts the back width range of 38 - 46.4cm showing slightly wider dimensions when compared to the drivers' hip width range of 34.70 - 40.15cm in table 8. However, the seatpan front width range is 48.5 – 53cm for category A and the range for category B is 47.15 - 49.7cm.

The backrests have different width dimensions at the low back and shoulder levels. The shoulder level range for category A is 42.25 - 47.5cm and 34.6 - 43.6 cm for B. These values in Tables 2 and 4 again fail to accommodate 95th percentile of shoulder breadth (50cm) dimensions of the sampled drivers' population shown in Table 5; while the ranges for the lumber level are 47 - 51.5cm for category A and 45.73 - 53.25cm for category B. The backrest height is determined by the shoulder height sitting. However, the backrest height result for category A of (50 - 57.35cm) seems to be closer to the anthropometric value range of the shoulder height (53 - 58.5cm) than that of category B (38.75 - 49.4cm), which is rather too short for the Nigerian driver to work with comfortably and efficiently.

Table 4 reveals that none of the luxury buses in category B has an armrest; while table 2 of the category A buses gives only constant values for the armrest parameters. Headrest provides support for the head while driving. Table 2 gives the height value range of 16 - 35cm for category A buses while category B has (20.2 - 23.8 cm) as in table 4. However, provision of iron stand made it adjustable up to 38cm. Meanwhile, the headrest widths for the two categories in tables 2 and 5showed that Category A buses has the width range of 22 – 32cm, and those in category B have 26.6 - 29.7cm range. Meanwhile, the head widths of the drivers are within 13.89 and 16cm range according to Table 5. It is to be noted that the backrest for one bus brand in that category B has no headrest.

Location of Hand (Steering Wheel) and Foot (Pedal) Controls

There were notable mismatches between the anthropometric data of the Nigeria bus drivers and the seat dimensions. Therefore, the present locations of the steering wheel and the pedal controls may not be ergonomically suitable for the Nigerian bus drivers.This study came up with four different mathematical models for easy computation of the ergonomically placement of the steering wheel and the acceleration pedal in the drivers workstation

In the study conducted by Rosemary *et al*,(2011), the steering wheel of a Jeepney was to be located at a vertical distance of 23.5cm from the floor using 95th percentile knee height of Jeepney driver population in Metro Manila, Philippines, while minimum horizontal distance of the steering wheel from the back rest was to be 27.1" representing 5th percentile of arm reach.

However, in this study, the seat reference point was used as the pivot for the measurement of placement of the steering wheel and pedals.

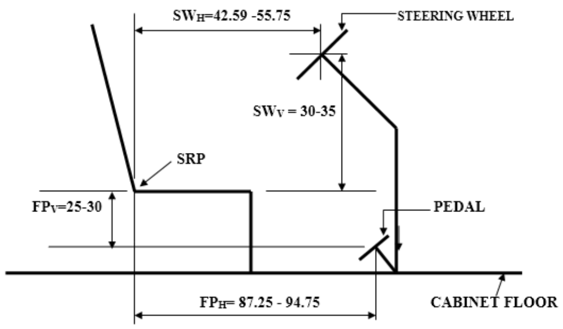


Figure.3: placements of the steering wheel and pedal in the mini buses

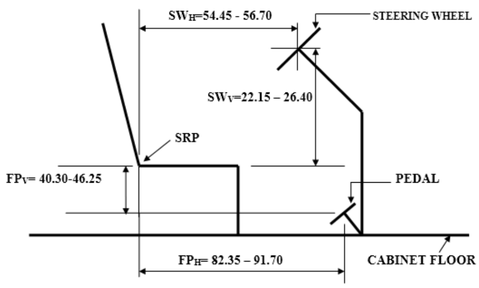
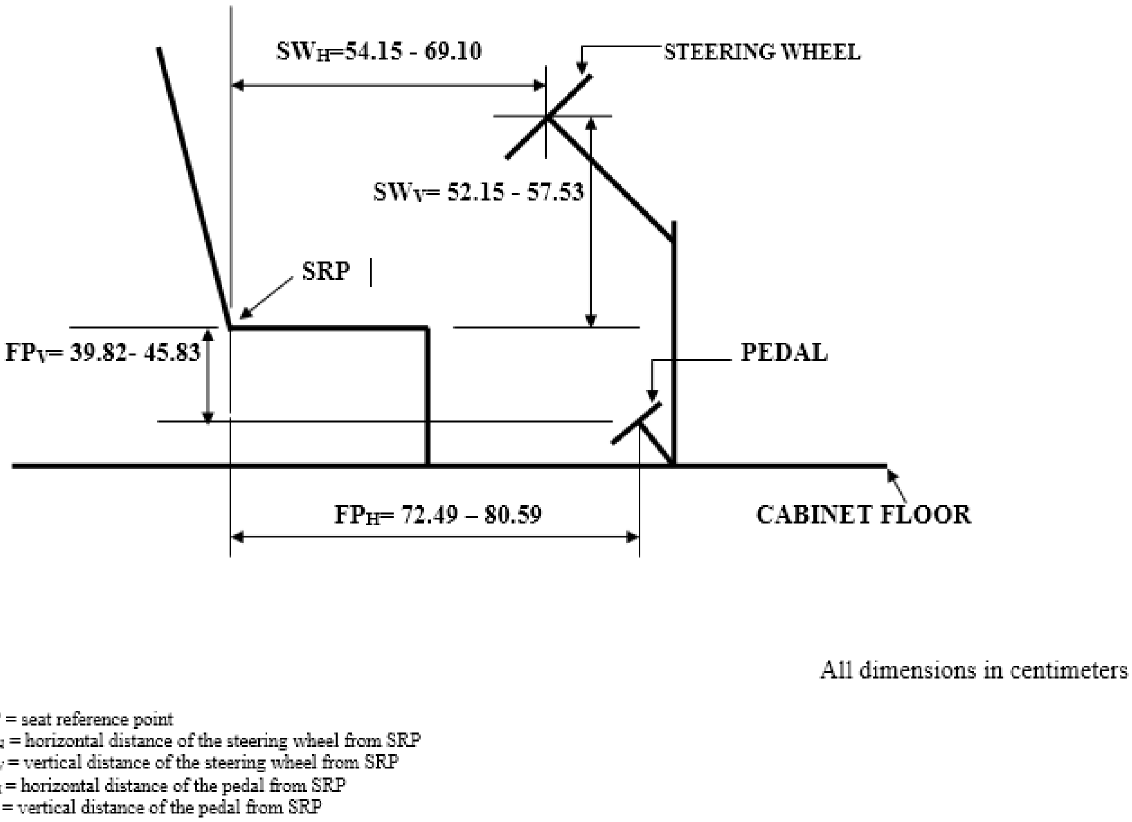


Figure.4: placements of the steering wheel and pedal in the large buses



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The 5th to 95th percentile ranges of values generated from the driver's data using the mathematical models for both horizontal and vertical distance of the steering wheel from the Seat Reference Point (SRP) were 54.15-69.10cm and 52.16-57.83cm respectively. Meanwhile, the ranges of values measured directly from the mini busses (A) and the large buses (B) were 42.50-55-75 cm horizontal, 30.00- 35.00 cm vertical distances for mini buses (A) and 52.45 – 56.70cm horizontal, 22.15 – 26.40cm vertical distances respectively for large buses (B).
Similarly, 5th to 95th percentile ranges of values generated from the drivers data using the mathematical models for both horizontal and vertical distance of the pedal from SRP were 72.49 – 80.59cm and 39.82 – 4 7.11cm respectively. However, the ranges of values obtained by direct measurement from the mini buses (A) and large buses (B) were 87.25 – 94.75cm horizontal, 25.00 – 30.00 cm vertical distance for mini buses (A) and 82.35 – 91.70 cm horizontal, 40.3 – 46.25 cm vertical distances respectively for large buses (B).
A typical link-joint biomechanical model of a seated urban bus driver was used to derive four mathematical models to determine the agronomical effective placement of the steering wheel (hand control) and pedal (foot control) in the driver's workstation.
The four mathematical models effectively calculate the horizontal and vertical distances of the steering wheel; as well as the horizontal and vertical distances of the pedal from the seat reference point.The armrest for the driver's seat should be attached to the right hand side of the backrest only because there is a provision for left armrest on the driver's door. The placement (elbow height) should be determined by subtracting the shoulder to elbow length (Lse) from the shoulder height sitting (Lsb).
The heights of the head rest used in all buses investigated were within the range comfortable for the Nigerian drivers. However, the head rests were wide. Therefore, a width range of 12cm to 20cm based on the dimensions of the drivers' heads is recommended.That the horizontal distances of the steering wheels to the Seat Reference Points in all buses in the two bus categories analyzed in this research work were not ergonomically convenient for the Nigerian drivers. Then, it is hereby suggested that the range of values given by the application of Model 1 derived in this study should be adopted for all buses to be driven by the Nigerian drivers.
The steering wheelsin all thesampled brands were positioned too low for effective and easy operations by the Nigerian drivers. Therefore, it is suggested that the height of steering wheels should be made adjustable within the range of valuesobtained from the application of Model 2 of this study.
The vertical height of the pedals in the buses in category A were high; therefore not suitable for the Nigerian drivers; while, the heights of those in the category B luxury buses were within the permissible range and suitable for them. Notwithstanding, the value range obtained from the application of the Model 3 is still suggested for the design of all buses to be driven by Nigerians.
The horizontal distances of the pedals from the SRP for all buses in the two categories were long or far, therefore not suitable for Nigerian drivers. Then, values obtained from the application of Model 4 of this study are hereby suggested for use as input data when designing bus cabin for Nigerian drivers. The diameter range of the steering wheels in the small buses in category A is comfortable for the Nigerian urban bus

drivers. While that of category B- luxury buses werewide for them. Therefore, the chest width range should always be considered for the wheel diameter design.The steering wheel rim thicknesses for all brands are alright for the driver as their circumferences are within the hand length range of the drivers.Similar models were derived by Drakopoulos and Mann, (2007) for the operation workstation in a tractor.

Conclusion

The study concluded that the drivers' workstations in the urban buses used in South-West Nigeria were analyzed but not ergonomically fit for the urban bus drivers in South-West Nigeria since the anthropometric data of the Nigerian male bus drivers were not put into consideration when designing the buses.The determination of the appropriate placement of the steering wheels and foot pedals was achieved by the derivation of four different mathematical models. Also, the quick application of the models was enhanced by the development of computer visual basic 6.0 software. Conclusively, this study had adequately made provisions for ergonomic drivers' seats and appropriate placement of the steering wheels and pedals in the urban buses to be ergonomically suitable for the Nigerian drivers.

The ergonomic placement of the steering wheel and the pedal, as well as the drivers' seat dimensions within the drivers' workstations to improve the efficiency and availability of urban bus drivers were well addressed within the scope. Various anthropometrical results obtained from this model are hereby recommended for direct use and also subjected for further ergonomic studies. The mathematical models developed in this study are recommended for use by automobile industries in the design of the drivers' workstations particularly for buses to be operated by Nigerian drivers and the world at large.

References

1. Ajayeoba, A.O. and. Adekoya, L.O. (2010). "Evaluation of the Ergonomic Suitability of Passenger Seats in Molue Buses in Nigeria".*Journal of Mechanical Engineering* 1(2): 4-6
2. Byran, E., Gilad, I. and Oxman, R. (2013). "Ergonomic Design: Experimental Studies of Multi-Task Vehicle". *Agriculture Forestry and Fisheries*2(1): 23-32
3. Drakopoulos, D. and Mann, D.D. 2007 An Ergonomic Analysis of the Controls Present in TractorWorkstation, *Canadian Biosystems Engineering Journal*, 49(2):2.15-2.21
4. Fondo, N. 1992.Clasificación de lasunidades de transportepúblico.Venezuela Agency of Standards
5. Gilmore, B.J., Bucciaglia, J., Lowe, E.B. You, H., and Freivalds, A. 1997. Bus Operator Workstation Evaluation and Design Guidelines, TCRP Report F-4, Transportation Cooperative Research Program (TCRP), Transportation Research Board.
6. Ismaila S.O, Odunlami S.A., Kuye S.I., Musa A.I and Olayanju T.M.A 2021. Ergonomics Evaluation of Urban Bus Drivers' Workstation in Southwest Nigeria. Journal of Engineering Science, Volume XXVIII (2) pp 51–64 ISSN 2587 – 3474, DOI.org/10.52326/jes.utm.2021.28 (2).04
7. Markovich, A. 2011. "Look, Ma-No Wheels". Popular Mechanics 123 (4): 91–93.
8. Sandatti, R., Amarnath, R. and Harish, R. 2015. Bus Passengers Seats – Simulations and Testing for Life Cycle Requirement. SAE Technical Paper 2015 – 26 – 0235.
9. Ullyman, B. M and Larsson, U. 2007.Acute low back pain in industry. A controlled prospective study with special reference to therapy and confounding factors. *Acta Orthop Scand* 170:1-117.