ORIGINAL ARTICLE

ERGONOMIC DESIGN OPTIMIZATION FOR TRAIN SEAT FIT PARAMETERS

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ABSTRACT

This study is aimed at seat design optimization for high-speed train based on the Malaysians sitting anthropometry data focusing on seat fit parameters. An analysis of anthropometry data composed of 15 dimensions that are required in seat design was done with 50 male subjects. These data were collected through direct measuring methods with standard equipment. According to the Malaysian automotive seat fit parameters, the backrest width, backrest height, cushion width, and cushion length were established based on these anthropometric dimensions: interscye breadth (5th percentile female and 95th percentile male), hip breadth (95th percentile female), sitting shoulder height (5th percentile female), and buttock-popliteal length (5th percentile female), respectively. This study uses the CATIA software to design and analyse the proposed seat design. The fit parameters proposed for the new design are seat height, 380mm; cushion width, 450mm; backrest width, 450mm and backrest height, 850mm. The CATIA human activity analysis (based on Rapid Upper Limb Analysis, RULA) was also executed. From the study, the new conceptual seat design gives the most optimized fit when compared to the current seat.

Keywords: *anthropometry; seat fit parameters; seat design; RULA; comfort*

INTRODUCTION

A comfortable seat is one of the key factors for ride comfort. It is directly related to the satisfaction of passengers. It was suggested that the level of seat comfort was on par with the functional and aesthetic design of automobiles[1]. It was also highlighted that the contact interface of geometry position is paramount in human-machine interface[2,3]. The environment in which work is performed can directly and indirectly affect not only to the comfort and health of people, but also the quality and efficiency of the work being done[4].

It was recommended that the comfort of the sitter depend on the adjustability of the lumbar region: the cushion width parameters, the thigh support, and the seatback lateral support[5]. The seatback lateral support or also known as the backrest width is obtained by taking the minimum width of a large man's interscye distance. Interscye breadth is measured across the back between the right and left posterior axillary fold landmarks. "A big size man" has a higher percentile. Therefore, the 95th percentile is usually used[6-8].

As the development of railway train now is toward high speed and frequency, the expectation of comfort ride is also becoming increasingly demanding[9]. Seats are the most basic and crucial facility, which directly influence the travelling mood of the passengers. In the early development stage of seat evaluation, selection of the appropriate subjects to represent the potential users of the seat is crucial. Nowadays, simulation solutions for automotive seating dimensions that are widely used in the automotive sector rely on diverse sources of databases[10]. It was pointed out that the height of the potential user is an important criterion and is usually taken from 5th to 95th percentiles[11]. Hence, there is a need to redesign the current train seats to include Malaysian data as the basis of its design.

In this study, the main target is to design a whole new structure of train seat based on anthropometric data of the potential users to ensure the passengers' comfort. In this case, the potential users are Malaysian.

METHODOLOGY

This project covers the seat design optimization for high-speed train by producing a whole new structure of an ergonomic seat. It is hoped the new design will provide passengers ofhigh-speed train comfortable train-riding experience.

For many real-world requirements, a relatively crude data collection and analysis are considered sufficient[7].There are established anthropometry data for both Malaysian male and female adults[12]. However, for research exercise, new data were collected for 50 male subjects.The direct measuring method was performed among university students. The subjects were selected based on their age of 21 and above. The female data used to establish the seat fit parameters is a secondary data[12].

All the anthropometric data is based on MS ISO 7250[13]. In order to obtain more potential users, the measurement was carried out using the direct measuring method to achieve flexibility and mobility. The equipment used for measuring was a standard anthropometric tool, such as the anthropometer, meter ruler, sliding compass, callipers, and measuring tape. With respect to local culture, the measurements were taken with clothes on where the clothes thicknesses were approximately 1 to 3 mm. The sitting surface was a flat seat pan without cushion and the subjects were sitting erect at approximately 90° looking straight ahead, the thighs are parallel and the knee flexed at 90° with the feet in line with the thighs. Throughout the completion of all dimensions taken per subject, the time consumption was about 15 to 20 minutes.

The main manufacturer for most of the buses' and trains' seats in Malaysia gave an approval to measure one of their seat. The seat measured is made for the local electric powered train service. The data was obtained from measurement carried out during a site visit to the company.

For the conceptual design process, the sketches for the designs were done based on the existing seat design in the local electric train with slight modification. The designing process were done using CATIA (Computer Aided Three- dimensional Interactive Application) software based on the dimensions of the seat fit parameters measured.RULA analysis using CATIA was also conducted for both the existing sear design and the new seat design. RULA analysis in CATIA is easy to use as it applies the anthropometry data given to create a manikin and simulate the sitting on the designs.

RESULTS AND DISCUSSION

Anthropometry Measurement

The results are tabulated as shown in Table 1. As mentioned earlier, the female Malaysian sitting anthropometric data is obtained fromsecondary data[12].

The mean value for male stature is 1,706 (SD = 224) while the mean value for female is 1,564 (SD = 64). Thus, from the two mean values or the 50th percentile, the stature of man is larger compared to the woman for all dimensions except popliteal height, sitting elbow height, and thigh clearance.

Table 1 - The Mean, SD, and 5th and 9th Percentile Anthropometric Data for Malaysian Male (n=50) and Female Subjects[12]

			Male			
	Dimension	**5th**	**Mean**	**95th**	**SD**	**CV**
1	Stature	1622.55	1706.02	1825.15	244.36	0.14
2	Interscye breadth	330.00	370.18	429.00	55.75	0.15
3	Hip breadth	343.25	376.00	419.00	52.25	0.14
4	Sitting height (erect)	852.98	853.13	880.00	114.96	0.13
5	Sitting eye height	721.55	718.20	740.90	95.62	0.13
6	Sitting shoulder height	480.15	572.29	648.90	88.68	0.15
7	Popliteal height	420.00	426.94	450.00	54.63	0.13
8	Cervical height	610.00	614.11	639.45	81.07	0.13
9	Buttock-popliteal length	460.55	479.51	515.40	63.93	0.13
10	Sitting knee height	520.00	539.90	583.60	73.32	0.14
11	Forearm-hand length	438.10	458.49	500.45	62.15	0.14
12	Sitting elbow height	132.35	168.88	200.00	25.10	0.15
13	Seat height	396.63	405.97	420.00	51.21	0.13
14	Thigh clearance	121.00	156.12	198.60	30.01	0.19
15	Upper leg length	531.55	577.76	636.45	81.37	0.14
			Female			
	Dimension	**5th**	**Mean**	**95th**	**SD**	**CV**
1	Stature	1459.44	1563.77	1668.10	63.62	4.07
2	Interscye breadth	239.55	316.83	394.11	47.12	14.87
3	Hip breadth	259.67	350.73	441.79	55.52	15.83
4	Sitting height (erect)	742.07	820.01	897.95	47.53	5.80
5	Sitting eye height	624.78	698.84	772.91	45.16	6.46
6	Sitting shoulder height	460.14	532.74	605.34	44.27	8.31
7	Popliteal height	358.69	433.98	509.27	45.91	10.58
8	Cervical height	529.63	602.45	675.28	44.41	7.37
9	Buttock-popliteal length	379.15	453.83	528.51	45.54	10.03
10	Sitting knee height	405.14	498.45	573.76	51.41	10.50
11	Forearm-hand length	357.54	420.78	484.01	38.56	9.16
12	Sitting elbow height	145.93	223.24	300.56	47.14	21.12
13	Seat height	356.10	422.84	489.59	40.70	9.62
14	Thigh clearance	129.94	205.16	280.38	45.87	22.36
15	Upper leg length	483.63	541.05	598.48	35.02	6.47

Seat Fit Parameter

In general, most automotive seat recommendations are mainly on driver seats but some of the parameters discussed are applicable to passenger seats as well. Measurements were chosen with the consideration of the Malaysian anthropometric data for sitting comfort of potential users ranging from 5th percentile to 95th percentile. Table 2 shows the related anthropometric data for new seat design estimated dimensions. The cushion width dimension is based on the 95th percentile of female's hip breadth, which is 442 mm. The cushion length dimension is based on the 5th percentile of female's buttock-popliteal length, which is 380 mm. The seat height is based on the popliteal height of 50th percentile female, which is 434 mm. The backrest width is based on the interscye breadth of the 95th percentile male, which is 430 mm. The backrest height is based on the sitting shoulder height of the 95th percentile of male, which is 649 mm.

For the evaluation of mismatch between anthropometric measure and the design patterns' dimensions, it was suggested that applied anthropometry and ergonomic principles have to be considered[14]. It is also important to define equation(s) in which the values for each design patterns' dimension could be established; if the dimension has a minimum and maximum limit, a two-way equation has to be selected and if it has only a maximum or a minimum limit, a one-way equation has to be opted[14].

There are many suggestions[15-18] on how seat height should be determined against popliteal height such as the popliteal height should be higher than the seat height but it does not have to be higher than four centimetres or 88% of the popliteal height in order to avoid compression in the buttock region. Also, popliteal height should be modified according to a shoe height of 3 cm. Therefore the suggested match criterion is as Equation (1)[14]:

$$(\text{Popliteal Height} + 3) \cos 30^\circ \leq \text{Seat Height} \leq (\text{Popliteal Height} + 3) \cos 5^\circ \quad (1)$$

For the seat length, it should be designated for the 5th percentile of buttock-popliteal length distribution[14,19-22].

A proper seat length is important so that the user will be able to use the backrest of the seat to support the lumbar spine without compression of the popliteal surface. Moreover, when the seat length is less than the buttock- popliteal length of the subjects, the thigh would not be supported enough. Hence, Parcells et al.[16] suggested that the match criterion as Equation (2):

$$0.80\ \text{Buttock-popliteal Length} \leq \text{Seat Length} \leq 0.95\text{Buttock-popliteal Length} \quad (2)$$

Table 2 - Seat dimensions and related anthropometric measurements

No	Seat dimension	Anthropometric measurement	Estimated value (mm)
1	Cushion width	Seated hip breadth	442
2	Cushion length	Buttock-to-popliteal length	380
3	Seat height	Popliteal height	434
4	Backrest width	Chest breadth/ interscye distance*	430
5	Backrest height	Shoulder height	649

*distance across back between the armholes of a garment

While for the seat width measurement against the hip breadth as summarized by Castelluci[14]he hip breadth should be narrower than the seat width, and is designated for the 95th percentile of hip breadth distribution or the largest hip breadth. As in this case, the match criterion was one-way that is shown in Equation (3).

$$\text{Hip breadth} < \text{Seat width} \quad (3)$$

Thus, by following the mismatch between the anthropometric measurement and the design pattern mentioned above, the new proposed seat design dimension is as depicted in Table 3.

Table 3 - Results of univariable analysis between QOL and socio-economic factors (n=308)

Seat Dimension	Current Design (mm)	New Conceptual Design (mm)
Seat Height	500	380
Cushion Width	415	450
Cushion Length	630	540
Backrest Width	425	450
Backrest Height	615	850

Seat Concept Design

Figure 1 shows the final sketch of conceptual design, which is chosen due to having proper cushion for comfort ride especially in long haul ride for high-speed train. The idea of this sketch comes from the automotive seat design for race cars where the person has to be seated or bonded tightly to the seat to avoid serious injury from accident. With the three sections of cushion on the backrest where the lower two sections function to provide comfort for the back up to sitting shoulder height and the upper section of the cushion provides neck rest. There is an additional feature that is the seat handle located right at the top of the backrest. This feature provides stability for standing passengers without disturbing the seated passenger. The final sketch of conceptual was imported into the CATIA software and the dimensions from the analysis of seat fit parameters will be included.

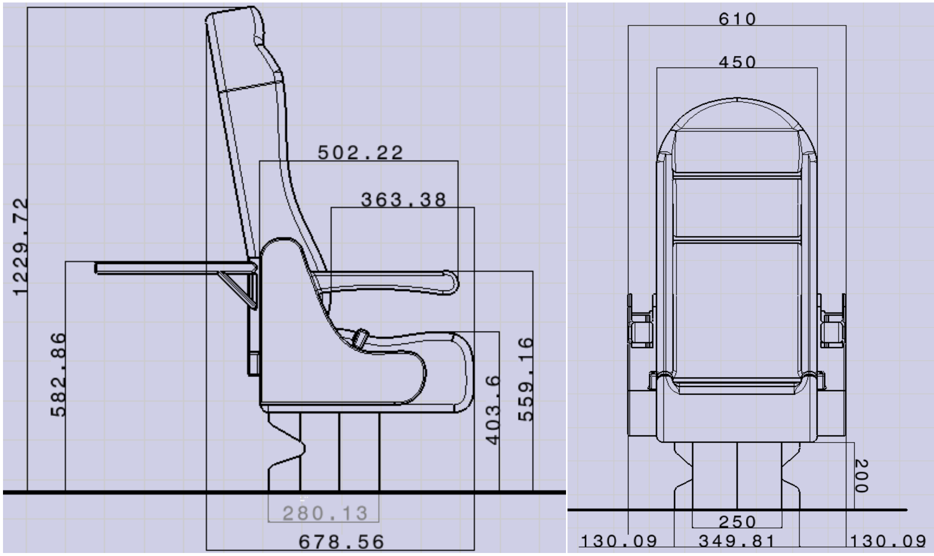


Figure 1- Detailed design of the new concept design train seat

The modelling process was also done in CATIA software complete with the rendering process of the new seat design. Figure 2 shows the complete model of new seat design.

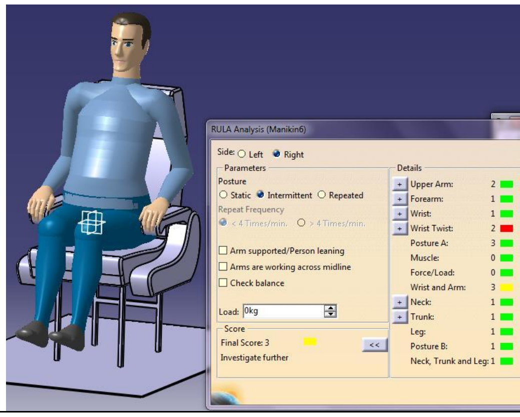
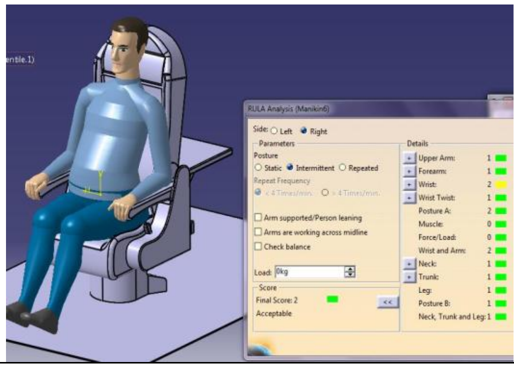
Seat Comparison (RULA analysis)

The complete seat design then were analysed with manikin of 95th percentile male adult (Malaysian) for both current seat design and new concept design. Results of RULA analysis are shown in Table 4. The new design has better RULA analysis result.

For the current existing design, the final RULA score is 3, which means that it needs to be investigated further while the new concept design seat RULA score is 2 which means that it is acceptable. This shown that the new concept design seat is more comfortable to the upper human body compared to the current seat. The current existing design has proper thigh support for the 95th percentile manikins but does not provide suitable seat height and neck support. The new conceptual design surpassed the current design as it provides sufficient seat height, arm support, backrest support and neck support as well as thigh support based on the 3D visualization in CATIA.

Figure2 - Complete model of new seat design in CATIA

Table 4 - RULA Analysis for the 95th Percentile of Malaysian Adult Male

Design Pattern	RULA Analysis Result
Current Design	
Conceptual New Design	

CONCLUSION

This study presented a new seat design that optimized the seat fit parameters based on Malaysian anthropometry data. The fit parameters proposed for the new design are seat height, 380 mm; cushion width, 450 mm; backrest width, 450 mm; backrest height, 850 mm. From the analysis done in CATIA, it was clearly shown that the new concept design seat is more comfortable than the current existing design. As for future research, it is recommended to explore the dynamic effects of seat pressure and vibration on the seat of the train.

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