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Integrated Approach of Ergonomics and MCDM into Truck Drivers' Seat Comfort: A Case Study in Bangladesh

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ABSTRACT
Seats are one of the most significant components for automotive vehicles. Prolonged driving a truck in Bangladesh is not so comfortable because no one design the seat properly considering anthropometric data. The improper seat design causes various health problems. Therefore, the improvement of seating posture is the urgency for reducing health issues. In this paper, a total of 120 Bangladeshi truck drivers were taken as sample for measuring anthropometric data. A comparison of health status between drivers and normal people showed that drivers suffer much than the control group. The relevant feedbacks required for the analysis were collected from the expert's opinion. The integrated approach (AHP-TOPSIS)found that among four health issues, back pain is more critical health issue associated with the existing seat dimension. Finally, the study suggested seat width as the most decisive design parameter on which designers should give much attention while designing truck drivers' seat.

Keywords: Anthropometry; Seat dimensions; Truck driver;AHP-TOPSIS; Bangladesh.

1. Introduction

Seating comfort is a verykey factor for drivers and other members of the workplace who are exposed to spend most of their time sitting[1]. Comfort is such a factor that helps to improve productivity as well as the level of the user's satisfaction. In Bangladesh, the truck drivers are used to frequently work 50 or more hours a week. For driving safely and comfortably, seating comfort for drivers are essential and proper designed automotive seats can play a vital role in improving the comfort and work environment for the driver [2–4].

Ergonomics deals with the fitting of the task to the individual for their comfort, not the individual to the task. The concept of ergonomic design of equipment, furniture, vehicle etc. are now broadly used in the industrial, agricultural, and service sectors to improve working efficiency as well as safety issues [5–7] There is a close relationship between the body dimensions of the users and seat dimensions of the vehicles. Therefore, properly designed vehicle's seats are necessary for sitting comfort which is made based on the body dimensions of the users.

A number of researchers and engineers have revealed that several factors, for instance, seat-interface pressure distribution, whole-body vibration, pressure change rate etc. affect theseating comfort of individuals [8–11]. Frechin et al. conducted a study on the effects of vibration and acceleration on an active seat [12]. The purpose of the study was to isolate the passengers and equipment in the vehicle from the negative impacts of vibration and acceleration and suggested the ways for compensating to acertain extent. Similar research works were conducted for driving seating comfort by several researchers [13–15]. Mehta et al.reviewed the existing seat dimensions and anthropometric considerations of tractor seat design [16]. The authors recommended proper measurements for optimal seat design of the tractor operator in India. Chimote and Gupta applied the integrated approach of ergonomics and fem into truck driver's seat comfort [17]. The objectives of the study were to conductsurvey amongst the truck drivers, examine the travel time factor, and seat discomfort and recommend best alternatives of optimal drivers' seat with the aid of ergonomics and advanced design tools such as CADand CAE. Ajayeoba and Adekoyaconducted a study of measuring anthropometric data of 939 passengers (612 male and 327 female) in Nigeria for the investigation of the fitness of seats of 92 locally made commuter buses and suggested modified seat dimensions based on anthropometric data [18]. Lucas and Onawumioutlined some suggestions from the ergonomic point of view to recommend in-vehicle interface design of taxicabs in Nigeria [19]. Marquez and Garciaoutlined suggestions 22 based on ergonomics to improve the design of a passenger vehicle in Venezuela [20].

From the literature, it is quite evident that the improvement of seating systems has become the subject of intense interest to many researchers for many years. There are many research opportunities for designing the truck driver's seat ergonomically in Bangladesh as the study related to truck driver's seat design is limited in the literature. Recently, our research group conducted two studies on designing truck driver's seat considering body dimensions [21,22]. In these studies, we measured the actual anthropometric measurements of the Bangladeshi truck drivers from Khulna zone and seat dimensions of three truck bands (TATA, ASHOK LEYLAND,and ISUZU) for exploring the existing mismatch and developed a model for predicting the seat dimension based on the drivers' anthropometry. Recently, the analytic hierarchy process (AHP) has been employed successfully in ergonomics in Bangladesh [23,24]. The aim of the current study is to study the existing seat

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dimensions and anthropometric measurements of the drivers for establishing a proper design guide using integrated AHP and technique for order preference by similarity to ideal solution (TOPSIS) approaches.

2. Research methodology

The study was conducted at the Central storage depot in Khalishpur, Khulna, Bangladesh. For this purpose, a set of structured written questionnaire form were circulated among the 120 truck drivers aged between 30 to 60 years and 10 doctors as the expert. The forms include details regarding their sitting posture, body part dimensions, and health-related problems due to prolonged driving. The sample size employed in this study was determined based on the Hicks recommendation considering 90% confidence level, z = 1.64 and 6% sampling error [25]. Four anthropometric measurements, for example, popliteal height (PH), hip breadth (HB), buttock popliteal length (BPL), and sitting shoulder height (SSH) were measured. The integrated AHP-TOPSIS techniques were implemented according to the previous study [26]. The AHP analysis was conducted to identify the most severe problem among four health issues. Finally, TOPSIS technique was applied to sort out seat dimensions on which designers should give much attention while designing truck drivers' seat. Following are the steps for this study.

Step 1: To analyzethe truck seat design by TOPSIS a decision matrix having R criteria/attributes and C alternatives are needed. The decision matrix is represented as

$$DM = [X_{ij}]_{mn} \quad (1)$$

Where,X_{ij} is the performance of ith alternative with respect tojth attribute.

Step 2: The normalized decision matrix is calculated based on the average decision matrix by using equation (2).

$$ND_{ij} = \frac{x_{ij}}{\sqrt{\sum_i^m x_{ij}^2}},\ j = 1,2,3 \ldots .n \quad (2)$$

Where, nr_{ij} are the elements of the normalized decision matrix of ith alternative with respect to jthattribute.

Step 3: To combine the TOPSIS and AHP process for evaluatingthe truck seat design it is necessary to determine the relative importance of different attributes with respect to the overall objective. AHP builds a hierarchy of decision items using comparisons between each pair of items expressed as a matrix and produce weighting scores whichare combined with the analysis of TOPSIS.

Let, CM represents an n×n pair-wise comparison matrix

$$CM = \begin{bmatrix} 1 & K_{12} & \cdots & K_{1n} \\ K_{21} & 1 & \cdots & K_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ K_{n1} & K_{n2} & \cdots & 1 \end{bmatrix} \quad (3)$$

Where,K_{ij} is the element of the pair-wise comparison matrix. The diagonal elements in the matrix CM are self-compared and those elements have equal importance, thusK_{ij}=1, where i=j, i=1, 2... n. The values on the left and right sides of the matrix diagonal represent the strength of the relative importance of the ith attribute compared with the jth attribute. Thus,K_{ij} = 1/K_{ij}, where K_{ij}> 0, i ≠ j, as CM is a positive reciprocal square matrix.

Let,W_i denotes the importance degree for the ith attribute, then,

$$W_i = \frac{(\prod_{j=1}^{n} K_{ij})^{1/n}}{\sum_{i=1}^{n}(\prod_{j=1}^{n} K_{ij})^{1/n}},\ i,j = 1,2,3 \ldots n \quad (4)$$

Let, C denotes an n-dimensional column vector describing the sum of the weighted values for the importance degrees of the attributes, then

$$C = [C_i]_{nxi} = AV, i = 1,2,3 \ldots n \quad (5)$$

Where,

$$AV^T = \begin{bmatrix} 1 & K_{12} & \cdots & K_{1n} \\ K_{21} & 1 & \cdots & K_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ K_{n1} & K_{n2} & \cdots & 1 \end{bmatrix} [W_1, W_2 \ \ldots . W_n] = \begin{bmatrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{bmatrix}$$

(6)

The consistency values for the attributes can be represented by the vector CV,

$$CV = [cv_i]_{1xn} \text{ Where, } cv_i = {C_i}/{W_i}, i = 1,2,3 \ldots n \quad (7)$$

The maximum Eigen value λ_{max} can be determined as follows

$$\lambda_{max} = \frac{\sum_i^n cv_i}{n}, i = 1,2,3 \ldots n \quad (8)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (9)$$

If CI = 0, the evaluation for the pair-wise comparison matrix is implied to be perfectly consistent. Generally, a consistency ratio (CR) can be used as a guide to check the consistency by the ratio given by equation (10),

$$CR = \frac{CI}{RI} \quad (10)$$

TheSaaty nine-point preference scale is adopted for constructing the pair-wise comparison matrix which deals with two distinct sets of numbers; i.e. one set {1, 3, 5, 7, 9} signifies the gradual priority in the importance of one criterion relative to the other as one moves from left to right of the set, whereas the other set {2, 4, 6, 8} contains the in-between preferences, which may or may not be used based on the preference scale.Therefore,the intermediate values are employed to interpolate the scale values if such preferences do exist.

Step 4: The weighted normalized fuzzy decision matrix was constructed by using weight of each problem and each design criteria that was obtained in AHP process following by equation (11).

$$WM = ND_{ij} W_{ij} \quad (11)$$

Step 5: The best alternative has the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. Here, the positive ideal solution and the negative ideal solution were found by equation (12) and (13).

$$\mathrm{WM}^{+} = \left\{ \left(\sum_{i}^{\max} \mathrm{WM}_{ij} / _{j \in J} \right), \left(\sum_{i}^{\min} \mathrm{WM}_{ij} / _{j \in J'} \right) \text{for } i = 1,2,\ldots,m \right\} = WM_1^{+}, WM_2^{+} \ldots\ldots WM_n^{+} \quad (12)$$

$$\mathrm{WM}^{-} = \left\{ \left(\sum_{i}^{\min} \mathrm{WM}_{ij} / _{j \in J} \right), \left(\sum_{i}^{\max} \mathrm{WM}_{ij} / _{j \in J'} \right) \text{for } i = 1,2,\ldots,m \right\} = WM_1^{-}, WM_2^{-} \ldots\ldots WM_n^{-} \quad (13)$$

Where, J = (j = 1, 2.….n)/j

Here, WM^{+} and WM^{-}positive ideal solution (PIS) and negative ideal solution (NIS).

Step 6: The separation of each alternative from the ideal solution is given by

$$d^{+} = \sqrt{\sum_{j}^{n} \left(WM_{ij} - WM_j^{+} \right)^2}, \text{ i=1, 2, 3…..n} \quad (14)$$

$$d^{-} = \sqrt{\sum_{j}^{n} \left(WM_{ij} - WM_j^{-} \right)^2}, \text{ i=1, 2, 3…..n} \quad (15)$$

Step 7: The relative closeness of a particular alternative to the ideal solution is calculated using equation (16).

$$CC_i = \frac{d_i^{-}}{(d_i^{+} + d_i^{-})}, i = 1, 2, 3 \ldots\ldots n \quad (16)$$

The higher value of closeness coefficient indicates that an alternative is closer to PIS and farther from NIS simultaneously. Here, d^{+} and d^{-} means the summation of distance under positive ideal solutions and negative ideal solutions respectively.

3. Results and discussion

The health-related data of the truck drivers and normal people (control group) were collected fromDecember, 2013 to November, 2014. The control group was the people selected in this study were not related to the driving.In our previous study we observed that the most frequent problems faced by drivers were back pain, foot cramp, neck pain, and muscle weakness[21]. A comparison chart between drivers and control groupis developed which is portrayed in Fig. 1. More than90% of drivers suffer from back pain and 83% suffer from foot cramps whereas the values of that for normal people are 40% and 34% respectively. Moreover, approximately 77% and 75% of the drivers suffer from neck pain and muscle weaknessbut the percentages for normal people are relatively low. We hypothesized that these problems were because of the improper design of truck drivers' seat[21].

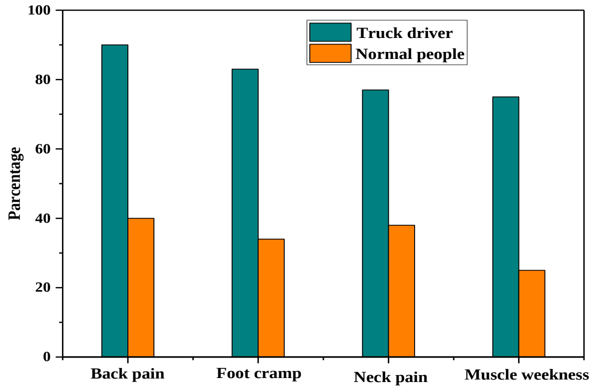

Fig.1 Comparison of health issues between truck drivers and normal people

The next step of this study is to identify the most crucial anthropometric measurement related seat dimension causing ergonomics problems. For this, firstly, the analytical hierarchy process (AHP) was applied to determine the weight of the four problems (attributes) faced by the drivers. A total of three groups consisting of 30 people were considered for making comparison matrix. They expressed their opinions using Saaty's1-9 scale[27].After that, an aggregated pair-wise comparison matrix was prepared using the opinion values.For all attributes,geometric means along with normalized weights were calculated with some developed formulas as described in the methodology section. With the aim ofchecking the validity of decision maker's judgments, a consistency ratio (CR) was calculated using random index data for respective number of attributes. The value of CRis approximately 8% which is less than Saaty's proposed CR value (0.1) indicating that the judgments specified by the decision makers are absolutely correct. The overall results for AHP analysisare presented in Table 1. Geometric mean value of different attributes varies from 3.37 to 0.30.The results revealed that among four health issues, back pain has the highest normalized weight with a value of 0.57. The second highest weight is muscle weakness with a normalized weighted value of 0.26 and neck pain has the lowest weight value of 0.05.In summary, the most severe problem among four issues suffered by the drivers is back pain.

At the final portion of the research work, TOPSIS approach was applied to sort the seat dimensions for designing truck drivers' seat. For each of the design criteria, the decision matrix was formed by taking the linguistic assessment of three decision makers. Then, linguistic variables were converted into numerical values. For example, thefirst decision maker expresses 'F' for showing the severity of seat height for causing back pain. Then, the linguistic variable 'F' was converted into numerical value 6.An aggregated decision matrix was formed using average techniqueandweighted normalized matrixes were developed. Weighted normalized values were obtained by multiplying the weights of criteria (health issues) and corresponding normalized values of all alternatives (four concerned design parameters). Finally, positive and negative ideal solutionswere calculated as presented in Table 2. The results revealed that the highest weighted normalized value (0.33) of back pain problem is observed for backrest height whereas,in the case of muscle weakness, the highest weight is found for seat height.It can be seen from the Table 2, that the back pain has the highest PIS and NIS values followed by muscle weakness, foot cramp and then neck pain.The estimation of d^+, d^- and closeness coefficient of four concerned design parameters using PIS and NIS values is illustrated in Table 3.

Table 1 Normalized weights of attributes for AHP analysis

Attributes	Back pain	Foot cramp	Neck pain	Muscle weakness	Geometric mean	Normalized weight
Back pain	1.00	5.00	7.00	3.67	3.37	0.57
Foot cramp	0.20	1.00	3.00	0.33	0.67	0.11
Neck pain	0.14	0.33	1.00	0.16	0.30	0.05
Muscle weakness	0.29	3.00	6.33	1.00	1.53	0.26
Consistency Ratio = 0.08 < 0.10						

Table 2 Weighted normalized decision matrix, PISand NISfor TOPSIS.

	Seat height	Seat width	Seat depth	Backrest height	PIS	NIS
Back pain	0.32	0.20	0.23	0.33	0.20	0.33
Foot cramp	0.07	0.06	0.03	0.07	0.03	0.07
Neck pain	0.03	0.02	0.02	0.03	0.02	0.03
Muscle weakness	0.17	0.11	0.11	0.16	0.11	0.17

Table 3 Computation of d^+, d^- and closeness coefficient

	Seat height	Seat width	Seat depth	Backrest height
d^+	0.14	0.02	0.03	0.14
d^-	0.01	0.15	0.12	0.01
Closeness coefficients	0.81	0.10	0.06	0.87

It can be seen from the Table 3 that the backrest height has the highest closeness coefficient value of 0.87 and the second highest design factor is seat heighthaving a value of 0.81. Seat depth has the lowest coefficient of value 0.06. Therefore, the most critical parameter is backrest height among the four concerned alternatives on which designers should give much attention tobackrest height while designing truck drivers' seat.

4. Conclusion

Due to prolonged driving on the ergonomically unfit seat, truck drivers suffer various health-related problems. Therefore, vehicle's seats are required tobe designed in such a way that the seats provide enough comfort and safety to drivers. Considering ergonomics or human factors for designing the seat or any furniture are very crucial. This research work identified the most common physical problems of drivers' occurred due to improper seat design. The paper also found the most critical seat dimensions responsiblefor the physical problem. As the concept is relatively new and quite obvious so it will be a helpful guideline for Bangladeshi industrial engineers and manufacturers to design drivers' seat according to their anthropometric data.

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