

# AHP Based Ergonomic Evaluation of Hospital Bed Design: A Case Study in Bangladesh

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# ABSTRACT

Hospital bed is one of the most significant and frequently used healthcare furniture for patients. Most of the hospital beds of the government hospitals in a developing country like Bangladesh lack proper ergonomic considerations. This research aims to assess the design of existing government hospital bed in the context of Bangladesh with respect to different ergonomic problems and anthropometric parameters. Anthropometric measurements and ergonomic data were collected from 230 male patients and 154 female patients of 6 public hospitals of Bangladesh. Dimensions of the hospital bed for patients were collected from different wards of the hospital. Independent t-test was used to analyze the relationship between the anthropometric parameters with respect to different ergonomic problems. The findings of this research are as follows: (i) common ergonomic problems among the patients are poor blood circulation, fatigue, back pain, ligament strain and muscle/tendon strain, (ii) anthropometric parameters related to these ergonomic problems and bed dimensions are: stature, elbow height, popliteal height and sitting elbow height, (iii) among these five ergonomic problems, muscle/tendon strain affects significantly and (iv) stature is the most significant anthropometric parameter for hospital bed design. A predictive model of bed dimension has been developed using a linear regression method. Finally, a new design of the hospital bed is proposed considering all the related anthropometric parameters.

Keywords: AHP; Anthropometric Parameters; Ergonomics; Hospital Bed Design.

# INTRODUCTION

Ergonomic furniture focuses on ensuring maximum comfort, health, and safety according to the users' anthropometric measurements. This type of furniture minimizes the risk of many ergonomic problems. The hospital bed is a piece of essential healthcare furniture for bedridden patients who need special care or treatment for a longer period. Patients spend most of the time laying or sleeping on the bed in the hospital while taking treatment. Therefore, hospital bed and healthcare furniture should be designed considering the ergonomic factors in healthcare facility. A lot of improvements have been taken place for the ergonomic design of healthcare furniture in developed countries. Revealed the challenges to improve the design of healthcare systems in developed countries. Identified the risk factors and their contribution to work-related musculoskeletal disorders for health care systems. Analyzed different patients handling activities in the health care environment using different ergonomic assessment tools. They proposed a new design of the health care system in accordance with some ergonomic conventions and patients requirements [1].

like back pain, blood circulation problem, fatigue, comfort, and sleeping problem. There is also a strong relationship between the quality of sleep and the design of bed. This grounds the need for ergonomic consideration of hospital bed design and resolving the inadequacies. Recent researches have emphasized considering ergonomic factors in designing a hospital bed to improve safety, health, and comfort of patients. Found that sleeping quality is affected by the sleeping posture and sleeping posture is largely dependent on the dimensions of the bed. Designed a multifunctional hospital bed to meet patients' physical demands ensuring comfortable sleeping. Modified the design of hospital bed ergonomically for the healthcare work environment. This study focused on the optimization of work-related musculoskeletal injuries among nurses and other healthcare workers [2].

Designed ergonomic hospital bed by adding a steering assistance feature, adjustable push height feature and a bed contour feature. This study aimed at reducing the physical demands placed on healthcare workers while performing patient transportation tasks. Found that improperly designed hospital bed causes many healthrelated problems such as back pain, fatigue, blood circulation

Improper design of hospital bed may cause many physical problems

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problem, conducted an ergonomic evaluation of patient transfer between hospital beds and stretchers using rapid entire body assessment (REBA) tool. Evaluated the hospital bed ergonomically to determine the acceptable forces requirements for transportation. Suggested considering the anthropometric parameters while designing the workstation and furniture in the healthcare environment. However, there are a number of anthropometric parameters that are closely related to the ergonomic issues as well as the dimensions of the hospital bed. Influences of these parameters vary among themselves for different ergonomic problems [3].

In developed countries, most of the hospital authorities use the ergonomic and modern bed for patients to improve their health safety and comfort. However, public hospitals of developing countries are still using the hospital bed where there is a little consideration of ergonomic variables. Bangladesh is one of the developing countries where most of the people take the service of public hospitals rather than private hospitals. Here, the design of hospital bed is not proper according to the ergonomic view. This is due to the lack of sufficient research on ergonomic design, anthropometric data bank and proper knowledge. As a result, students are suffering various health related problems. But, it is imperative to incorporate the consideration of ergonomic variables in the design of public hospital beds for improving patient's satisfaction. Currently, few studies have focused on the use of anthropometric dimensions for designing ergonomically hospital bed for patients. But this research was done to design hospital bed for male patients [4].

In this study, authors intended to analyze and re-design the existing hospital bed of public hospitals in southern districts in Bangladesh to implement the proposed methodology for improving the bed ergonomically for both male and female patients. However, this method is applicable for designing the hospital beds of any region. For implementing the proposed methodology, authors collected different ergonomic and anthropometric data of patients from different public hospitals of Bangladesh. Dimensions of existing hospital beds were also collected. Different ergonomic problems were analyzed through analytic hierarchy process (AHP) and dimensions were analyzed using regression analysis. Dimensions of new hospital bed were proposed using the developed equations from linear regression. AHP is a widely used multi-criteria decision making tool which was developed by. The main reason behind choosing AHP for ergonomic analysis in this study is that it is easily understandable and it captures and calculates the insights of experts' opinions very systematically [5].

## MATERIALS AND METHODS

## Study area and data collection

In this research, the design of public hospital bed has been assessed with respect to different ergonomic problems and anthropometric parameters using AHP. To conduct this assessment, data of

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different anthropometric and bed dimensions were collected using a measuring tape from a group of patients from 6 public hospitals. In this study, these 6 public hospitals were randomly selected from south-west zone of Bangladesh. Table 1 represents the profile of these public hospitals for the current study. Assuming a 95% confidence interval and allowing a 5% sampling error, the sample size was determined as 384 for this research using the principle of sample size determination. The age limit of these patients was more than 20 years old. This age limit has been considered for getting a normally distributed data. Among these patients, 230 were males and 154 were females. These patients were surveyed through a structured questionnaire [6].

The opinions of the patients and the measurements of four anthropometric variables were collected which were required for designing improved bed and furniture in the healthcare system. These four variables were: stature, elbow span, popliteal height, andsitting elbow height. As highly reliable anthropometric data were required for hospital bed design, the authors used anthropometric equipment for collecting precise measurements of these variables. Here, 100 hospital beds from the selected 6 public hospitals were selected for measuring the bed dimensions. In this study, four bed dimensions were measured for ergonomic evaluation. For evaluating the anthropometric parameters using AHP, four ergonomic problems were selected which have close relationships with bed design and dimensions [7].

Here, Independent t-test was used to analyze the relationship between the anthropometric parameters and bed dimensions. Furthermore, AHP was used to identify the most critical seat dimension related to anthropometric factors responsible for causing severe health problems. Linear regression analysis was performed for developing correlation equations for anthropometry measurements of users based on their stature. And finally, a proper bed design was proposed to mitigate the severity of health-related problems. The proposed research framework is shown in Figure 1.

#### Independent t-test

Independent t-test is used to compare the statistical difference between two sample means from two separate groups. After collecting the data, a test statistic (t-value) is calculated and compared with critical value. If this t-value is greater than the critical value, the null hypothesis will be rejected which implies a relationship between the two means. But, if the t-value is less than the critical value, it will indicate that there is a significant difference between the two means. The t-value is calculated using the following equation:

$$t \ value = \frac{\left|\overline{x}_{1} - \overline{x}_{2}\right|}{\sqrt{\frac{s_{1}^{2}}{n_{1}} + \frac{s_{2}^{2}}{n_{2}}}} \tag{1}$$

Where,  $x_1$  and  $x_2$  are sample means of two different groups respectively,  $s_1^2$  and  $s_2^2$  are two sample variances and finally,

Table 1: Profile of studied public hospitals of Bangladesh

Hospital name	Location	No. of beds
Jashore general hospital	Jashore, Bangladesh	250
Khulna medical college hospital	Khulna, Bangladesh	250
Abhaynagar health complex	Abhaynagar, Jashore, Bangladesh	30
Magura general hospital	Magura, Bangladesh	100
Adhunik sadar hospital	Narail, Bangladesh	50
Kushtia general hospital	Kushtia, Bangladesh	250

n, and n, are the sample sizes of two sample groups [8].

## Analytic hierarchy process

Analytic Hierarchy Process (AHP), developed by Thomas L. Saatyisa structured methodology for making decisions in a complex environment. It has been widely used in group decision making and has large applications in different fields like business, industry, government, health care. AHP has also been applied to show the interrelationship between the ergonomic factors and the patient physical demands and the influence on one another. In AHP, complex decisions are cascaded down into a hierarchical structure composed of different levels. The steps of the AHP method are presented below:

Step 1: Problem or goal formulation of research.

The objective is defined as assessing the influences of different anthropometric parameters with respect to different ergonomic problems.

Step 2: Weight calculation of different criteria and sub-criteria.

In this step, the pair wise comparison matrix A is developed with the assistance of expert input and Table 2 represents the fundamental scale of the relative importance of Saaty.

In the matrix A, each element  $a_{ij}$  represents the relative importance of *i*<sup>th</sup> factor over *j*<sup>th</sup> factor. If the number of factors is *m*, then the pairwise comparison matrix will be as follows:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1m} \\ a_{21} & 1 & \cdots & a_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & \cdots & 1 \end{bmatrix}$$
(2)

Step 3: Weighted normalized decision matrixconstruction.

In this step, each element in the normalized matrix is calculated as follows:

C<sub>ij</sub> = 
$$\frac{a_{ij}}{\sum\limits_{j=1}^{n} a_{ij}}$$
 ij = 1,,2,,...m (3)  
Determining the sample size  
Collecting the data of anthropometric parameters, ergonomic  
problems and hospital bed dimensions  
Performing independent t-test to check the relationship between  
anthropometric parameters and bed dimensions  
Collecting the significance of ergonomic problems and  
anthropometric parameters using AHP  
Developing linear regression equations of bed dimensions  
considering most significant parameter  
Designing a new hospital bed according to the measurement

Figure 1: Flow diagram of the proposed methodology

from the equations

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Table 2: Fundamental scale of Saaty (2005).

Relative importance $(a_{ij})$	Description
1	Equal importance of <i>i</i> and <i>j</i>
3	Moderate importance of <i>i</i> over <i>j</i>
5	Strong importance of <i>i</i> over <i>j</i>
7	Very strong importance of <i>i</i> over <i>j</i>
9	Absolute importance of <i>i</i> over <i>j</i>
2,4,6,8	Intermediate values

Step 4: Construction of weighted normalized decision matrix.

Elements of the weighted normalized matrix are calculated using equation (4) and the weighted normalized matrix is formulated using equation (5)

$$E = N^{th} rootvalue / \sum N^{th} rootvalue$$

$$CR = CI / RId$$

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ \vdots \\ w_a \end{bmatrix}$$
(5)

Step 5: Calculation of eigenvector & row matrix.

Eigenvector and row matrix are calculated as follows:

$$E = N^{th} rootvalue / \sum N^{th} rootvalue$$
(6)

$$Rowmatrix = \sum_{j=1}^{m} a_{ij} * e_{ji}$$
(7)

Step 6: Calculation of the maximum eigenvalue  $\lambda_{\max}$  .

In this step, maximum eigenvalue  $\lambda_{max}$  is calculated using equation (8) and equation (9).

Eigen value ( $\lambda$ ) max =  $\sum$  (Normalized weight of each row\*sum of respective column) (8)

$$\lambda_{\rm max} = Rowmatrix / E$$

Step 7: Calculate the consistency index & consistency ratio.

Consistency index Cl and consistency ratio CR are calculated as follows

 $CI = (\lambda_{\max} - n) / (n - 1) \tag{9}$ 

$$CR = CI / RId \tag{10}$$

#### Linear regression

Linear regression is used to model the relationship between a response variable also known as a dependent variable and one or more independent variables. One of the main purposes of linear regression is to develop a predictive model. In this research, linear regression is used to develop the predictive model for determining the dimensions of a hospital bed. Linear regression model assumes that the relationship is linear between the response variable and the predictors. Performance of a linear model is measured by using R-squared value. If the R-squared value is closer to 1, it will indicate a strong relationship between the response variable and predictor variables [8].

# **RESULTS AND DISCUSSION**

Analysis of ergonomic problems

In this step, prevalence of ergonomic problems was identified and analyzed for male and female patients separately through a prepared questionnaire. Here, 230 male patients and 154 female patients were interviewed. Figure 2. Illustrates the percentage of prevalence of different ergonomic problems among patients. For male patients, back pain have been identified as the most frequent ergonomic problem. About 84.78% of the male patients have mentioned this problem in their questionnaires. However for female patients, poor blood circulation was found the most frequent one. About 86.36% of the female patients responded to this problem. The second most frequent ergonomic problem among the male patients was poor blood circulation (80.43%) whereas for female patients it was fatigue (76.62%). Ligament strain was found the least frequent for both male patients (about 44.78%) and female patients (about 58.44%). Overall, it is clear that prevalence of ergonomic problems for both male and female patients is very normal phenomena.

## Analysis of related anthropometric measurements

In this step of the study, it has been tried to find out the causes of the presence of these ergonomic problems among the male and female patients. To achieve this aim, a discussion has been done with a group of ergonomic experts. After consulting with the experts and reviewing various literatures, this study found four anthropometric measurements which are closely related to these ergonomic problems. These are: (i) stature, (ii) elbow span, (iii) popliteal height sitting and (iv.) sitting elbow height. For designing effective ergonomic hospital bed, measurements of these anthropometric variables of users are required. In this study, measurements of these four anthropometric variables were taken from 230 male and 154 female patients using measuring tape. Table 3 represents the descriptive statistics of the selected anthropometric data of male and female patients. In this research, mean value, standard deviation, 5th and 95th percentile have been calculated of the collected data in order to determining the related dimensions of the ergonomic hospital bed.



Figure 2: Prevalence of ergonomic problems among patients

#### Independent t-test analysis

Independent t-test or two sample test determines whether there is a statistically significant difference between the means of two unrelated groups. In this study, one group is four anthropometric measurements and another group is four hospital bed dimensions. If t-value is greater than the critical value, then null hypothesis is rejected. Here, null hypothesis:  $H_a$  = problems are not related to anthropometric variables and alternative hypothesis:  $H_a$  = problems are related to anthropometric variables. Table 4 shows the results of independent-test for male patients for different anthropometric variables and hospital bed dimensions.

All the null hypotheses are rejected because all the calculate datevalues are higher than the critical values. This proves that the five ergonomic problems are related to the four anthropometric variables for male patients. Table 5 shows the results of independent t-test for female patients. Here, all the null hypotheses are also rejected which indicates the existence of a relationship between the ergonomic problems and hospital bed dimensions for female patients. For all the cases, the p-values are 0.05.

## Evaluation of anthropometric variables using AHP

Firstly, hospital bed dimensions related to the anthropometric variables were identified consulting with healthcare furniture experts. Figure 3 illustrates the relationship of hospital bed dimensions with anthropometric variables and ergonomic problems. Here, bed length and width are dependent on stature and elbow span respectively. Again, bed height and bed stand height are dependent on popliteal height sitting and sitting elbow height respectively.

The selected four anthropometric variables were evaluated against the five ergonomic problems for male and female patients individually. Using pair-wise comparison, the relative weights of five ergonomic problems were found for male patients as shown in Table 6. Weight of muscle strain is0.383 which is relatively more than other problems and poor blood circulation problem has got the least weight valued 0.374.

All the four anthropometric variables were then evaluated against the individual ergonomic problem. Figure 4 summarizes the local weights of four variables against each problem. Stature has a higher impact on poor blood circulation than other variables. Stature has also relatively higher impact on fatigue, back pain, and ligament strain. For muscle/tendon strain, popliteal height has the highest impact among the four variables. However, the second most affecting variable is stature.

Table 7 represents the global weight of each anthropometric variable against each ergonomic problem for male and female patients. Stature has got the highest value of 0.3561 and ranked first. For

Addie 17 Independente e teot for indre patiente	Table 4:	Independent	t-test for	male	patients
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Groups	Mean	Standard deviation	t-value	p- value	Critical value	Accept or reject
Stature and hospital bed	167.989	7.295	9.5	.05	1.96	Reject
length	208.125	15.607				
Elbow span and hospital bed	44.047	3.876	117.49	.05	1.96	Reject
width	82.325	2.130				
Popliteal height sitting and	52.825	3.793	2.436	.05	1.96	Reject
hospital bed height	63.344	3.833				
Sitting elbow height and bed	80.817	6.219	5.99	.05	1.96	Reject
stand height	72.254	4.047				

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		Table 5: Independent t-te	st for female pat	ients		
Groups	Mean	Standard deviation	t-value	p- value	Critical value	Accept or reject
Stature and hospital bed	162.662	4.131	24 155	05	1.0/	Datas
length	208.125	15.607	24.155	Idue         p- value         Critical value         Addition           155         .05         1.96         1.96           0.38         .05         1.96         1.96           189         .05         1.96         1.96           474         .05         1.96         1.96	Keject	
Elbow span and hospital bed	42.760	3.913	110.20	05	1.0/	Distant
width	82.325	2.130	110.36	.03	1.90	Reject
Popliteal height sitting and	44.279	2.618	17 190	05	1.0/	Datas
hospital bed height	63.344	3.833	17.189	.05	1.90	Reject
Sitting elbow height and bed	73.429	3.254	10 474	05	1.0/	Datas
stand height	72.254	4.047	10.474	.05	1.90	Reject



Figure 3: Relationship between anthropometric variables and hospital bed dimensions.

Table 6: Relative weights of	different ergonomic	problems for mal	e patients
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Ergonomic problems	Poor blood circulation	Fatigue	Back pain	Ligament strain	Muscle/Tendon strain	Relative weight
Poor blood circulation	1	1/2	1/5	1/6	1/9	0.037
Fatigue	2	1	1/5	1/4	1/6	0.069
Back pain	5	5	1	1/3	1	0.236
Ligament strain	6	4	3	1	1/3	0.275
Muscle/Tendon strain	9	6	1	3	1	0.383

λ<sub>max</sub> = 0.711969; CI= -1.02, RI= 1.12; CR = -0.9017<0.10



Figure 4: Local weights of anthropometric variables with respect to each ergonomic problem for male patient.

female patients, stature has also got the highest global weight (0.4993) and ranked first as like as male patients. This indicates that statue is the most influential anthropometric variable in bed design for both patients. In case of male patients, popliteal height (0.3195) and elbow span (0.2654) have been ranked second and third respectively whereas the scenario is just opposite for female

patients.Sitting elbow height has got the least value and ranked last for both cases.

## Correlation analysis between stature and bed dimensions

Correlation analysis was used to identify the relationship between the stature and hospital bed dimensions as stature has got the most

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Anthropometric variables	Poor blood circulation (0.037)	Fatigue (0.069)	Back pain (0.236)	Ligament sprain (0.275)	Muscle/Tendon strain (0.383)	Global weight	Global Rank
Stature	0.422 (0.537)	0.372 (0.427)	0.407 (0.535)	0.336 (0.557)	0.330 (0.405)	0.3561 (0.4993)	1(1)
Elbow span	0.224 (0.279)	0.267 (0.320)	0.216 (0.284)	0.315 (0.293)	0.264 (0.374)	0.2654 (0.2972)	3(2)
Popliteal Height	0.288 (0.135)	0.267 (0.208)	0.314 (0.117)	0.273 (0.101)	0.369 (0.174)	0.3195 (0.1554)	2(3)
Sitting elbow height	0.065 (0.049)	0.041 (0.045)	0.061 (0.063)	0.075 (0.049)	0.035 (0.048)	0.0536 (0.0419)	4(4)

Table 7: Global weights and rank of anthropometric variables for both patients

significance value from AHP. High correlation coefficient implies high association among the variables. Correlation analysis between stature and hospital bed length for male and female patients are illustrated [9].

By contrast, poor correlation has been found in the case of stature and other hospital bed dimensions. For popliteal height sitting and sitting elbow height, stature exhibits poor correlation with two dimensions. From the ergonomic point of view, bed length has become the highest considerable parameter for designing the hospital bed for both male and female patients. But other parameters have also influence on the design of the bed [10].

#### **Regression Analysis**

In this part of the study, the relationship among the four anthropometric variables has been formed by using regression analysis. The main objective was to accelerate the design process by choosing the value of only one parameter. Values of other parameters can be found by using the relationship.

## CONCLUSION

Patients comfort, safety, and health should be considered as of great significance in hospitals and clinics. A hospital bed is one of the major and frequently used healthcare furniture by the patient in hospital. Therefore, hospital beds are required to design in such a way so that both patients and healthcare workers feel comfortable with minimum physical demands. However, hospital beds of government hospitals in developing countries like Bangladesh lack proper ergonomic design. Since most of the general patients are used to take treatment from the government hospital, they face many ergonomic problems like back pain, poor blood circulation, etc. Therefore, ergonomic considerations must be incorporated in the design of the hospital bed.

This study aims to redesign the hospital bed of the government hospital of Bangladesh incorporating ergonomic considerations. The data were collected from 6 public hospitals of Bangladesh for 230 male and 154 female patients. A t-test revealed the relationships between hospital bed dimensions and anthropometric parameters. The study found stature as the most significant anthropometric parameter through AHP. Finally, a new ergonomic design of hospital bed has been proposed.

In the future, more anthropometric data can be considered for a more suitable design of the hospital bed. This research has considered the environment as non-fuzzy. Different fuzzy approach and other MCDM tools can be used in the future for designing ergonomic bed and other healthcare furniture.

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