An Ergonomic Approach for Designing of an Industrial Trolley with Workers Anthropometry

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Abstract

Industrial trolley is an essential material handling equipment which is available in many industries and carries up to 1 ton weight. But in some cases, these trolleys are not ergonomically designed and so many workers suffer from various musculoskeletal disorders (MSDs). The purpose of this study is to find the mismatch between trolley dimension and anthropometric data. Anthropometric measurements (2) of 50 workers and dimensions (2) of industrial trolley were taken and so these were differentiated. Mismatches were found out by doing chi-square test. According to a survey, workers' experiencing pain was found out in their various body parts. It was found that wheel radius and handle height were too short which cause discomfort to the workers. These inspections suggest dimensions for the design of an industrial trolley so that comfort and efficiency of the workers can be ensured.

Keywords

Measurement of Anthropometry, Industrial Trolley, Trolley Design, Mismatch, Musculoskeletal Disorders, Dimensions of Trolley

1. Introduction

This research studies about designing of an industrial trolley. Industrial trolleys are essential parts of material handling that are found in various industries. They have an important role in various kinds of industrial purposes. Industrial trolleys should be made according to the anthropometric measurements of the workers. Various kinds of musculoskeletal disorders, posture defect and other causes are the reasons for the discomfort of the workers. These MSDs occur because of the mismatches between trolley dimensions and workers' anthropometry. To reduce

the MSDs, there must be higher percentage of matches between anthropometric data and trolley dimension. For this purpose, anthropometric measurement is very much essential. As workers spend most of the time on working in an industry, this research is very much essential not only for physical health of workers but also to enhance their efficiency.

In this research, a trolley design is proposed that will decrease the MSD's. For this purpose, first, the anthropometric measurements of the workers were collected and then two parameters of the existing trolley were identified on which this research focuses on. According to the anthropometric dimensions, these two parameters were evaluated and the proper ergonomic dimension was proposed.

2. Literature Review

Study found that an intelligent platform trolley can be made to research things and analyze various loads by concentrating stress (static) at right panel, connectors, front and back ends of trolley [1]. Communication interaction and also obstacles can be avoided by using raspberry pi and also a robot for making a trolley. This is made to track target [2]. Research found that an ergonomic chair can improve efficiency, reduce disease caused by infection and other MSDs problems. It can also improve nutrition level of elderly persons [3]. A single and double wheel trolley can be used to reduce lifting stress that is only on flat ground and also a mechanism for transporting over stairs of masses may be done by it [4]. In garments industries management of total quality is a prerequisite for the safety of the workers also for management system implementation which is normally integrated [5] [6].

Some analyses pointed out that mismatches can be found between anthropometric measurements of school furniture and anthropometric measurements of primary school students, university furniture and anthropometric measurements of students of many universities and these mismatches can be reduced by using t-test analysis, mismatch equation and also using chi-square distribution [7] [8] [9] [10].

Again some studies found out that in a manufacturing system initial force and height range of handle is calculated while pushing a trolley [11]. Another research recognized that workers may suffer from MSDs for wrong design of trolleys and hence handle height is calculated to reduce back pain and other MSDs of workers [12]. Work efficiency is increased by using a tool called pig in a pigging operation while handling a trolley [13]. According to another research in a material handling operation a trolley is used to lift a self-weight job keeping in the shortest distance [14]. Also quality management is important for increasing workers' efficiency. But there are some obstacles behind it [15]. These problems have to be understood properly for ensuring workers' safety [16].

Pulling and pushing are one of the most essential parts in an industrial world because of variety of material handling equipments that are being largely used [17]. Again some studies found that in agricultural works ergonomic hand tools

are used to reduce the MSDs and other injuries of the workers [18]. Again another research found out that different types of injuries like elbow and shoulder injuries are related to each other [19]. Some analysis found out the external force on wheel chair loading system [20]. An ergonomically designed trolley eliminates MSDs and improves efficiency [21]. Another study suggested that in cylindrical trolleys various things affect handle design but best configuration can not be found by this [22]. In marble cutting process, a transfer trolley can be designed and manufactured in marble industry that can reduce pain of workers [23]. A well developed and creative trolley can perform as both the airport trolley and shopping mall trolley [24] [25].

In short distance movement, various types of office trolleys can be used [26]. In horizontal pulling action handle design has great influence [27]. To push a cart 3D hand forces are calculated [28].

According to ergonomic study, in dryland weeder (push pull system) that is manually operated, optimum handle height is determined [29]. Other researches considered that various industrial transport carts are ergonomically made by proper handle and wheel design and to find out optimum force application, new design is being used [30]. In pushing and pulling system, handle interface for biochemical analysis is being used [31]. Study pointed out wheel design, handle height design, weight of load, direction of movement, move phase, type of floor in accordance with ergonomic rule and also their effect [32]. However, a meal mart in hospital is made by following ergonomic rules that reduce problems of previously made mart [33]. Ergonomic Compatibility also can be determined in mini-buses [34]. Some analyses found that safety awareness has a great importance for reducing health hazard of workers [35]. In garments industry various critical factors are included for TQM implementation that is important for ensuring quality of work to be done [36].

Shoulder motion range can be realized by reliability test [37]. Hand tool is designed by considering grip diameter [38] and in horizontal pulling action handle design has great influence [39]. According to ergonomic consideration wheelbarrows, wheel, truck are designed and various types of mobile trolleys are also designed for material handling system [40].

3. Methods

3.1. Sample Population

From machine shop of an industry in Khulna, Bangladesh, sample population was taken as in the whole machine shop uses industrial trolley. The anthropometric measurements were taken from 50 workers (male). Only male workers were taken as the sample population because there were no female workers found in the machine shop. Permission was granted for the workers to take participation in this research by the managing director of the industry.

The age of the workers was between 25 years and 42 years, the mean of their age being 34 years. Population distribution of study in accordance with age and designation is explained in Table 1. Using Equation (1), the sample size was

calculated (Odunaiya, Owonuwa and Oguntibeju 2014). Here, it can be seen that n = anticipated sample size, N = population size, and e = level of accuracy. In this study, $N = 50$, $e = 5\%$ at 95% confidence level.

$$n = N/(1 + Ne^2). \tag{1}$$

From the equation, the minimum acceptable sample size was calculated to be 44 or more. The available workers number is 50 having no physical issues and the probability of unsuitable measurements of data or inappropriate deviation in the data was reduced. The workers were given assurance of their safety before the measurements were taken.

3.2. Survey Performed

A survey was performed where questions were in a yes/no format. Pain experienced by workers was found out by this survey which helped to find out the dimensional problem of the industrial trolleys. It was found that because of handle height lower back pain occurred and for wheel MSDs occurred among the workers.

It was also found from the survey that most of the workers who were suffering from back pain, used the trolley. But while using the trolley, they had to bend unexpectedly to drive the trolley, and so consistent use of the trolley aided in the development of back pain among its users. Also, because of the improper wheel radius, the workers had to push the trolley with excessive force which leads to MSDs among the workers. **Figure 1** demonstrates the percentage of pain experienced by the workers.

Table 1. Distribution population according to age and designation.

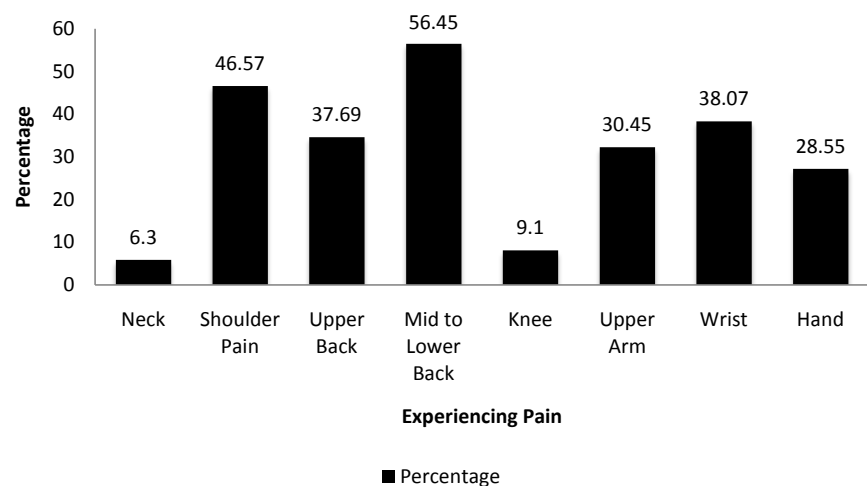| Age range	Designation	No. of workers
25 - 29	Technician	24
30 - 34	Foreman	16
35 - 39	Supervisor	8
40 - 42	Assistant manager	2

Figure 1. Percentage of pain experienced by the workers.

3.3. Anthropometric Procedures, Dimensions and Equipments

According to studies (S. Pheasant, 2003; Kroemer and Kroemer, 1997; Weiner and Lourie, 1969), 2 anthropometric measurements of the workers in the industry in standing in a straight posture were taken by the researchers along with assistant. The measurements were taken at barefoot. The assistant reduced intra and inter observer error. Dimensions were taken in centimeter (cm). Figure 2 shows the anthropometry of workers.

An anthropometric tool available in the ergonomics laboratory of Khulna University of Engineering & Technology's Department of Industrial Engineering and Management was used. Also, slide calipers and tape were taken for taking anthropometric dimensions. These measurements were taken precisely and accurately.

The measurements were taken in 2 weeks and these were taken twice to ensure that there is no error.

Following anthropometric measurements were taken for the purpose of the study from source (Standard 2003):

Stature (S)	Natural height of a person
Elbow Height (EH)	Distance from the floor surface to underside of elbow taken vertically

3.4. Measurement of Trolley

As local workshops manufactured or produced most of the trolleys, they are not ergonomically designed because manufacturers have lack of experience and knowledge about ergonomic facts and designs. Following parameters of an industrial trolley were considered.

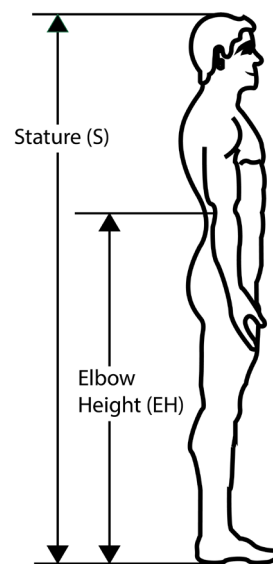|	
Handle Height	Distance from floor to the trolley handle that is taken vertically
Wheel Radius	Circular wheel radius

Figure 2. Anthropometry of workers.

3.5. Mismatch Equations between Dimensions of Industrial Trolley and Workers' Anthropometry

Following ergonomic rule was evaluated to perform the mismatch equation.

Stature (S) against Handle Height (HH)

Handle height is corelated to Stature. Elbow height can be used as a proportion of overall human height or stature (S) that ranges between 66% and 77%. 3 cm allowance was added for shoe to the condition as workers wore shoes while taking measurements [9]. So the following relationship between S (Stature) and HH (Human Height) is expressed in Equation (2),

$$(0.66S + 3) < HH < (0.77S + 3). \tag{2}$$

3.6. Levels of Compatibility

There are three kinds of conditions that were considered: 1) High mismatch which means anthropometric measurements are found to be lower than the evaluated lowest limit; 2) Low mismatch which means anthropometric measurements are found to be higher than the evaluated highest limit; and 3) Match which means anthropometric measurements remain within the evaluated limits.

4. Data Analysis

4.1. Measurement of Anthropometry of Workers

The calculation of 2 anthropometric measurements of industry workers such as minimum (minm), maximum (maxm), standard deviation (SD) and percentile values (5th, 50th and 95th) were performed by SPSS v25. Table 2 shows the measurements of anthropometry of workers in cm.

4.2. Existing Trolley Dimension

To calculate potential mismatch between workers' anthropometric data and existing industrial trolley dimensions, it is important to learn about the existing dimensions. Table 3 shows existing trolley dimensions in cm following standard procedure.

Table 2. Anthropometric dimensions of workers.

Dimension	Minimum	Maximum	SD	Mean	Percentile Values		
					5th	50th	95th
Stature	154.34	172.72	4.23	166.61	158.65	167.16	172.13
Elbow Height	121.84	135.99	3.25	131.28	125.16	131.71	135.53

Table 3. Existing trolley dimension.

Trolley Parameters	Dimensions (cm)
Handle Height (HH)	113.2
Wheel Radius (WR)	2.8

4.3. Calculation of Mismatch Equations of Existing Trolley

Dimension of trolley handle height was evaluated and match and mismatch percentage values were listed. Table 4 shows the potential mismatch and match percentage of the existing industrial trolley.

4.4. Chi-Square Test between Anthropometric Data and Trolley Dimensions

Chi-square test was performed and calculated statistically (Spiegel, Stephens, 2003) to find out the relationship between trolley dimensions and anthropometric dimensions of the workers. Table 5 shows chi-square test having 2 dimensions of human body with percentile values and also observed and expected values.

5. Results and Discussion

5.1. Anthropometric Measurements Analysis of Workers

Table 2 shows anthropometric dimensions of workers. Mean stature, mean elbow height, mean shoulder height, mean grip strength were the following 166.61 ± 4.23, 131.28 ± 3.25, 39.56 ± 1.39, 4.07 ± 0.276. The percentile values for Stature were 158.65, 167.16, 172.13; the percentile values for elbow height were 125.16, 131.71, 135.53; the percentile values for shoulder breadth were 37.38, 39.69, 41.72; the percentile values for grip breadth were 3.63, 4.12, and 4.49.

5.2. Analysis of Mismatch Equations

Table 4 shows that there is 52% mismatch for handle height.

From Figure 3, it was found that the existing handle height was not compatible with the anthropometric measurements of the workers as the mismatch percentage was 52% which was not acceptable, as our target was to minimize the mismatch as far as possible.

5.3. Chi-Square Test Analysis

Existing trolley dimension was compared with anthropometric data by chi-square test where the calculated values were weighed against critical values of chi-square

Table 4. Match and mismatch percentage of trolley dimensions.

Trolley Dimensions	Low Mismatch	High Mismatch	Total Mismatch	Total Match
Handle Height (HH)	52	0	52	48

Table 5. Chi-square values for trolley dimension.

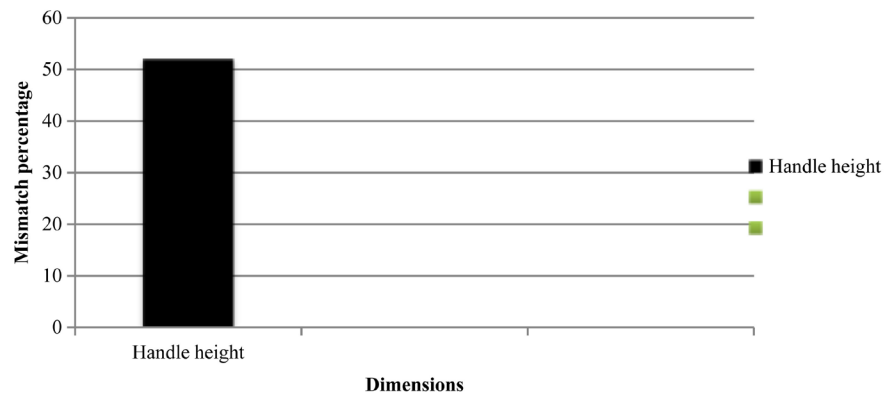| Association	Value	Percentile Value			Chi-square Values	Chi-square (DF = 2)	Decision
		5th	50th	95th			
Elbow Height (EH) and Handle Height (HH)	Observed	125.16	131.71	135.53	7.14	5.99	Reject
	Expected	117.47	113.20	114.55			

Figure 3. Mismatch percentage of dimensions of industrial trolley.

(0.103), degree of freedom (2) and 95 percent confidence level (5.33). For handle height, calculated value is larger than 0.103 (critical value). So the result was "Reject".

5.4. Proposed Furniture Dimensions

As there were mismatches between trolley dimension and anthropometric measurements it was necessary to redesign of the existing trolley with proper anthropometric measurement to reduce the pain experienced by the workers.

Table 6 shows the mismatch percentage of proposed dimension. For handle height mismatch percentage is 2% and so there is 98% match where existing wheel radius was found to be 2.82 cm.

From Figure 4, it is found that the minimum wheel radius for a load of 1 ton should have been 4 cm. But the existing radius is 2.82 cm. As minimum requirement for wheel radius for 1 ton load is not satisfied, the wheel radius is considered as 4 cm in the proposed trolley dimension (Butin, Vasiliev, Tumasov, & Bagichev, 2018). Now the author recommends cast iron as a trolley material considering cost and other aspects. 2D view of an industrial trolley is shown in Figure 5. However, a comparison of existing and proposed dimension of an industrial trolley is shown in Figure 6.

6. Conclusions

Workers' efficiency and comfort at work place largely depend upon MSDs risk factors, anthropometric measurements and trolley dimension. Existing trolley dimensions had mismatch with the anthropometric measurements of the workers and so the trolley was designed again to reduce the MSDs of the workers.

2 anthropometric measurements of 50 workers were taken. Survey showed that MSDs occurred among the workers for 2 parameters (Handle height, wheel radius). Stature and elbow height were evaluated to point out the mismatch between trolley and anthropometric measurement of workers. Chi-square test was performed to find out the connection between the anthropometric dimension and trolley dimensions. Handle height was not accepted because of the higher percentage value. Also, wheel radius was found to be too small.

Table 6. Proposed measurements of trolley dimensions.

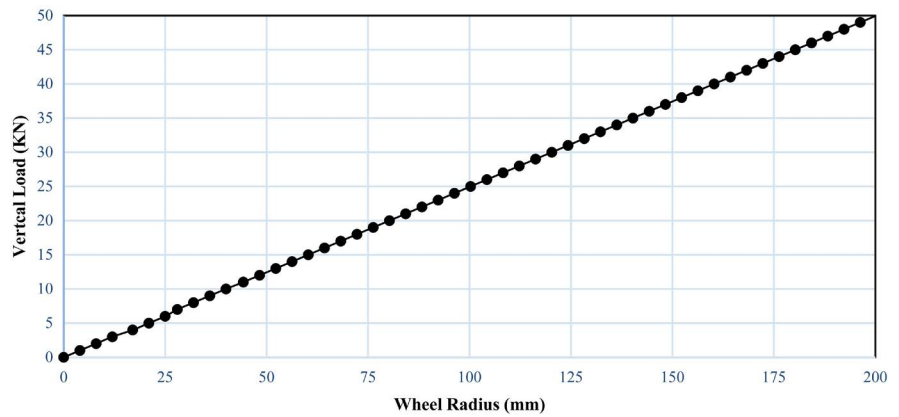| Trolley Dimension	Proposed Measurements	Criteria	Mismatch Percentage		
			Low	High	Total
Handle Height	122.5	Average of 50th percentiles of higher and lower elbow heights	0	2	2

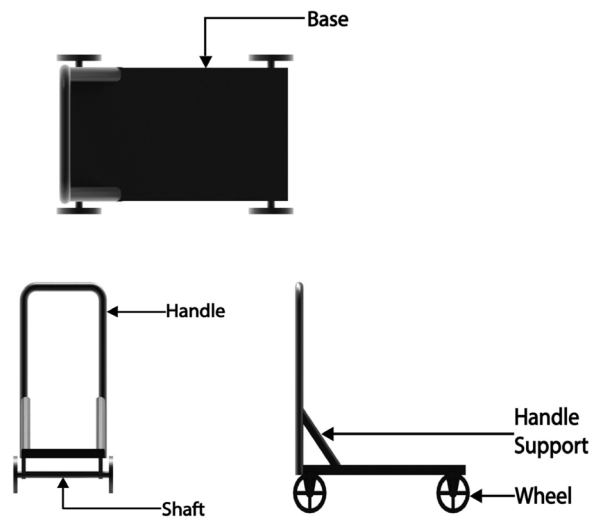Figure 4. Vertical load vs. wheel radius curve.

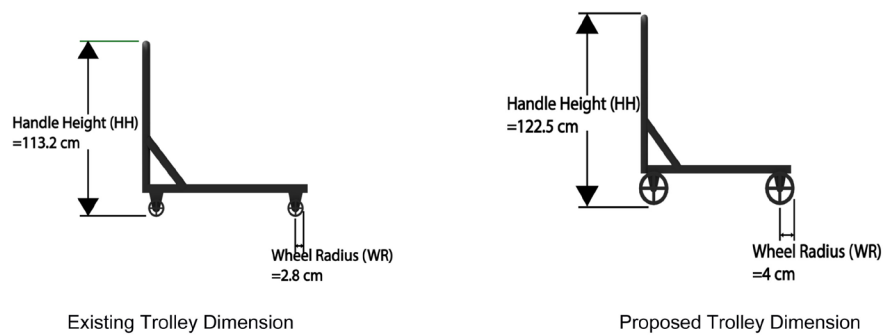Figure 5. 2D view of an industrial trolley.

Figure 6. Comparison of existing dimension and proposed dimension of an industrial trolley.

So in this research, a new trolley was introduced based on workers' anthropometric measurements to increase their efficiency in workplace. For handle height mismatch percentage was lower than before, wheel radius was found out from the graph. So it can be said that proposed trolley is more acceptable than the previous one.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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