ORIGINAL ARTICLE

An Integration of Statistical and Anthropometric Measurement Approach Towards Improving Ergonomic Design for Production Workbench

Mohd Norzaimi Che Ani[1], Ishak Abdul Azid[2]

[1] Manufacturing Section, Malaysian Spanish Institute, Universiti Kuala Lumpur, Kulim Hi-Tech Park, 09000 Kulim, Kedah, Malaysia.
[2] Engineering Section, Malaysian Spanish Institute, Universiti Kuala Lumpur, Kulim Hi-Tech Park, 09000 Kulim, Kedah, Malaysia.

ABSTRACT

Introduction: Ergonomics design has been demanded and considered the main factor in optimizing production efficiency and effectiveness for the last several decades. Nowadays, most workstations or production workbenches apply ergonomic aspects to their production floor to improve production performance. Production efficiency and effectiveness measurement can be achieved through achieving the effective interaction between the production workbench and the worker. **Methods:** This paper presents integration methods of statistical approach and anthropometric measurement to improve the ergonomic design of the production workbench in fulfilling ergonomic philosophy. **Results:** A model of the integration between statistical approach and anthropometric measurement has been developed based on selected quality tools and the application of the ergonomic approach. **Conclusion:** A sample workbench had been chosen and data were collected to verify the developed model and the obtained results show the developed model potentially improves the production performance because the obtained dimensions within the specification as guided by iHFG and ESA.
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Corresponding Author:
Mohd Norzaimi Che Ani, PhD
Email: mnorzaimi@unikl.edu.my
Tel: +604-4035199

INTRODUCTION

Ergonomics or also known as human factors is a discipline of analysing, understanding, designing, and improving workplace conditions specifically achieving an effective interaction between humans, workstations, and environments to achieve comfort, quality, and towards optimizing overall workplace system performance. Normally, ergonomics study focuses on short-term or long-term injury prevention through design and evaluation of product or workplaces design, including body postures, repetitive movements, or any situation related to the human body (1). Ergonomics study also focuses on changing the working condition, modifying a workstation by using ergonomically philosophy to improve efficiency and to reduce the risk hazard either discomfort or injury. Ergonomic hazards in the workplace can threaten employee safety and cause injury to employees. The ergonomic hazards can be divided into several factors such as awkward position whether working standing or sitting, direct pressure from the workspace, repetitive tasks throughout the work, constant vibration, work stress, constant noise, and extreme temperatures such as too cold or too hot (2).

The primary goal of ergonomics study is to reduce exposure to workplace hazards and minimizing the potential injuries towards safer working conditions (3). In addition, to ensure achieving the minimization or zero injuries, the study of ergonomics also focuses on minimizing the errors, increasing productivity, and reducing quality issues (4). Ergonomics looks at efficiently tailoring the personal work environment to achieve comfort and safety (5), and to achieve this objective anthropometrics measurement has been applied.

An ergonomics analysis consists of applying anthropometric data for designing a workplace or

making improvements in working conditions, while an anthropometric method is research that consists of measurements of the human body (6). Anthropometry requires measurement of the physical sizes of human body structures to ensure the ergonomic design of the products. In ergonomics studies, anthropometry has been used as the basis for designing the various situations such as product, workstations, or production workbenches (7). In the elements of anthropometric measurement, the dimensions of human body structures will be measured based on the size and strength of the human body (8). An anthropometric measurement is a method of using the measurement of the human body structures and percentiles category to be used for designers to design any product. Typically consists of 5th percentile represents the smallest size, 50th percentile for the average size, and 95th percentile represent the biggest size (9). It can help the designers collect useful data to suit the human body's size and shape. The physical size, the postures that can be adopted, and the tasks that can be performed are all will be considered by anthropometry to ensure achieving ergonomic design (10). However, some designs of workstations, or production workbenches are unable to meet the ergonomic philosophy due to lack of data collection. Furthermore, most of the production workbenches are designed based on the experience of designers, or benchmarking from similar workbenches, without considering the body sizes of the workers. This situation requires an effective method to improve the ergonomic workstation of production workbenches especially for manual process assembly.

Workers who are sitting or standing at a poorly designed workbench in performing a routine job may spend most of their time bent over while working and can cause negative safety and health implications to the human body, including spinal discomfort, back pain, and cognitive function (11). This situation will cause back pain, spine problems, and a decrease in physical health. It is requiring designers to design more comfortable and safe workstations to reduce the risk of ergonomic hazards. The design of the workbench should be set at a level at which a worker can remain comfortable. Storage containers on the bench should be at a reaching area that allows easy access. Workers should not have to bend the upper portion of the back to constantly retrieve items. This situation exposed the production workers to the risk of ergonomic hazards in terms of workloads and repetitive work throughout the working time (12).

According to the International Health Facility Guidelines (iHFG) in Australia, the recommended dimension height of the workbench for standing operation is between 660 mm to 1180 mm. In addition, Ergonomic System Associates (ESA) in Canada has provided a guideline for the design of standing workbench and recommended dimensions height of workbench as shown in Table I.

Table I Recommended dimension the height of workbench for standing operation

Type of works	Height (mm)
Heavy work	890 - 990
Light work	960 - 1070
Precision work	1160 - 1260

The accuracy and reliability are important during data collection process through surveys or sampling analysis. To ensure the accuracy of data collection and analysis the most suitable method to be adopted in the anthropometric analysis is applying statistical analysis. Statistical analysis is the collection and interpretation of data to evaluate the patterns and trends (13). It can be used in situations such as gathering data interpretations or designing surveys and studies (14). Most of the studies in anthropometric measurement do not consider the statistical approach in their study to design the production workbenches. Thus, in this paper, the statistical approach and anthropometric measurement will be integrated to ensure an effective model of designing workstation or production workbench to meet ergonomic philosophy. Since the data surveys of the human body sizes are required in anthropometric measurement, the sampling method as applied in statistical approach is employed in this study. In addition, the three classes of percentiles have been used and the most suitable statistical analysis to be applied is a histogram. Both mentioned statistical tools will be used in the development of the effective model of this ergonomic design.

Therefore, the focus of this study is to discuss the findings from various literature reviews, and the implementation of ergonomic design to the selected workbench in the selected production floor. The main objective is to identify the methodology used in designing the product using ergonomic measurement. The selection of suitable statistical tools in the integration process is the following goal from the main mentioned objective to ensure an effective model of the product design towards the ergonomic design of the production workbench. The final objective is to verify the developed model by the selection of the production workbench in the selected production floor of the case study industry. In this paper, the concept of the integration model to achieve ergonomic design improvement is discussed, collected data is analysed and the conclusion is given at the end of this paper.

MATERIALS AND METHODS

Building an effective integration model of statistical analysis and anthropometric measurement is not only applying the tools and methods that have been identified but depending on the data to be obtained and the availability of required data. In the determination of the sampling size, normally the surveys are based

on the target correspondences. Since the ergonomic measurements require the size of the human body structure, the sampling might be different based on ethnics, culture, and population. The size of the sampling from the selected population focusing on the production workers must be determined upfront prior to conducting the anthropometric measurement. As recommended by Noordzij et. al. (15), the calculation of the required sample size will be based on Equation (1).

$$\text{Required Sample Size, } N = \left[\frac{zs}{hx}\right]^2$$

Where:
z = standard deviation for the confident level 95% (Z value 1.96)
s = standard deviation for initial sample
x = mean for initial sample
h = desired accuracy level (100% - confidence level)

Then, anthropometric will be classified into the suitable group according to the defined anthropometric classes of percentile which are 5th percentile, 50th percentile, or 95th percentile. Since there are no people whose body dimensions are all at the same size, the classification based on percentile is required. Body dimensions classified in this stage must meet the purpose for the workbench design. Once the target group has been classified, then the data collection from the sampling size will be evaluated analysed. The number used for class interval in the histogram was 3 because the anthropometric measurement was segregated it into classes (5th, 50th, and 95th percentile). The class width of the data collection was then calculated by using equations (2). Once the class width had been identified, the data from the sampling study would be classified based on dedicated class interval to define the final design.

$$\text{Class Width} = \frac{(\text{Max. Value - Min. Value})}{\text{Class Interval}}$$

In overall, an effective integration model of statistical analysis and anthropometric measurement has been developed in this paper to improve the ergonomic of production workbench. This approach was developed based on the selection of the statistical tools integrated with anthropometric measurement and it was divided into four phases which are sampling size determination, anthropometric measurement, histogram analysis, and final product dimension as shown Figure 1.

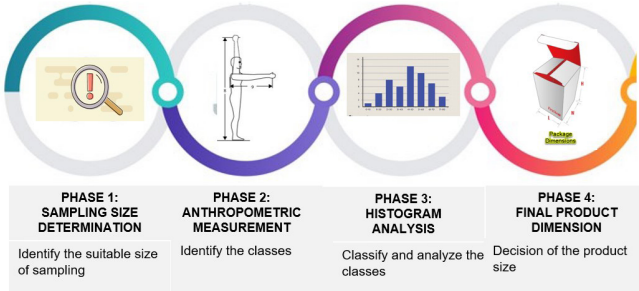

Figure 1: The model of integrated ergonomic design

Based on Figure 1, 4 phases of the study are required in this paper. Phase 1 consists of the determination of the sampling size will be applied to the equation (1). This is important to ensure the accuracy of the data collection. Once completion of the sampling size analysis, the anthropometric measurement will be applied in phase 2. The purpose of this phase is to ensure suitable determination size of the production workbenches. Percentile analysis will be used in this phase consists of the 5th percentile (smallest size), 50th percentile (average size), and 95th percentile (biggest size) to represents the population size. Then, in phase 3, the histogram analysis will be applied as equation (2) and this identified histogram will be linked with the anthropometric analysis in phase 2. Completion of the analysis in the 3 phases, the final product dimensions will be measured to suit the purpose of production workbenches and ensure the effective interaction between workbench and worker.

RESULTS

As guided by iHFG and ESA, the implementation of the developed model in the previous discussion was then carried out. The workbench for the manual assembly process had been selected on the production floor of the selected case study industry. The selected production floor produces an automotive component and requires manual standing operation in the final assembly process. The selected production layout in the production floor is equipped with five manual workbenches of a continuous process of the product-based system and this layout is designed according to the 'U' shape. Since every production layout requires manual assembly, every workbench requires a dedicated worker for the repetitive tasks. One of the workbenches has been selected in the implementation of the developed model consists of standing operation with light weight tasks.

The selected workbench and worker were assigned to perform screwing and manual soldering process and it could be classified as 'light work', with the recommended height of between 960 mm to 1070 mm as mentioned in Table II. The purpose of this implementation study is to recommend the suitable height of the workbench towards eliminating the ergonomic hazard and indirectly improving production performance. The results analysis and evaluation of the developed model will be discussed in the next discussion.

Phase 1: Sampling Size Determination

This phase consists of two stages which are data collection for the initial sample to determine the sample size and data collection for the defined sample size to decide the actual design. As selected classes from the previous section, which is 'light work' for standing operation, five workers had been measured in which the dimension between the floor to worker's elbow was taken as initial sample. The result of the data collection from the initial sample is 900 mm, 1100 mm, 1150 mm, 950 mm, and 900 mm. From this result, the calculated mean and standard deviation are 1000 mm and 117.26 mm.

From the data collection of the initial sample, the confidence level was set up at 95%. Referring to discussion from the previous section, the Z value is 1.96, and desired accuracy level is 5% or 0.05. By using equation (1), the required sample size is 21 samples, and these samples were collected as shown in Table II.

Table II The data of actual sample size

Sample number	Height (mm)	Sample number	Height (mm)
1	980	12	950
2	1110	13	1150
3	950	14	1110
4	1000	15	900
5	1000	16	900
6	980	17	1000
7	1150	18	1170
8	990	19	980
9	1000	20	850
10	980	21	1000
11	900		

Phase 2: Anthropometric Measurement

As mentioned in the previous discussion, the anthropometric measurement consists of three classes (5th, 50th, and 95th percentile). The purpose of the anthropometric is to ensure the design is suited for all users and avoiding the ergonomic hazard. Based on this situation, the justification of the selection percentile class is shown in Table III. Based on this analysis, the class of 50th percentile has been recommended because it potentially fits the purpose of the workbench design.

Table III Evaluation anthropometric classes

Classes	Explanation	Justification
5th percentile	Shortest height	Suitable for shortest group but for tallest group need to lay down their arm causing stress of hand.
50th percentile	Average height	Both tallest and shortest groups, need to move their hand with minimum motion.
95th percentile	Tallest height	Suitable for tallest group but shortest group need to lift their arm causing awkward posture.

Phase 3: Histogram Analysis

As collected data in Phase 1 consists of 21 actual samples and the class of 50th percentile has been recommended in Phase 2, the histogram analysis in this phase will be used to verify the recommended classes and selection of the actual dimension height of the workbench in the next phase. Since the anthropometric classes consist of 3 classes, the interval classes of the histogram should be the same which is 3. From the data tabulated in Table 3, the maximum value is 1170 mm, and the minimum value is 850 mm. Then, the class width was calculated using Equation (2) The class width was then calculated by using Equation (2), and the calculated result was 107 mm. Based on this result, the data collection from Table III has been re-grouped into dedicated classes as shown in Table IV.

Table IV The re-grouped data collection

5th percentile	50th percentile	95th percentile
850 - 957	**958 - 1065**	**1066 - 1073**
850	980	1170
900	980	
900	980	
900	980	
950	990	
950	1000	
	1000	
	1000	
	1000	
	1000	
	1110	
	1110	
	1150	
	1150	

The result shows, of most of the sizes of the actual sample or 67% data classified was in the class of 50th percentile. This result explained the recommended anthropometric measurement in Phase 2 is significant as illustrated in Figure 2.

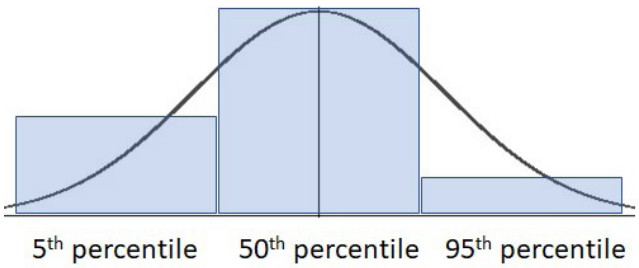

Figure 2: The histogram from obtained results

Phase 4: Final Product Dimension

Finally, the suitable dimension height of the workbench was calculated from the average of data from the class of 50th percentile as recommended from Phase 3 and 4. The calculated dimension was 1031 mm. This is considered suitable for the selected workbench on the production floor because within the range as guided by iHFG and ESA. This recommended dimension will optimize the interaction between workbench and worker and indirectly will improve the production performance. The final product dimension is based on the analysis from previous phases as illustrated in Figure 3.

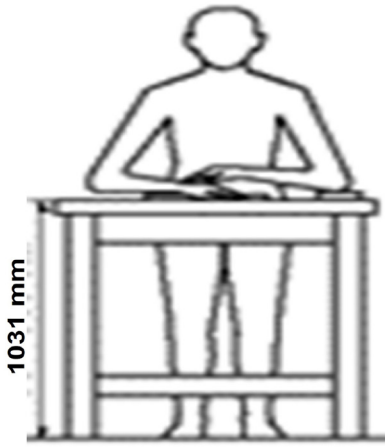

Figure 3: The illustration recommended dimesion of workbench of standing operation

DISCUSSION

The production workbench is the main element on the production floor. Poor design of production workbench will cause low efficiency and productivity due to fatigue element of workers, especially for the manual assembly process (16). To solve this issue, the effective approach of designing a production workbench consisting of a combination between statistical analysis and anthropometric measurement is needed. Conventionally, designing the workbench is normally based on the experience of designers, historical data, or benchmarking process from a similar workbench and it is not enough to improve the efficient and effective interaction between workbench and worker. This situation creates hidden issues which are normally overlooked or unseen during designing the production workbench. Thus, a systematic approach of the interaction between statistical analysis and anthropometric measurement in designing a production workbench was developed, where the hidden or overlooked wastes were eliminated or minimized to maximize the effectiveness of the man-workplace interaction to in the production floor.

This study explains the detailed steps of improving the design of the production workbench using an integrated approach of statistical analysis and anthropometric measurement and its implementation in the production floor for minimizing ergonomic hazard and improving production effectiveness. By implementation of the statistical and anthropometric analysis of designing the production workbench, the effectiveness of the designed workbench was verified by comparing it with a guideline from iHFG and ESA, and the results had shown a significant improvement in the design. The approach presented had systematically synthesized the overall issue to ensure the root cause was defined either directly or indirectly. The approach is expected to solve the hidden root cause which is poor interaction between workbench and worker.

Successful implementation of the developed integration model in the selected production floor of real industry practices shown significant impacts on the approach. The main impacts of implementing the proposed approach are minimizing the ergonomic approach and maximizing the efficiency of production flow. The interaction between workbench and worker will be drastically improved through minimizing human body fatigue (17). In contrast, poor interaction between workbench and worker will give a bottleneck process and indirectly unable to maximize the production efficiency and effectiveness. For the long-term impacts, the poor design will potentially increase the risk of Musculoskeletal Disorder (MSD). Any manufacturing industry actively implemented continuous improvement programs to ensure maximizing the effectiveness of the production system and at the same time ensure their employees in a safe condition during performing assigned tasks. The developed approach of this study will help manufacturing organization improve their production performance and eliminating the risks of ergonomic hazards. Through the result of the implementation, the desired free wastes ergonomic hazard can be achieved.

CONCLUSION

In this paper, the integration of the statistical analysis and anthropometric measurement for ergonomic design production workbench has been successfully discussed, developed, and implemented in the selected production floor of the real industrial practices. This integration model was developed to eliminate the ergonomic hazards and indirectly improved the production system to ensure the production processes achieving maximum efficiency and effectiveness. Even though an

ergonomic hazard has been widely applied using an anthropometric measurement, normal practice focuses more on the individual measurement of ergonomic tools and less consideration of integration with other available approaches such as quality tools. The implementation of this interaction model in designing the production workbench will eliminate the ergonomic hazard and indirectly maximizing the production performance. The results of this research show that the recommended height of the selected workbench is within the specification as guided by iHFG and ESA. The future expectation of developed approach in this study will drastically performance the performance of the production process.

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