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Analysis for Response Factors of a Work Station Considering Issues Ergonomically.

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Abstract: *Ergonomics is concerned with making the workplace as efficient, safe and comfortable as possible. Effective application of Ergonomics in work system design can achieve a balance between worker characteristics and task demands. This can enhance operator productivity, provide worker safety and physical and mental well being and job satisfaction. This thesis describes the results of an experiment study and analysis conducted to investigate the effects of assembly and disassembly of a product on operator performance.*

Although, many thesis exist conducting the experiment for ideal conditions assuming a smart workstation and power screw drivers etc…the result and conclusions also remain ideal. In the real life situations, considering an industry or an office or a college class room, people need to deal with all elements which are not ergonomically designed. The effects of such non ergonomic components on the production rate of a simple component by two equally knowledgeable students with same training and theoretical knowledge are analyzed using Minitab 17 Statistical

Software in this particular case. Students most often work with chairs and tables of different heights in labs, classrooms, drawing hall etc… the main objective of this thesis is to analyze the performance of students working on different chairs and tables. The non-ergonomic components are considered as a combination of five tables and five chairs of different heights with successive and cumulative variation in a range of 7cm to 2cm periodically. Two college students each with a different height (S1: 172 cm and S2: 180 cm) are assigned to conduct the experiment on five different tables with a rotation of five chairs on each table. The task is given to assemble and dis-assemble a small car (toy) unit containing 6 parts and time taken for the operation to complete is observed. The observed values which are in sec/unit are converted to units/hour (production rate). In this way the rate of production is analyzed graphically and compared. A conclusion is drawn estimating the comfort, efficiency, and consistence of the students with different heights for this particular combination of tables. The results show that a student with greater height is more comfortable and efficient for this particular combination of tables and chairs.

I. Introduction To Ergonomics

1.1 Introduction

The word ergonomics has its origin in two Greek words **ERGON** meaning **work** and **NOMOS** meaning **laws**. So it is the study of the man in relation to his work. The word ergonomics is used commonly in Europe. In USA and other countries it is called by the name "human engineering or it is also called human factors engineering". ILO defines human engineering as- "The application of human biological sciences among with engineering sciences to achieve optimum mutual adjustment of men and his work the benefits being measured in terms of human efficiency and well being." The human factors or human engineering are concerned with man machine system. Thus another definition which highlights the man- machine system is: " The design of human tasks, man machine system, and effective accomplishment of the job, including displays for presenting information to human sensors, controls for human operations and complex man –machine systems."

1.1.1 Objectives of Human Engineering

Human engineering (ergonomics) has two broader objectives:

- To enhance the efficiency and effectiveness with which the activities (work) is carried out so as to increase the convenience of use, reduced errors and increase in productivity.
- To enhance certain desirable human values including safety, reduced stress and fatigue and improved quality life.

Thus in general the scope and objective of ergonomics is "designing for human use and optimising working and living conditions".Thus human factors discovers and applies information about human behaviour, abilities and limitations and other characteristic to design of tools ,machines , systems, tasks, jobs and environment for productive, safe, comfortable and effective human use.

1.1.2 Ergonomics In Multidisciplinary

The various disciplines that are going to have influence on human factors are:

- Engineering: Design of work system suitable to worker.
- Physiology: Study of man and his working environment.
- Anatomy: Study of body dimensions and relations for work design.
- Psychology: Study of adaptive behaviour and skills of people
- Industrial hygiene: Occupational hazards and workers health.

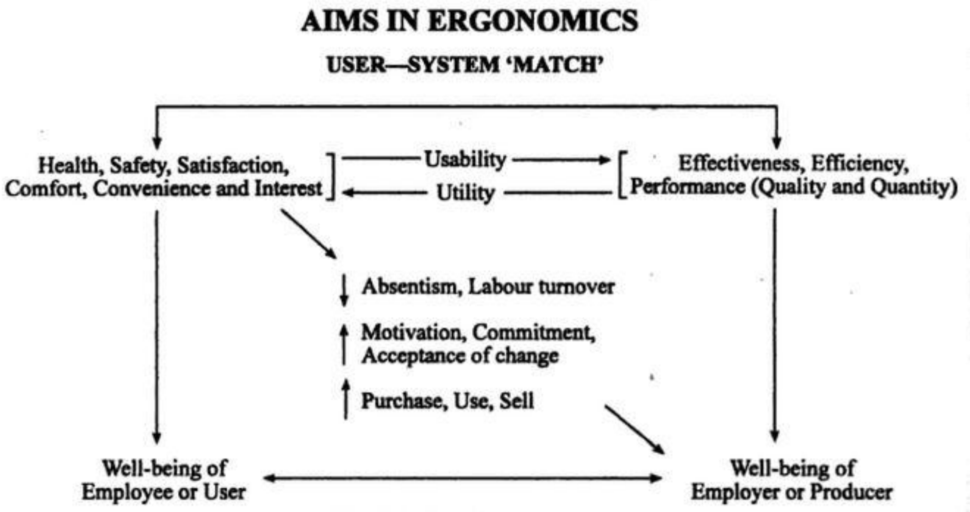

Figure 1.1: Aims in ergonomics

1.1.3 Study of Human Engineering Areas

- Anthropometry and bio mechanics
- Control of physical work environment
- Design of man machine system
- Design of controls and display
- Accidents fatigue and safety
- Work place design

1.1.4the Functions Performed By Man and Machines

It is very essential to know as o which functions are performed by man and which functions does a machine better perform.

Man is unique or better.

- At discriminating relevant from irrelevant signals.
- At innovation and creative in problem solving.
- In reasoning.
- Ability to select his own outputs
- In improving, adopting flexible procedures, exercising judgement based on minimal information.
- Sensitive to wide variety of stimuli.
- In selective recall of old information

Machines are unique and better.

- Routine processing and storage of large amounts of facts and details.
- For repetitive and monotonous operation.
- For monitoring men and machines.
- In operating under conditions that are stressful.
- Rapid response to signals.
- For rapid and complex situations.
- For concurrent operations.
- In sensing stimuli beyond the range of human sensitivity.

Ergonomics is concerned with making the workplace as efficient, safe and comfortable as possible. Effective application of ergonomics in work system design can achieve a balance between worker characteristics and task demands. This can enhance operator productivity, provide worker safety and physical and mental well-being and job satisfaction. ***Many research studies have shown positive effects of applying ergonomic principles in workplace design, machine and tool design, environment and facilities design***.Research studies in ergonomics have also producedData and guidelines for industrial applications. The features of ergonomic design of machines, workstations, and facilities are well known. However, there is still a low level of acceptance and limited application in industries, especially in developing countries. The main concern of work system design is usually the improvement of machines and tools. Inadequate or no consideration is given to the work system design as a whole. Therefore, poorly designed work systems are a common place in industry .Neglect of ergonomic principles brings inefficiency and pain to the workforce. An ergonomically deficient workplace can cause physical and emotional stress, low productivity and poor quality of work. Workstation should be laid out such that it minimizes the working area so that while carrying out the operations the worker could use shorter motions and expend less energy and thus reduce fatigue. Das and Grady reviewed the concept of workspace design and the application of anthropometric data. Itindicated that an adjustable chair and a workbench of standard size were highly desirable at the workplace. However, the standard height of the workbench could not be defined without the anthropometric data of the user population. Many of the user population do not have anthropometric data. It is therefore, desirable also to have the worktable adjustable. A study by Yeow concentrated on improving productivity as well as health and safety of workers ina printed circuit assembly (PCA) factory. The improvement involved the use of an ergonomicallydesignedworkstation with other ergonomic intervention such as clear segregation of tested and untested boards to prevent mix-up and retraining of operators by more qualified trainers. This had resulted in an improvement in quality and productivity of the workers, reduction in
Rejectionrate as well as an increase in the revenue. The use of an ergonomically designed workstation and better structured processes along with other features, such as improved lighting, shelves and containers for parts and display boards, had helped and solved the problems of assembly processes at a German company. The objective of this research was to study the productivity of operator by assembly a product on the smart workstation for a repetitive industrial assembly task taken into consideration table, chair adjustable and type of gender.**Ergonomics** is a science focused on the study of human fit, and decreased fatigue and discomfort through product design. Ergonomics applied to office furniture design requires that we take into consideration how the products we design fit the people that are using them. At work, at school, or at home, when products fit the user, the result can be more comfort, higher productivity, and less stress.

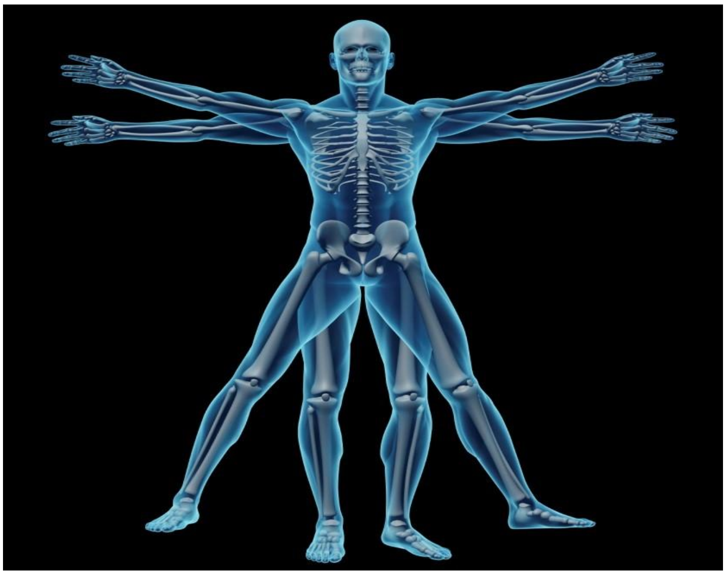

Figure 1.2: Introduction to ergonomics

Ergonomics can be an integral part of design, manufacturing, and use. Knowing how the study of anthropometry, posture, repetitive motion, and workspace design affects the user is critical to a better understanding of ergonomics as they relate to end-user needs. This reference will explain some of the human factors that can be observed and should be applied to ergonomic product design.

"Ergonomics is a way of designing work stations, work practices, and work flow to accommodate the capabilities of workers. Ergonomic design reduces risk factors known to contribute to occupational ergonomic injuries, such as sprains and strains and cumulative trauma disorders (CTDS)."

1.2Risk Factor

1.2.1 Ergonomic Studies the Interaction among Three Risk Factor Areas

Ergonomics studies the various risk factors brought to a job. Listed below are the three areas within which Ergonomic Risk Factors exist.

- Risk Factors inherent in the worker.
- Risk factors inherent in task.
- Risk factors inherent in the environment.

Workers come in all shapes and sizes, each with unique attributes that present certain Ergonomic risk factors to a job. The task of the job itself can present risk factors that increase the likelihood of an injury. Finally, the work place environment, within which the worker and the job exist, may also contain exposures to risk factors.

Figure 1.3: Disorders due to non-ergonomic workstation

1.2.2 Who Is At Risk?

Risk for developing MUSCULOSKELETAL DISORDERS (MSDs) increases for the workers who must:

- Repeat the same motion throughout their work day
- Do their work in an awkward position
- Use a great of force to perform their jobs
- Repeatedly lift heavy objects
- Face a combination of these risk factors

The level of risk depends on how long a worker is exposed to these conditions, how often they are exposed, and the level of exposure.

1.3 Musculoskeletal Disorders (Msd's)

MSD's include a group of conditions that involve the nerves, tendons, muscles and supporting structures such as inter vertebral disks. They represent a wide range of disorders, which can differ in severity from mild periodic symptoms to severe chronic and debilitating conditions. Below is a list of examples.

- Carpal tunnel syndrome
- Tenosynovitis
- Tension neck syndrome
- Low back pain

MSDs are often confused with Ergonomics. Ergonomics is the science of fitting workplace conditions and job demands to capabilities of works. In other words, MSDs are the problem and Ergonomics is the solution.

Contributing factors are aspects of work tasks that can lead to fatigue, MSD symptoms and injuries, or other types of problems. These factors may be present in one or more of the tasks employees must perform to accomplish their jobs. The contributing factors the employees should be aware of include:

- Awkward postures
- Repetitive motions
- Forceful exertions
- Pressure points
- Vibrations

There are also environmental factors associated with the work space that can cause problems
Extreme high temperatures can increase the rate at which the body will fatigue. Exposure of the hands and feet to the cold temperatures can decrease the blood flow, muscle strength, and the manual dexterity. These conditions can also cause excessive grip force to be applied to tool handles or objects. Another problem may be caused by tools or equipment that exhausts cold or hot air directly onto the operator.

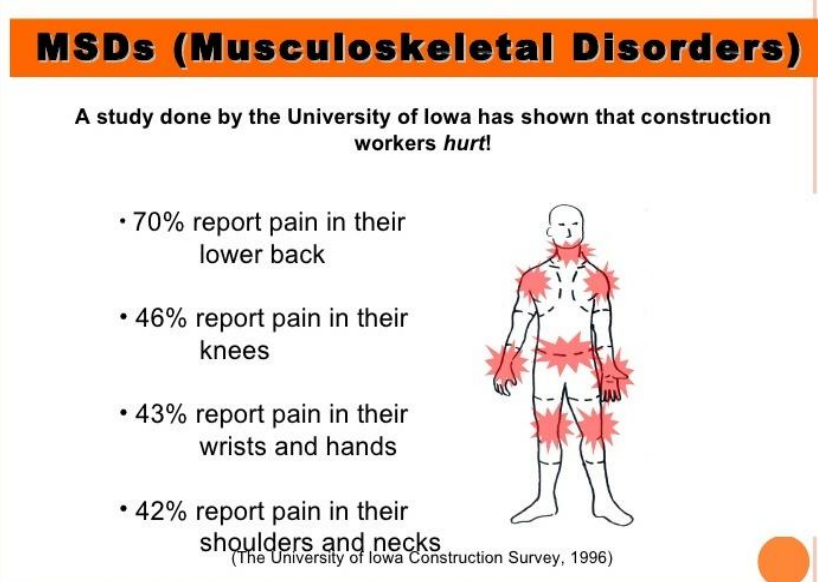

Figure 1.3: MSD's analysis

1.3.1 Proactive Approach
A proactive approach to Ergonomics will ensure that:
• Designers will receive training in ergonomics and have appropriate information and guidelines regarding risk reduction
• Decision-makers planning new work processes should have knowledge of Ergonomics principles that contribute to the reduction or elimination of risk.
• Design strategies emphasise fitting job demands to the capabilities and limitations of workers. For example, for tasks requiring heavy materials handling, use of mechanical assist devices to reduce the need for manual handling would be designed into the process
• Other aspects of design should be considered including load design, layout of the workplace to allow for ease of access when using mechanical aids and eliminating unnecessary lifting activities

1.3.2 Ergonomic Principles That Contribute To Good Work Place Design
The goal for the design of workplaces is to design for as many people as possible and to have an understanding of the Ergonomic principles of posture and movement which play a central role in the provision of a safe, healthy and comfortable work environment. Posture and movement at work will be dictated by the task and the workplace, the body's muscles, ligaments and joints are involved in adopting posture, carrying out a movement and applying a force. The muscles provide the force necessary to adopt a posture or make a movement. Poor posture and movement can contribute to local mechanical stress on the muscles, ligaments and joints, resulting in complaints of the neck, back, shoulder, wrist and other parts of the musculoskeletal system.

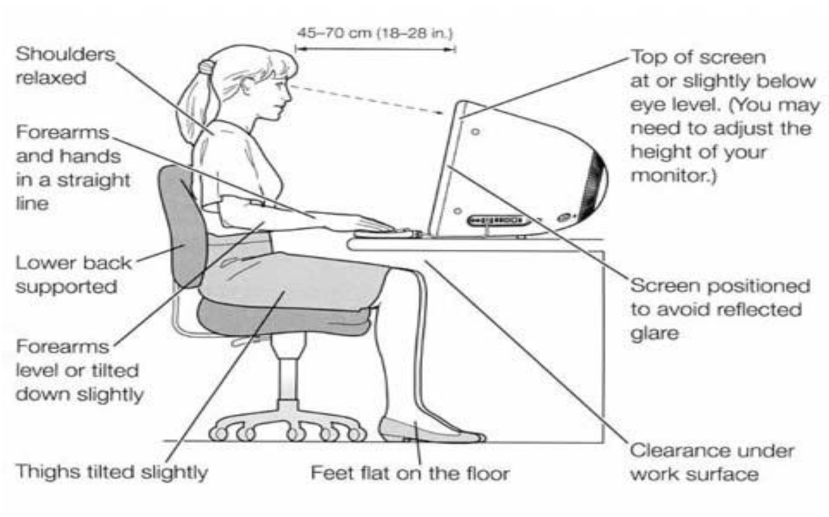

Figure 1.4: Ergonomic Work Station

1.3.3 Risk Factors Inherent Inthe Worker

The worker brings certain ergonomic risk factors to the job.
It’s important to understand that each workers ability to respond to external factors, such as high force demands, is different and unique. The level, duration, andfrequency of the loadsimposed on tissues, as well as adequacy of recovery time, are critical components in whether increased tolerance or reduced physical capacity occurs. Reduced physical capacity can lead to cumulative trauma disorders (CTDs) as well as other musculoskeletal disorders (MSDs).

1.4 Musculoskeletal System

The musculoskeletal system is made up of the soft tissues and bones in the body. Below are the basic parts of the musculoskeletal system.

- Bones:the load bearing structure of the body.
- Muscles:tissues that contract to create movement.
- Tendons:tissues that connects muscles to bones.
- Ligaments:tissues that connect bones to bones.
- Cartilage:tissues that provide cushioning and reduce friction between bones.
- Nerves:the communication system that links tendons, and other tissue with the brain.
- Blood vessels:tubes that circulate nutrients throughout the body.

The following personal risk factors may be generalized across populations. Its important to understand that when designing a workstation or procedure it should be designed for the specific individual working at the workstation. Below are the criteria that should be considered.

1.4.1AGE

The prevalence of CTDs increase as people enter their working years (ages 25 to 65). By the age the 35, most people have had their first episode of back pain. Once in their working years, the prevalence is relatively consistent. Musculoskeletal impairments are among the most prevalent and symptomatic health problems of middle and oldage.

Nonetheless, age groups with the highest rates of compensable back pain and strains are the 20-24 age group for men and 30-34 age group for women. In addition to decrease in musculoskeletal function due to the development of age related degenerative disorders, loss of tissue strength with age may increase the probability or severity of soft tissue damage from the given injury.

Another problem is that advancing age and increased number of years on the job are usually high correlated. Older workers have been found to have less strength than younger workers, although hand strength does not appear to decline with aging. In one study, average hand pinch and grip scores remained relatively stable in their population with a range of 29 to 59 years. Other studies have reported a lack of increase risk associated with aging.

1.4.2GENDER

Whether the gender differences seen with some MSDs in some studies are due to physiological differences or differences in exposure is unclear. One 1991 study found no gender difference in workers compensation claims for CTS. Another study found no gender difference in reporting of neck or upper extremity MSD symptoms among newspaper employees using video display terminals.

In contrast, other studies have reported that neck and shoulder muscular pain is more common among females than males, both in the general population and among industrial workers.

Any important study noted that significant gender differences I work poster are related stature and concluded that the lack workplace accommodation to the range worker's. Height and reach may, in part, account for the apparent gender differences. Also, the fact that more women are in hand intensive jobs and industries may account for the greater number of imported work related MSDs among women. Another study reported that men were more likely to develop deep dequervain's disease.

1.5 Anthropometry

1.5.1 Introduction

Anthropometry is the science that measures the range of body sizes in a population. When designing products it is important to remember that people come in many sizes and shapes. Anthropometric data varies considerably between regional populations. For example, Scandinavian populations tend to be taller, while Asian and Italian populations tend to be shorter.

Anthropometry is the study of the measurement of the human body in terms of the dimensions of bone, muscle, and adipose (fat) tissue. Measures of subcutaneous adipose tissue are important because individuals with large values are reported to be at increased risks for hypertension, adult-onset diabetes mellitus, cardiovascular disease, gallstones, arthritis, and other disease, and forms of cancer. Combined with the dietary and related questionnaire data, and the biochemical determinations, anthropometry is essential and critical information needed to assist in describing the data collected from persons in the NHANES III sample.

Some studies have reported that people back pain are usually taller than those without it. A Finnish population study found that height was a significant predictor of herniated lumbar disc in both sexes, but moderately increased BMI was predictive only in men.

1.5.2 Purpose of Anthropometry

Actual stature, weight, and body measurements including skinfolds, girths, and breadths will be collected in the MEC for purposes of assessing growth, body fat distribution, and for provision of reference data. Measurements of stature and weight will allow for a revision of the child growth charts which are based in part on data collected in NHES cycles II and III and data from the Fels Longitudinal Study. Anthropometric measurements such as skinfolds and circumferences and bioelectrical impedance (a method used to estimate the amount of lean tissue) will allow cross-sectional analysis of the relationship between obesity and risk of disease. Therefore, many of the measurements included in NHANES III will repeat ones made in previous NHANES and HHANES so that trend analyses can be conducted. Some measures have been added to provide further information on body frame size and fat distribution, while others have been dropped because new data have determined that other measures are more informative.

1.5.3 Principles in Application of Anthropometric Data

- Design for extreme individuals: designing for maximum population value is the recommended strategy if a given maximum value of some design feature should accommodate of doors.
- Designing for adjustable range: in the design features for equipment or facilities the provision for adjustment should be there for the individual who use them.
- Designing for average: there is average individual and a person may be average on one or two dimensions. Designers often design for average as a compromise as they do not have to deal with anthropometric data.

1.5.4 Anthropometric Database

Anthropometric datasets compare people of different ages and occupations. Data in anthropometric databases may represent static dimensions, such as "lower leg length" or functional dimensions such as "reach.".

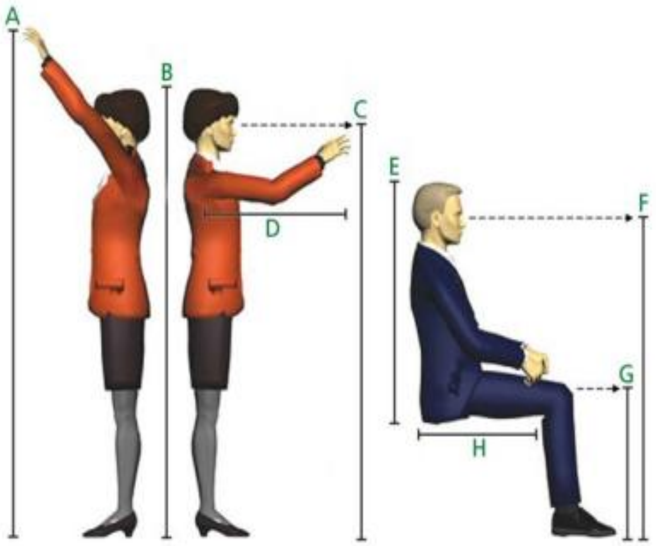

Figure1.5: Anthropometric measurement

Table 1.2 Anthropometric Database

Measurement	Letter	Female	Male
Standing Overhead Reach	A	74.9" – 86.8"	81.2" – 93.7"
Standing Height	B	60.2" – 68.4"	64.8" – 73.5"
Standing Eye Height	C	56.9" – 65.0"	61.4" – 69.8"
Standing Forward Reach	D	30.8" – 36.1"	33.8" – 39.5"
Sitting Height	E	31.3" – 35.8"	33.6" – 38.3"
Sitting Eye Height	F	42.6" – 48.8"	46.3" – 52.6"
Sitting Knee Height	G	19.8" – 23.2"	21.4" – 25.0"
Seat Depth	H	16.9" – 20.4"	17.7" – 21.1"

1.5.5 Posture

Correct seated posture is a continual debate with ergonomic professionals. Some say that users need to have a 90-90-90 degree placement for the elbow, hip, and knee joints, respectively. Others feel that a variation in this placement is better, as long as it does not lead to slouching or hunching over. A good seated posture is one that is comfortable and does not put a lot of stress or strain on the user's buttocks, back, or arm muscles, and allows the user's feet to be on the floor.

Table 1.2 Anthropometric Database

Measurement	Letter	Female 5th – 95th%	Male 5th – 95th%	Overall Range 5th – 95th%
Sitting Height	A	31.3" – 35.8"	33.6" – 38.3"	31.3" – 38.3"
Sitting Eye Height	B	42.6" – 48.8"	46.3" – 52.6"	42.6" – 52.6"
Waist Depth	C	7.3" – 10.7"	7.8" – 11.4"	7.3" – 11.4"
Thigh Clearance	D	21.0" – 24.5"	23.0" – 26.8"	21.0" – 26.8"
Buttock-to-Knee	E	21.3" – 25.2"	22.4" – 26.3"	21.3 – 26.3"
Knee Height	F	19.8" – 23.2"	21.4" – 25.0"	19.8" – 28.0"
Seat Length/Depth	G	16.9" – 20.4"	17.7" – 21.1"	16.9" – 21.1"
Popliteal Height	H	15.0" – 18.1"	16.7" – 19.9"	15.0" – 19.9"
Seat Width	Not Shown	14.5" – 18.0"	13.9" – 17.2"	13.9" – 18.0"

1.5.6 Moving

Users will move around in their environment to file papers, answer a phone, or stretch. An occasional break from sitting is encouraged because it helps to stimulate muscles, and increases blood flow, which decreases fatigue. The space in a cubicle or desk area should allow the chair to move around easily. Also, a wheelchair may need to turn around or move in the office space, requiring a 60" diameter turning radius and at least 36" of passage width (refer to Figure 6). Please see Design for Universal Consideration section for more specific information on wheelchairs and other Universal Design topics. Chairs and other devices in the workspace can allow the user to easily get up and move around without having to move armrests, adjust other chair settings, or put undue stress on the body.

1.6 Common Workplace Motions

Ultimately, the workplace should be comfortable for users and adapt to their needs as much as possible. Workplace products designed with this in mind can lead to higher worker productivity and lower risk of injury and illnesses. The human body has a natural range of motion (ROM). Movement within the proper ROM promotes blood circulation and flexibility which could lead to more comfort and higher productivity. Despite the need to promote motion, users should try to avoid repetitive movements and certain extremes in their ROM over long periods of time. By considering both ROM and repetitive motion, products can be designed to operate within the optimal ranges to help reduce the occurrence of fatigue and muscle disorders.

1.6.1 Good and Bad Zones

There are 4 different zones that a user might encounter while sitting or standing: • Zone 0 (Green Zone) Preferred zone for most movements. Puts minimal stress on muscles and joints. • Zone 1 (Yellow Zone) Preferred zone for most movements. Puts minimal stress on muscles and joints. • Zone 2 (Red Zone) More extreme position for limbs, puts greater strain on muscles and joints. • Zone 3 (Beyond Red Zone) Most extreme positions for limbs, should be avoided if possible, especially with heavy lifting or repetitive tasks. These zones are ranges where body limbs can move freely. Zones 0 and 1 include smaller joint movements, while Zones 2 and 3 represent more extreme positions.

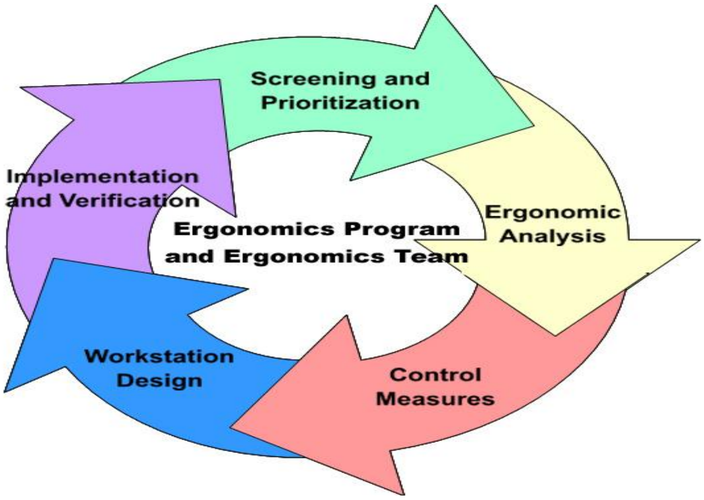

Figure 1.7 :Ergonomic cycle

Zone 0 and Zone 1 are preferred for most movements to occur. Zones 2 and 3 should be avoided when possible, especially for repetitive and heavy tasks. Motion in these ranges puts more strain on muscles and tendons and could lead to the development of musculoskeletal disorders.

1.7 Organisationofthesis

- Discussion about Ergonomics, its Definition, Importance and Application. Explanation of the types of Risk Factors involved leading to Musculoskeletal Disorders (MSDs), Principles of good Work Place Design and Introduction to the Anthropometric data and its application.
- The Literature Review of the topic Ergonomics and previous research work regarding the study of Ergonomics and analysis of any work place using graphical analysis software such as Minitab17 Statistical software.
- The history, general procedure and applications of Minitab17 Statistical software is discussed in the 3rd chapter. It also gives a brief idea about the software working procedure and generation of graphical analysis of any Ergonomic work place.
- In the 4th chapter, the problem description and the method of solving the problem related to Ergonomic work place or the way of approachto analyse the problem using Minitab Statistical software is explained. The various plots like the mean and interaction plots are also obtained using the software.
- The results and conclusions of the experimental study on assembly and dis-assembly work station considering the ergonomically issues are produced.

II. Minitab Statistical Software

2.1 Overview

Most statistical analyses require a series of steps, often directed by background knowledge or by the Subject area that weinvestigate. So the basic need for Minitab software is as follows:-

• Explore data with graphs.
• Conduct statistical analyses.
• Assess quality.
• Design an experiment.
• Generate a report.

Minitab software provides a comprehensive collection of statistics andgraphs andincludes a user-friendly designthat allows to master quickly statistical concepts.Before the widespread availability of powerful computers and pre-packaged statistical software,tedious manual computations were routine in statistics courses. Today, computers have revolutionized data analysis, which is a fundamental task of statistics. Packages such as Minitab allow the computer to automate calculations and graphs. Minitab can perform a wide variety of tasks, from the construction of graphical and numerical summaries for a set of data to the more complicated statistical procedures.

2.2 The Minitab User Interface
From the Windows taskbar, choose
Start >**All Programs** >**Minitab** >**Minitab Statistical Software**.

By default, Minitab opens with two windows visible and one window minimized.The Session window displays the results of your analyses in text format. Also, in this window, you can enter sessioncommands instead of using Minitab's menus.

2.2.1worksheet

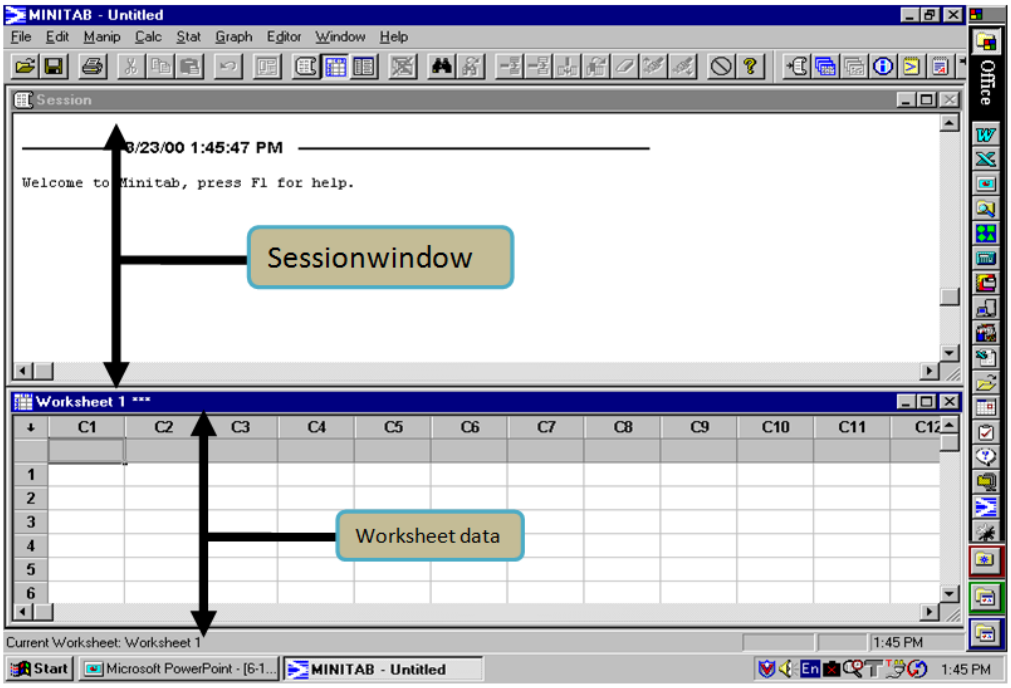

Figure 3.1:Worksheet in Minitab

The Minitab worksheet is arranged by rows and columns. The columns, C1, C2, C3, and so on, correspond to the variables in your data, the rows to observations. The columns can be viewed in the Data window. In addition, the worksheet may also include stored constants, K1, K2, K3, and so on. Most of the Minitab commands address the columns. In general, a column contains data for one variable, and each row contains all the data for a subject or observation. Columns can be referred to by number (C1, C2, C3, and so on.) or by name such as "height" or "weight."

In the Minitab worksheet, constants are referenced by the letter K and a number (K1, K2,K3, and so on). Unlike columns, constants are single values and do not show up in the datawindow. Storing a constant tells Minitab to remember this value; it will be needed later. Constantsare analogous to the memory functions on most calculators. For instance, Minitab allowsyou to quickly find the average of a column of numbe

III. Ergonomic Analysis Using Minitab

3.1 Methodology

The experimental study was conducted in the Ergonomics Lab of the Department following a soundmethodology. Details of the study elements are described in the following sections.

3.1.1 The Task

The selected task was an assembly task of a toy car which consists of 6 parts. Usually, simulated tasks are chosen for research purposes that do not represent real life industrial tasks.The selected task was a highly repetitive task and it was performed on workstations that were not designed ergonomically.Also, the task method was not designed following ergonomic principles. The assembly task involves in picking up different parts of car such as wheels, chassisscrews and tightening with a screw driver. The steps of the assembly task were modified in the new design considering motion study and ergonomic principles.

3.1.2 Participants

Two college students were participated in the experimental study on a voluntary basis. The average age of the participants was 21.5 yrs with a standard deviation of 1.11 yrs. Mean stature was 1850 mm with a standard deviation of 101 mm. This indicated a significant size difference among the participants. The participants had no prior experience on the assembly task. They were given instructions on the assembly workstations and task and trained for 15 minutes on the task, as required based on their experimental conditions. Fifteen minutes training was considered adequate as the assembly task was not a complex task according to the learning rate. Environmental condition (light, temperature, humidity and noise) was comfortable and kept constant. The participants wore light and comfortable clothes.

3.1.3 An Ideal Experimental Study

Experiments were conducted using an ergonomically designed smart assembly workstation. Details of the ergonomically designed smart assembly workstation were reported.

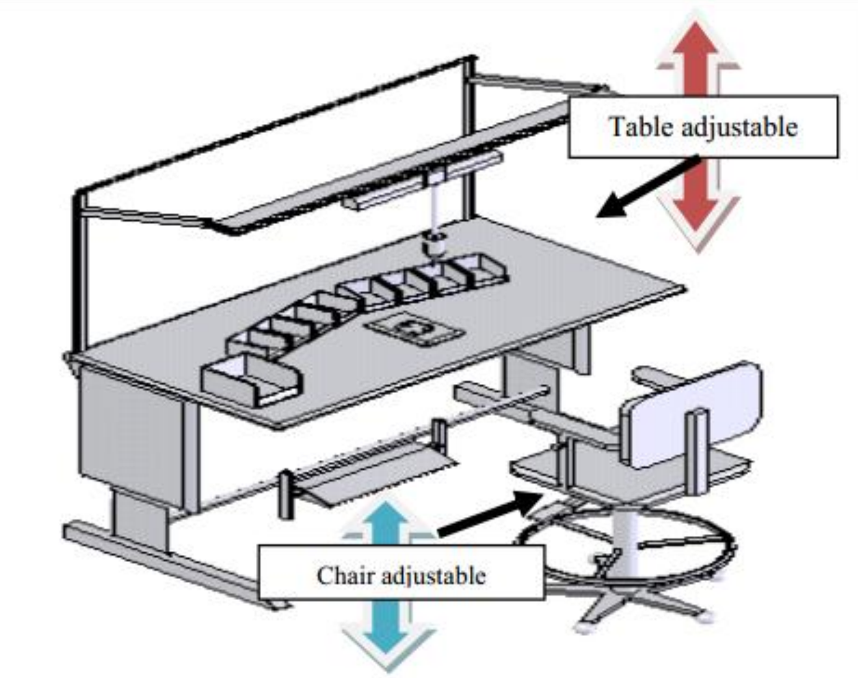

Figure 4.1: Smart work station

3.1.4 The Smart Assembly Workstation

The smart assembly workstation was designed and developed considering ergonomics in all aspects of design and layout with full adjustability. The size of the tabletop (work surface) was calculated based on the mean reach of the user population with anallowance. A special table frame was designed for the vertical and angular movements of the tabletop using small motors. The frame mechanism was designed for precise movements of the tabletop. Push-button switches were provided for the control of these movements. Operators could adjust the tabletop to their most preferred work heights. The table could be used for sit, stand, and sit-stand assembly workstations. Attachments were provided to the frame for bins and tools holders for adjustments. A fully adjustable ergonomic chair was provided to the operators. Major features of the ergonomic adjustablechair were: adjustable seat height by gas suction,adjustable and titled back support, tilted seat pan covered with porous and breath-able material, removable and adjustable arm rests, footrest and a foot ring. An adjustable hydraulic footrest was provided for the operators. The existing hand tools were replaced with a power screwdriver that was supported by a balancer in front of the operator. The workplace layout was made according to the calculated normal and maximum work areas. Squire's method was adopted in the calculation. The bins were laid out based on this calculation and in a logical work sequence and a systematic method. Figures (1 -2) show the isometric view and the schematic layout of the ergonomically designed smart assembly workstation, respectively. An improved work method following the assembly of parts sequence was developed for the task performance on this workstation. A jig was designed for ease of holding the base of the switch.

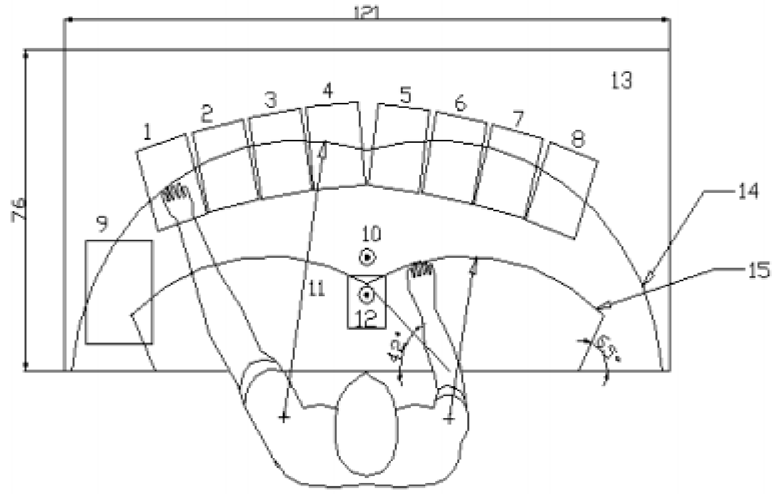

Figure 4.2: Ergonomic views

3.2 Experimental Setup

The experimental setup mainly consists of different chairs and tables which are not ergonomically designed. The car which should be assembled consists of six parts and a power screw driver for tightening screws. The experiment is conducted for both the students in different weeks. The heights of the tables are measured by taking ground floor as reference point. Heights of the tables are as follows (83cm, 76cm, 70cm, 66cm, and 61cm) and also heights of different chairs are (60cm, 53.5cm, 46cm, 44.5cm, and 42.5cm).

Participants were given a demonstration and then trained for 15 minutes the smart workstations and methods before starting the experimental sessions. Each experiment was conducted 5 times and the average value is taken into the final readings. The operator performance is recorded in terms of (units/hour).

3.2.1 Description of Assembly Parts

These are the different parts used for assembly and disassembly for the car.

- PART 1 ------------------------CHASIS
- PART 2 ------------------------ FRAME
- PART 3 ------------------------ AXLE AND WHEEL
- PART 4 ------------------------ ATTACHMENT
- PART 5 ------------------------ SCREW DRIVER
- PART 6 ------------------------ SCREWS

3.2.2 DESCRIPTION OF RESPONSIVE FACTORS

There are five different tables and five different chairs of variable heights on which the experimental study of assembly and disassembly workstation considering agronomical issues are conducted by two students of successive heights.

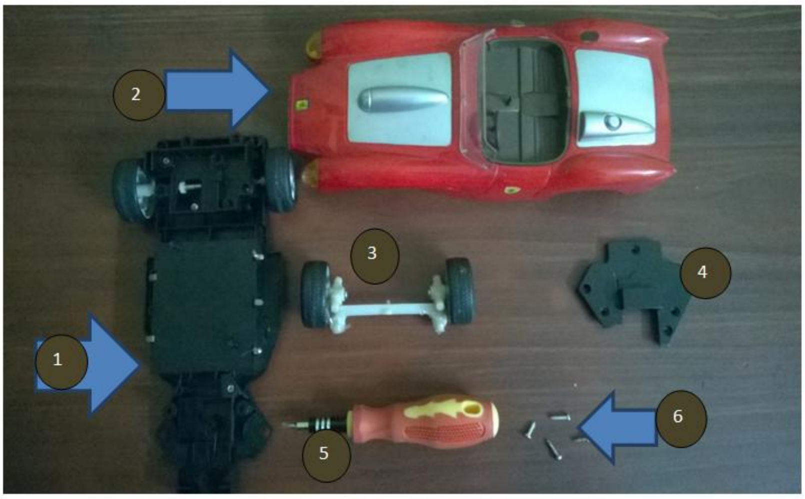

Figure 4.3: Assembly parts of experiment

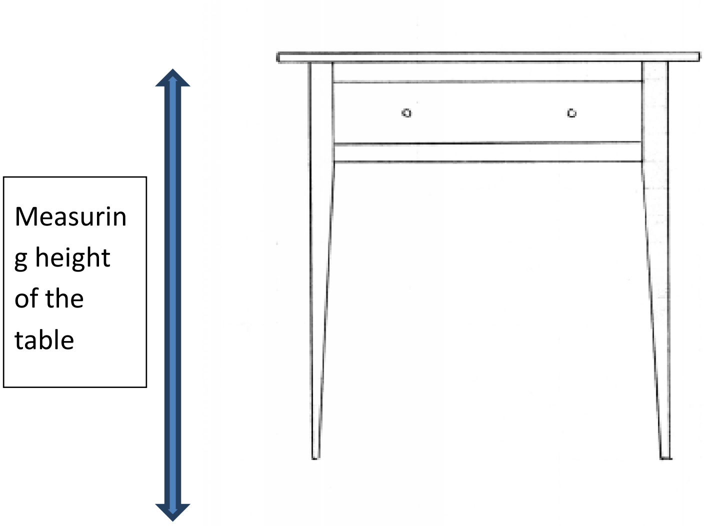

FIG 4.4: TABLE

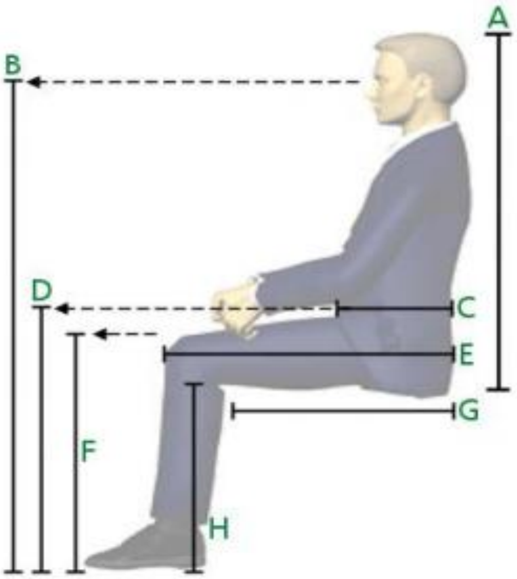

Figure 2: Sitting position on chair

Figure 4.15: chair-5 (height 42.5)

These are the different tables and chairs used for the assembly and disassembly of car at work stations related to agronomical issues by two students of different heights.

4.1 Analyzing Data

For the first student of height 172cm the following table is obtained. The experiment is conducted in such a way that the student performs the assembly of car by considering each table as workstation and exchanging five different chairs for the same table , and collects the data for the time taken to assemble the car. Later on the data is converted into production rate in terms of (units /hour) from (sec/unit).

The same procedure is repeated for disassembly of the car by exchanging chairs of different height for a fixed table and the data is collected.

After the completion of first set of data the experiment is continued by replacing other tables and by exchanging five different chairs on each table. The data which is collected is used for producing the maximum production rate among the collected data by analysing using a Minitab statistical software.

Different plots are obtained for each table and chair. For estimating maximum production rate, the mean plot curve and the interaction curve plays a crucial role.

For the second student of height 180cm the same procedure is followed for the collection of data relating to the assembly and disassembly of the car with respect to five different tables and chairs.

Given below are the experimental values of both the students after taking the mean of five different readings on one table and one chair. For one table and one chair readings, five different iterations of values have to be taken and their mean is considered as the final value of that particular table and chair. All the observations for five different trials on each table for each chair is clearly mentioned in appendix. The related graphs are also posed in the appendix.

The main observation considering the mean of all the trials on each table for corresponding chair is given below in the tables and graphs.

SUBJECT (S1)=172cm=HEIGHT OF STUDENT 1
SUBJECT (S2)=180cm=HEIGHT OF STUDENT 2

4.2 Observations and Graphs

Table 4.1 Production rate of students of different heights for assembly and disassembly

S_1	TABLE-1	TABLE-2	TABLE-3	TABLE-4	TABLE-5
A CHAIR-1 D	30 44	43 56	54 55	51 75	40 64
A CHAIR-2 D	45 74	47 67	47 65	48 75	40 55
A CHAIR-3 D	44 87	43 66	43 66	43 63	40 62
A CHAIR-4 D	46 69	43 74	41 69	45 84	36 62
A CHAIR-5 D	47 70	36 52	43 52	42 94	42 55
S_2	TABLE 1	TABLE 2	TABLE 3	TABLE 4	TABLE 5
A CHAIR-1 D	55 85	40 114	51 99	39 99	55 106
A CHAIR-2 D	58 139	50 100	42 91	39 92	60 107
A CHAIR-3 D	53 111	47 99	48 99	49 91	60 121
A CHAIR-4 D	44 95	52 90	57 91	57 124	36 118
A CHAIR-5 D	36 86	47 88	66 99	65 80	51 95

The MAIN EFFECT PLOTS for production rate of student with height S1 are derived from the below mean of observations which are plotted between number of tables and table mean and correspondingly number of chairs and chair mean.

Table 4.2 Mean Production Rate of subject 1 for different tables and chairs.

S_1	TABLE-1	TABLE-2	TABLE-3	TABLE-4	TABLE-5	CHAIR MEAN
CHAIR-1	37	50	55	63	52	51
CHAIR-2	60	57	56	62	48	45
CHAIR-3	66	55	54	53	51	56
CHAIR-4	58	59	55	65	49	57
CHAIR-5	59	44	48	68	49	54
TABLE MEAN	56	53	54	62	50	

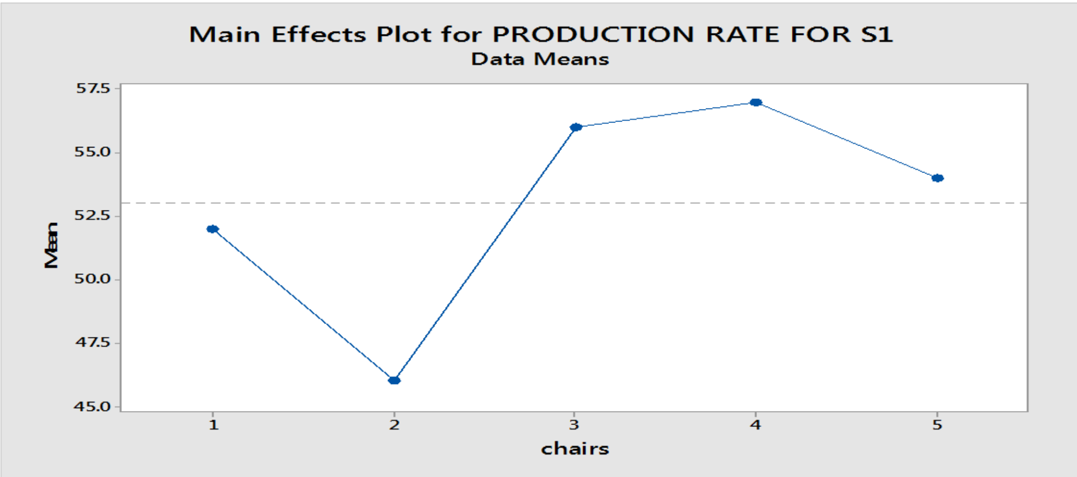

Figure 4.16: MAIN EFFECTS PLOT FOR PRODUCTION RATE OF S1 (CHAIRS)

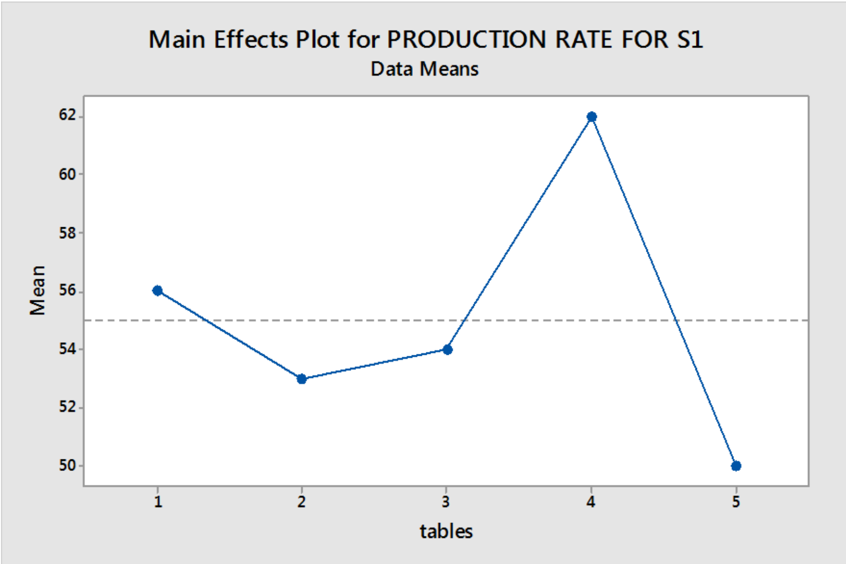

Figure 4.17: Main Effects Plot For Production Rate Of S2 (Tables)

The plots above show the production rate for H1 among tables.

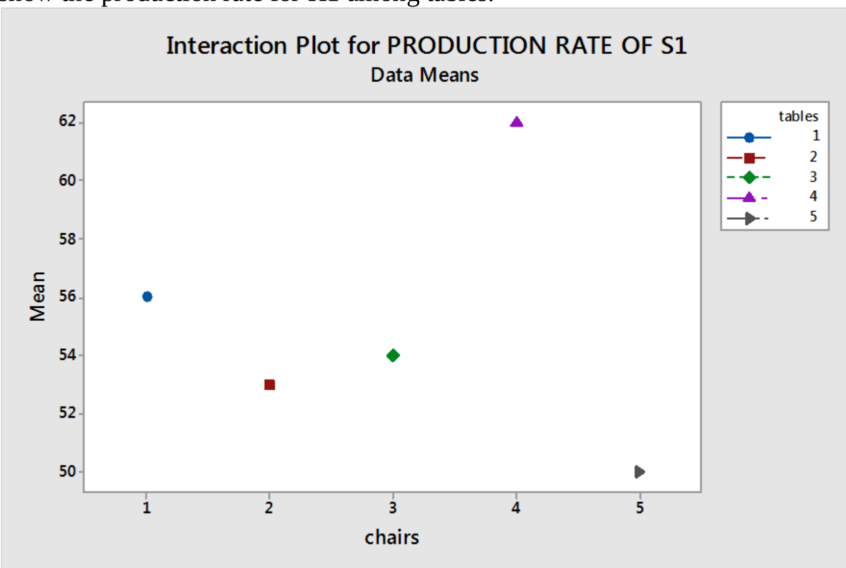

Figure 4.18: Interaction Plots For Production Rate Of S1

Table 4.3 Mean Production Rate of subject 2 for different tables and chairs

S_2	TABLE 1	TABLE 2	TABLE 3	TABLE 4	TABLE 5	CHAIR MEAN
CHAIR-1	71	77	50	67	81	75
CHAIR-2	99	75	65	66	83	78
CHAIR-3	83	63	42	70	91	78
CHAIR-4	70	69	43	87	78	77
CHAIR-5	61	68	49	64	73	72
TABLE MEAN	76	73	75	74	80	

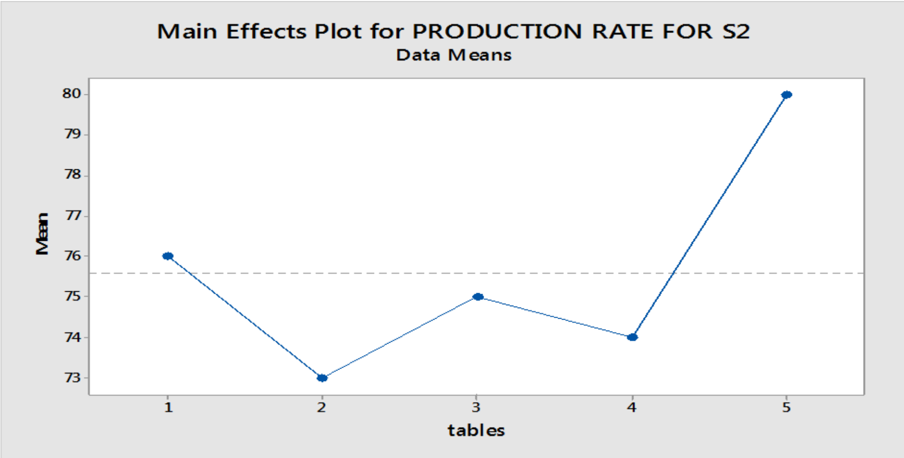

Figure 4.19 Main effects plot for production rate of S2

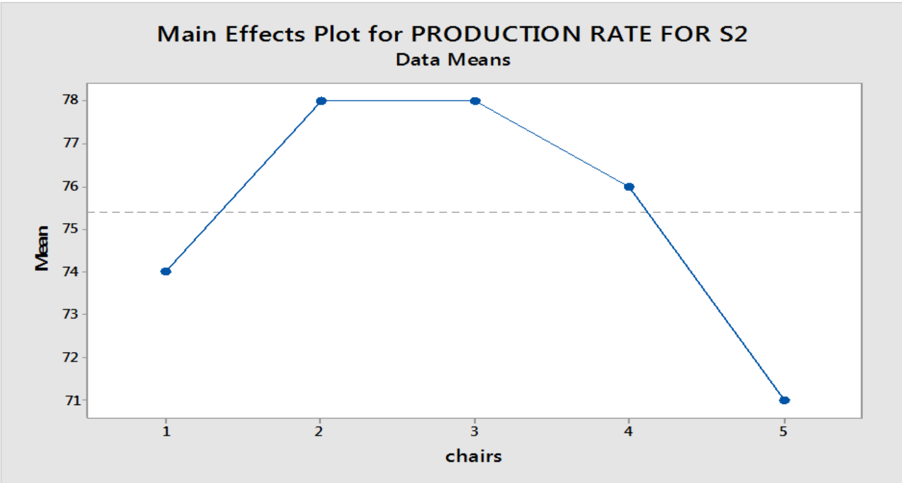

Figure 4.20: Main Effects Plot On Production Rate Of S2 (Chairs)

The above plots give the rate of production of height S2 student among the combination of five different chairs. The interaction plot gives the level of dependency of factor on each other.

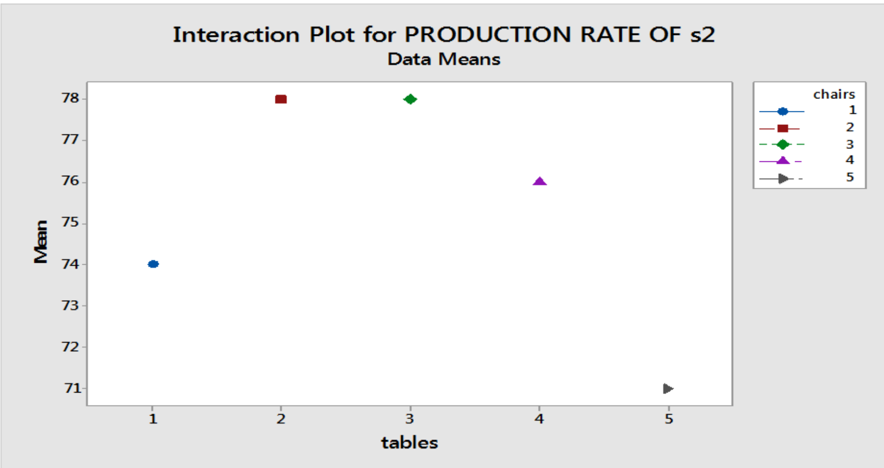

Figure 4.21: Interaction Plots On Production Rate Of S2

The below graph describes the maximum production rate compared to the heights of the two students.

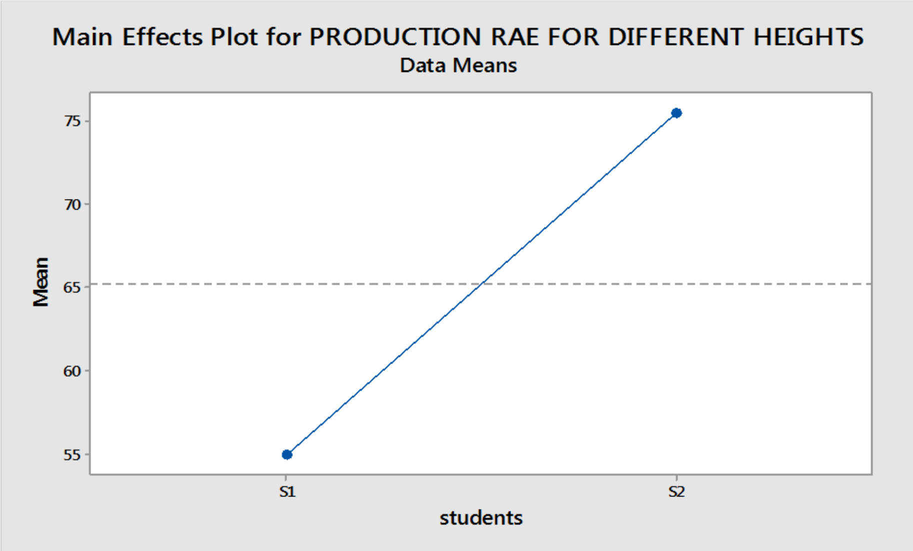

Figure 3.22: Main Effects Plot For Production Rate Of Different Heights

The graph shows the relationship between the production rate of the students with height S1 and height S2. The plots mention that the student with height S2 is more comfortable and more efficient compared to the student with height S1 with respect to this particular experiment and workstation.

Therefore, from these plots there can be some results drawn base upon the operator efficiency, consistency and rate of maximum production within this particular workstation and table and chair combination and cannot be declared in general.

IV. Results and Discussions

This thesis describes the results of an experimental study and analysis conducted to investigate the effects of assembly of a product and disassembly of a product on operator performance. Although, many thesis exist conducting the experiment for ideal conditions assuming a smart workstation and power screw drivers etc…the result and conclusions also remain ideal. In the real life situations, considering an industry or an office or a college class room, the people need to deal with all elements which are not ergonomically designed. The effects of such non ergonomic components on the production rate of a simple component by two equally knowledgeable students with same training and theoretical knowledge are analysed using Minitab 17 Statistical Software in this particular case.

Therefore, below are the results obtained from the experiment conducted between two students of different heights to assemble and disassemble a car using response factors.

For Subject 1:
For chairs

- The Sample Mean table shows the rate of production for the combination of different chairs and heights.
- In this table, the results show that,the maximum production rate for chair 1 is obtained with table 4 as 63 units/hour.
- The maximum production rate for chair2 is obtained with table 4 as 62 units/hour
- Chair 3 obtains maximum production rate with table 1 as 66units/hour.
- Chair 4 also exhibits maximum production rate withy table 4 as 65units/hour
- The maximum production rate for chair 5 is obtained with table 4 as 68 units/hour

For tables

- The sample mean shows that the maximum rate of production for table 1 is obtained with the combination of chair 2 as 66units/hour
- Table 2 exhibits maximum production rate with chair 2 as 59units/hour
- Table 3 also exhibits maximum production rate with chair 2 as 60 units/hour
- Table 4 varies with other tables results by exhibiting maximum production rate with chair 5 as 68units/hour
- Table 5 exhibits maximum production rate with chair 1as 52units/hour

The maximum production rate of the assembly and disassembly of the car in subject 1 is clearly obtained at table 4 with a combination of chair 5.

For Subject 2:

For chairs

- The sample mean observation clearly shows the maximum production rate for subject 2.
- In this result, chair 1 exhibits maximum production rate with tabe 5 as 81units/hour.
- Chair 2 exhibits maximum production rate with table 1 as 99units/hour
- Chair 3 gives maximum production rate with table5 as 91 units/hour
- Whereas chair 4 obtains maximum production rate with table 4 as 87units/hour
- Chair 5 gives maximum production rate with table 5 as 73units/hour

For tables

- Table1 gives maximum production rate with a combination of chair2 as 99units/hour
- Table 2 exhibits maximum rate with chair 1 as 77unitshour
- Table 3 also gives maximum production rate chair 2 as 65units/hour
- Table 4 exhibits maximum production rate with chair 4 as 87units/hour
- Table 5 gives maximum production rate with chair 3 as 91unitshour

The maximum production rate for the assembly and disassembly of the car with subject 2 is obtained at chair2 at table1.

From the above results, it is stated that the student of height S2 is more comfortable and efficient with respect to given tables and chairs as when compared to the other student with height S2.

V. Conclusions

The following conclusions were drawn from this experimental study:

1. Operators' performance with regard to productivity with the ergonomically smart assembly workstation condition is studied and investigated.
2. The fully adjustable ergonomically designed smart assembly workstation was preferred by the operators and they adjusted and organized the workstation to their comfort.
3. Workstations for assembly tasks should be designed so that any operator can adjust to his/her comfort to relieve stress and improve performance. The ergonomically designed smart assembly workstation is a solution to ergonomic and productivity problems in the workplace.
4. The students with greater heights are more efficient and consistent than those compared to shorter heights.
5. Creating a regression model representing operator performance (productivity) was built based on the experimental work.

The main contribution of this work is how to measure the production rate of manual assembly lines based on design ergonomically assembly workstation. The author plans to conduct the future research in real life case studies through validation this research in different sectors of industries (manufacturing parts, food industry and so on) and presented a new performance measure for each specified operator in these sector

Acknowledgements

We are grateful to our parents and the faculty who always supported us with great love and responsibility. We are indebted to the Department of Mechanical Engineering, Andhra University, for all the technical and infrastructure support.

Table 1: Production rate of Subject 1 on table 1 for different chair heights

TABLE 1						
S_1	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
CHAIR-1 A	29.85	32.82	35.61	25.76	26.55	30.12
CHAIR-1 D	49.72	45.26	40.42	39.81	42.49	43.54
CHAIR-2 A	45.85	47.07	49.26	39.9	42.41	44.89
CHAIR-2 D	78.60	79.99	70.31	69.77	71.63	74.05
CHAIR-3 A	41.86	45.06	47.33	40.68	42.62	43.51
CHAIR-3 D	85.71	88.15	87.92	89.94	82.99	86.94
CHAIR-4 A	43.39	44.16	40.01	49.05	51.00	45.52
CHAIR-4 D	67.23	64.82	72.26	70.16	69.19	68.73
CHAIR-5 A	43.86	44.91	56.23	47.7	44.0	47.34
CHAIR-5 D	71.74	72.71	64.19	73.0	68.08	69.84

Table 1: Production rate of Subject 1 on table 2 for different chair heights

Table 2						
S_1	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
CHAIR-1 A	41.37	42.89	39.31	44.63	46.23	42.88
CHAIR-1 D	59.01	59.16	56.26	54.01	52.73	56.23
CHAIR-2 A	46.81	49.46	47.11	45.37	43.87	46.52
CHAIR-2 D	68.83	69.63	67.29	64.14	63.16	66.61
CHAIR-3 A	40.44	42.23	45.45	39.72	46.11	42.79
CHAIR-3 D	69.23	67.65	68.49	65.11	61.03	66.30
CHAIR-4 A	43.63	44.62	45.63	39.46	41.01	42.87
CHAIR-4 D	71.14	73.92	76.75	74.89	71.91	73.72
CHAIR-5 A	31.66	39.55	37.80	32.31	36.26	35.51
CHAIR-5 D	49.72	52.41	54.93	49	56.13	52.43

Table 2: Production rate of Subject 1 on table 3 for different chair heights

Table 3						
S_1	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
CHAIR-1 A	58.25	57.47	55.50	50.47	46.25	53.58
CHAIR-1 D	52.63	53.42	49.56	56.28	57.63	53.91
CHAIR-2 A	45.28	46.85	49.42	42.28	49.28	46.66
CHAIR-2 D	64.28	65.50	62.67	63.61	67.72	64.76
CHAIR-3 A	47.61	49.91	35.48	41.72	42.47	43.33
CHAIR-3 D	73.72	64.48	69.91	60.15	61.42	65.6
CHAIR-4 A	46.15	37.67	40.50	39.31	40.85	40.8
CHAIR-4 D	70	71.49	72.85	64.73	65.67	68.9
CHAIR-5 A	41.72	42.57	47.42	43.15	42.49	43.4
CHAIR-5 D	52.38	54.46	49.47	53.80	47.48	51.5

Table 3: Production rate of Subject 1 on table 4 for different chair heights

Table-4						
S_1	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
A CHAIR-1 D	46.15 76.59	49.54 79.72	51.52 78.69	52.54 69.72	54.54 72.69	50.85 75.48
A CHAIR-2 D	44.17 74.22	45.47 75.61	47.45 76.45	52.51 76.92	51.43 72.72	48.20 75.19
A CHAIR-3 D	38.25 61.43	39.42 62.85	42.45 65.42	45.25 62.77	47.75 61.59	42.62 62.81
A CHAIR-4 D	44.77 82.75	47.39 84.92	49.85 85.95	41.17 81.22	42.43 85.77	45.12 84.12
A CHAIR-5 D	39.69 91.36	40.72 95.51	42.92 97.42	45.59 93.15	39.45 92.85	41.67 94.06

Table 4: Production rate of Subject 1 on table 1 for different chair heights

Table 5						
S_1	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
A CHAIR-1 D	37.69 63.61	39.53 61.43	42.69 67.42	39.42 61.64	41.34 67.30	40.13 64.287
A CHAIR-2 D	37.26 57.23	39.61 56.34	40.26 57.23	41.26 52.63	42.64 51.61	40.20 55.00
A CHAIR-3 D	37.69 60.30	38.61 61.39	41.71 63.64	42.72 64.51	39.26 60.61	39.99 62.09
A CHAIR-4 D	34.64 60.61	35.67 64.41	36.69 62.26	39.23 63.41	34.43 61.53	36.13 61.84
A CHAIR-5 D	41.71 56.42	43.51 57.39	41.30 58.26	42.63 51.71	43.69 53.69	42.46 55.49

Table 5: Production rate of Subject 1 on table 1 for different chair heights

Table 6						
S_2	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
A CHAIR-1 D	55.55 85.71	51.08 87.21	57.21 83.45	55.39 82.19	59.41 89.23	54.72 84.55
A CHAIR-2 D	59.8 133.3	55.45 144.32	56.73 134.12	58.63 142	59.8 140.19	58.07 138.78
A CHAIR-3 D	53.09 110.09	53.19 110.11	52.9 109.8	53.19 104.21	55.09 121.3	53.49 111.30
A CHAIR-4 D	48 98.36	43.21 97.16	44.23 96.23	45.10 90.19	40.19 93.10	44.19 95
A CHAIR-5 D	38.46 84.5	39.47 85.63.	37.53 87.23	32.13 89.23	33.29 84.13	36.17 86.14

Table 6: Production rate of Subject 1 on table 1 for different chair heights

TABLE-7						
S_2	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
A CHAIR-1 D	34.2 116.0	43.6 113.2	38.21 111.23	41.23 121.34	40.31 107.51	39.51 113.85
A CHAIR-2 D	44.1 89	54.5 113.2	50.31 114.2	55.12 89.23	47.21 95.12	50.24 100.13
A CHAIR-3 D	45.8 85.6	46.8 95.2	52.33 105.19	40.13 95.19	43.93 110.15	46.79 99
A CHAIR-4 D	50 85.9	45.8 95.2	55.18 90.38	49.34 91.92	59.17 86	51.89 89.88
A CHAIR-5 D	43.4 95.2	49.5 64.5	47.83 97.26	45.21 93.37	50.30 89.48	47.24 87.96

Table 8: Production rate of Subject 1 on table 1 for different chair heights

TABLE-8						
S_2	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
A CHAIR-1 D	43.3 74.5	46.36 72.5	48.12 83.46	65.26 79.01	50.33 85.69	50.67 98.66
A CHAIR-2 D	41.8 96.7	36.8 84.5	45.39 85.46	49.54 93.93	40.57 92.89	42.8 90.69
A CHAIR-3 D	42.8 93.6	52.1 96.4	51.7 100.92	44.87 90.66	46.97 112.60	47.56 98.83
A CHAIR-4 D	47.61 88.2	50.46 89.39	71.74 87.63	60.89 99.50	54.50 92.25	57.04 91.39
A CHAIR-5 D	60.54 82.1	65.6 94.01	76.61 87.74	62.21 90.09	65.05 99.28	66 90.62

Table 9: Production rate of Subject 1 on table 1 for different chair heights

TABLE 9						
S_2	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
A CHAIR-1 D	36..31 96.7	40.97 97.44	42.09 92.63	37.62 105.22	39.19 101.04	39.19 98.61
A CHAIR-2 D	36.36 92.3	39.26 96.60	40.14 89.77	41.19 92.84	38.23 86.92	39.03 91.68
A CHAIR-3 D	49.5 90.90	48.16 89.24	46.46 94.07	514.98 86.76	50.02 92.89	49.22 90.77
A CHAIR-4 D	58.7 125	50.24 129.62	52.26 120.91	62.64 119.34	59 123.19	56.56 123.59
A CHAIR-5 D	60.84 79.76	71.45 89.61	63.96 75.07	66.74 72.49	64.08 81.32	65.36 79.65

Table 10: Production rate of Subject 1 on table 1 for different chair heights

TABLE 10						
S_2	TRAIL-1 (units/hour)	TRAIL-2 (units/hour)	TRAIL-3 (units/hour)	TRAIL-4 (units/hour)	TRAIL-5 (units/hour)	TRAIL-MEAN
A CHAIR-1 D	51.7 100.8	55.23 108.23	61.34 119.06	54.36 110.19	50.29 91.14	54.58 105.88
A CHAIR-2 D	60 105.2	63.56 109.01	55.67 112.76	57.11 111.84	63.02 97.11	59.87 107.18
A CHAIR-3 D	59.8 127	62.12 117.23	57.37 10956	63.41 132.64	58.56 120.32	60.25 121.35
A CHAIR-4 D	36.1 115.3	37.11 116.62	40.67 127.12	35.39 123.31	32.52 109.01	36.35 118.27
A CHAIR-5 D	50.84 90.90	57.12 100.2	55.40 97.61	43.31 97.72	49.99 86.62	51.37 94.61

References

[1] Hasselquist, R.J., 1981 . Increasing manufacturing productivity using human factors principles. Proceedings of the Human Factors Society – 25th Annual Meeting, pp.204-206.

[2] Schnauber, H., 1986. Ergonomics and productivity as reflected in a new factory. Trends in Ergonomics/Human Factors III, Karwowski Ed., Elsevier Science Publishers, pp. 459-465.

[3] Ryan, J.P., 1989. A study of selected ergonomic factors in occupational safety. Advances in Industrial Ergonomics and Safety I, Anil Mital Ed., Taylor and Francis, pp. 359-364.

[4] Das, B., 1987. An ergonomic approach to designing a manufacturing work system. Int. J. of Industrial Ergonomics. 1(3), 231-240.

[5] Resnik, M.L., Zanotti, A., 1997. Using ergonomics to target productivity improvements. Computers and Industrial Engineering. 33(1/2), 1 85-188.

[6] Burri, G.J., Helander, M.G., 1991 . A field study of productivity improvements in the manufacturing of circuit boards. Int. J. of Industrial Ergonomics. 7, 207-215.

[7] Shikdar, A., Das, B., 1995. A field study of worker productivity improvements. Applied Ergonomics. 26(1), 21-27.

[8] Das, B.,Sengupta, A., 1996. Industrial workstation design: A systematic ergonomic approach. Applied Ergonomics, 27(2), 157-163.

[9] Das, B., Shikdar, A., 1999. Participative versus assigned production standard setting in a repetitive industrial task: a strategy for improving worker productivity. Int. J. of Occupational Safety and Ergonomics. 5(3), 417-430.

[10] Grandjean, E., 1988. Fitting the task to the man: An ergonomic approach, Taylor and Francis, London.

[11] Konz, S., 1995. Work design: IndustrialErgonomics, 2ndedn, Grid Columbus, Ohio.

[12] Das, B., Grady, R.M. 1983. Industrial workplace layout design: An application of engineering anthropometry. Ergonomics. 26(5), 433-443.

[13] Salvendy, G., 1987. Handbook of Human Factors. John Wiley, New York.

[14] Melamed, S., Luz, J., Najenson, T., Jucha, E., Green, M., 1989. Ergonomic stress levels, personal characteristics, accident occurrence and sickness absence among factory workers. Ergonomics. 9, 1101-1110.

[15] Sanders, M.S., McCormic, E.J. 1992. Human Factors in Engineering and Design, 6th edn, McGraw Hill, New York.

[16] Wilson, J.R., Corlett, E.N., 1992. Evaluation of Human Work: A Practical Ergonomics Methodology. Taylor and Francis, Philadelphia.

[17] McLeod, D., 1995. The Ergonomics Edge: Improving Safety, Quality and Productivity, John Wiley, New York.

[18] Ayoub, M.A., 1990a. Ergonomic deficiencies: I. Pain at work. J. of Occupational Medicine. 32(1), 52-57.

[19] Ayoub, M.A.1990b. Ergonomic deficiencies: II. Probable causes. J. of Occupational Medicine. 32(2), 131-136.

[20] Shikdar, A., Al-Hadhrami, M., 2007. Smart workstation design: an ergonomics and methods engineering approach. Int. J. of Industrial and Systems Engineering. 2(4), 363-374.

[21] Shikdar, A., Garbie, I., Khadem, M., 2011. Development of a smart workstation for an assembly task. Proceedings of the 2011 International Conference on Industrial Engineering and Operations Management (IEOM), Kula Lumpur, Malaysia, January 22-24, 2011.

[22] Yeow, P.H.P., 2003. Quality, productivity, occupational health and safety and cost effectiveness of ergonomic improvements in the test workstations of an electronic factory. Int. J. of Industrial Ergonomics 32(3), 147-163.

[23] Anon, A., 2005. Workstations, track system smooth assembly. Assembly. 48(4), 32-35.

[24] Montgomery, D.C., 2009. Design and Analysis of Experiments. 7th Edition, John Wiley and Sons, Inc., Hobaken, NJ, USA.

[25] Montgomery, D.C., and Runger, G.C., 2011. Applied Statistics and Probability for Engineers. 5th Edition, John Wiley and Sons, Inc., Hobaken, NJ, USA.

[26] Navidi, W., 2008. Statistics for Engineers and Scientists. 2nd Edition, Mc GrawHill, New York, NY, USA.