Integration of Ergonomic and Work Study to Redesign J-Bolt Production Line: The Case of Ferric Belt Metal Processing and Engineering Factory

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A Thesis Submitted to

The School of Mechanical and Industrial Engineering

Presented in Fulfilment of the Requirements for the Degree of Master of Science in Mechanical Engineering (Industrial Engineering Stream)

Addis Ababa University

Addis Ababa, Ethiopia

June, 2018

Addis Ababa University
Addis Ababa Institute of Technology
School of Mechanical and Industrial Engineering
Industrial Engineering Stream

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Declaration

I hereby declare that the work which is being presented in this thesis entitled "**Integration of Ergonomic and Work Study to Redesign J-Bolt Production Line**" is original work of my own and has not been presented for a degree of any other university and all the resources of references used for the thesis have been duly acknowledged.

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Abstract

Work study is a tool of the investigation of a process by means of regular system the work is done in an industry, in order to achieve the best possible use of human, machine and materials available in the workstation. Ergonomics is fitting workplace conditions and work demands to capability of workers. The integration of ergonomics and work study requires new methodological framework that evolves from single approaches. Which clearly applies the principles of both and simultaneously guaranteeing better productivity and working condition.

The objective of this study is to develop standard working procedures with reduced non-value adding activities and ergonomically designed working condition. Both primary and secondary data was used. To collect primary data direct observation and questionnaire was used. To analyze qualitative and quantitative analysis was employed and to compare the existing system and the proposed system arena simulation was conducted. The findings of this thesis indicate that the layout of the J-bolt production line is exposed to wastage of motion of workers and material that consume production time and there was no mechanical material handing on the line as well as there was awkward postures like forward bending and leaning, lateral bending and twisting, sitting above and below normal height and excessive forward reaching. Workers on the line facing different degree of pain in their body parts more than 53% of them face higher degree of pain in the lower back and half back. Also on average 9 injures are recorded per year. From the work measurement conducted and redesign the workstations the unit production time is reduced by 42.33% and the production volume is increased by 7 pieces per hour.

Acknowledgement

I am grateful to the almighty God in whom I have every good thing.

I would like to express my deepest gratitude to my advisor, Dr. Kassu Jilcha and Co-advisor Ms. Merertu Wakuma for their guidance, corrections, constructive comments, suggestions and consistent weekly advices, throughout the research work in more ways than can be stated.

I would also like to thank Ferric belt metal processing and engineering factory manager Abdela Yesuf, production manager Biniyam Tekle, finance manager Ginbaru Tuka and workers of j Bolt manufacturing line for providing me with the necessary information with which the research has come into being.

My thanks also goes to Abebe Negeri, Lemi Negeri, Lelise Hayile, Getachew Beyene and Kebene Gedefa for their support and encouragements during my study and research work.

My special thanks are due to my father Tolera Nikussa and my mother Kemisi Sori without whom I would not have moved a step in my education. My sincere gratitude also extends to my brother Mekonnen Tolera and my sister Bakashe Tolera for their encouragement and assistance during the research work.

Finally, and most importantly, I would like to thank my Wife Marge Kuma, for her support, encouragement, prayer and continual support and love and also my daughters Bontu and Nahilet, my sons Ibsa and Beki for their support and encouragement during my study.

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List of Abbreviations/Acronyms

AF – Allowance Factor

CTD – Cumulative Trauma Disorders

HF – Human Factors

HFE – Human Factors and Ergonomics

ILO – International Labour Organization

LBP – Low-Back Pain

MOT – Mean Observed Time

MSD – Musculoskeletal Disorders

NIOSH – National Institute of Occupational Safety and Health

NT – Normal Time

PRF – Performance Rating Factor

RMI – Repetitive Motion Injuries

RMT – Repetitive Motion Trauma

RSI – Repetitive Strain Injuries

RSIs – Repetitive Strain Injuries

ST – Standard Time

WHO – World Health Organization

WMSDs – Work-Related Musculoskeletal Disorders

Chapter One

1. Introduction

1.1. Background

People are one of the most important resources in an enterprise. In today's industrial and service operations, physical tasks of assembling and handling materials, as well as sensory and cognitive tasks such as inspecting components, entering data, issuing tools, and managing people and operations are performed through people. Simply put, it takes people to make products and provide services. The efficiency at which people can accomplish these tasks is a primary driver of productivity, and productivity is a primary driver of economic activity (Lehto & Landry, 2013).

Ergonomics is the study of people at work. This field got its name in the summer of 1949 when a group of interested individuals assembled in Oxford, England to discuss the topic of human performance. The group consisted of anatomists, psychologists, physiologists, industrial medical officers, design engineers, industrial hygienists, work study engineers, architects, illuminating engineers, and anyone whose work concerned some aspect of human performance (Lehto & Landry, 2013)

A proposal was put forth at that meeting to denominate a new word for this emerging field, ergonomics, which couples ergos, the Greek word for work, with the word nomos, meaning natural laws. The group decided to adopt this term and called themselves the Ergonomics Research Society. One of the advantages of this new term was that it did not imply that any of the contributing disciplines were more important than the others (Lehto & Landry, 2013). Ergonomics is the study of the interaction between people and machines and the factors that affect the interaction (Bridger R. , 2018). The ergonomics is one of the most important elements in enterprise operations, for it is through people that management can control the utilization of its resources and the sale of its products or services. To give the best of their ability, workforces must be motivated to do so. Managers must be able to provide a motive or a reason for doing something, or make people want to do it (Kanawaty, 1992).

The current attention in human factors arises from the fact that technological developments have focused attention (in some cases dramatically) on the need to consider human beings in such developments (Sanders & McCormick, 1993).

HFE is the study of the interactions between people and technology and the factors that affect the interactions. Its purpose is to assure the performance of system so that defined users with defined skills and knowledge can carry out defined tasks, using defined equipment, to defined standards under defined situations. Thus, HFE is concerned with classifying and defining user characteristics; designing and understanding the tasks; understanding and documenting existing skills and knowledge; defining and operationalizing the required level of task performance and understanding the environmental and psychosocial conditions in which work takes place (Bridger R. , 2018). Objective of ergonomics is to improve the performance of systems by improving human machine interaction. This can be done by 'designing-in' a better interface or by 'designing-out' factors in the work environment, in the task or in the organization of work that reduce human – machine performance (Bridger R. , 2003). There are two major objective of ergonomics. The first is to enhance the effectiveness and efficiency with which work and other activities are carried out. Included here would be such things as increased suitability of use, reduced errors, and increased productivity. The second objective is to enhance certain desirable human values, reduced fatigue and stress, including improved safety, increased comfort, greater user acceptance, increased job satisfaction, and improved quality of life (Sanders & McCormick, 1993).

Work study aims at examining the way an activity is being carried out, simplifying or modifying the method of operation to decrease unnecessary or excess work, or the wasteful use of resources and setting up a time standard for performing that activity. The relation between productivity and work studies therefore obvious. If work study results in cutting down the time of performing a certain activity by 20 percent, merely as a result of reorganizing the sequence or simplifying the method of operation and without additional expenditure, then productivity will increase by a corresponding value, that is by 20 percent. To appreciate how work study acts to cut down costs and reduce the time of a certain activity, it is necessary to examine more closely what that time consists of (Kanawaty, 1992). Work study can be divided into method study/analysis and work measurement (time study). It is used to systematically study and improve human working methods by considering all factors that affect the working efficiency and conditions (Cengiz Duran & Aksu, 2015).

1.2. Statement of the problem

Ferric belt metal processing and engineering factory is producing different art metals for input of building constructions. J-bolt is one of the product of the factory and J-bolt manufacturing line is one of the manufacturing lines of the factory. On this line form direct observation the manufacturing method is exposed to wastage of resources through transporting of material longer distance than necessary and also following complex flow line. And also operators of these machines are facing different ergonomic problems which leads to muscle fatigue that can be summarized as follow:

Awkward posture**:** The machinists adopted awkward postures associated with trunk flexion while loading the workpiece into the machine chuck. The other is that due to the machinists that have to lean forward to reach and manually lift the material from the ground buffer area. This may cause the machinists to feel pain especially in their arms, shoulder and neck, lower back. Awkward posture can result in discomfort and permanent injury (Hedge, 2017).

Prolonged standing: The machinists are exposed to prolong standing while performing monitoring, observation. This happens as a result of not having a chair. This process will lead to muscle fatigue to the machinists. They tend to sense this muscle fatigue especially on their lower back, knees and legs. Performing jobs in prolonged standing has contributed numerous health effects such as work-related musculoskeletal disorders, chronic venous insufficiency, preterm birth and spontaneous abortion, and carotid atherosclerosis (Ansari & Sheikh, 2014).

Repetitive movements: The machinists operations in repetitive movements were during the machining, transporting material between machines and observation. This may exposed the machinists to serious injuries and illness. They may experience musculoskeletal disorder such as neck pain, shoulder pain and back pain if there is no improvement occurred. According to Coury et al., (2002) sited in Arezes & Carvalho, (2016) Repetitive movements, are considered as an important source of musculoskeletal disorders.

Heavy load**:** The machinists need to carry heavy load of the raw material manually during the work-piece transport and during chuck changing. Until now, there is no mechanical device being provided. This may exposed the machinists to experience pain in their arms due to this activity.

Frequent injuries: The hot chips from the work piece are hit hands of and stacked to operators' shoes. This produces some minor injuries and discomfort on operators while working on the machine.

As a consequence of this ergonomic risk factor, this working condition may reduce the productivity, accuracy, quality and efficiency of the factory.

Therefore, this paper is to apply the concept of ergonomics and work study to this manufacturing line to improve the productivity, health, safety and well - being of the operators.

This study is to redesign the workstations to avoid these ergonomic problems and develop standard work procedures and standard time.

1.3. Research question

Questions that were raised in the paper are:

- What are abnormal postures observed in the manufacturing line of J-Bolt in Ferric belt Metal Processing and Engineering Factory?
- What are the main musculoskeletal injury workers are facing?
- What are the standard working method and standard time of the activities?
- How can we improve manufacturing line of J-Bolt through integration of Ergonomics and work study?

1.4. Objective of the Research

1.4.1. General objective

The general objective of this study is to Redesign J-Bolt Manufacturing Line through Integration of Ergonomic and Work Study: The Case of Ferric Belt Metal Processing and Engineering Factory.

1.4.2. Specific objectives

The specific objectives of the study were to:

- To identify the types of abnormal postures in the J-bolt manufacturing line of Ferric belt Metal Processing and Engineering Factory.
- To assess the main musculoskeletal injury workers are facing.
- To develop standard working method and standard time of the activities.
- To suggest how to improve manufacturing line of J-Bolt through integration of Ergonomics and work study.

1.5. Significance of the Study

This study was used to integrate ergonomic and work study to redesign J-Bolt production line in Ferric Belt Metal Processing and Engineering Factory and it can also be adapted to similar work shop and manufacturing lines. Moreover, the study will have academic significance in that the paper is used as a partial fulfillment of the requirement of MSc and it will also be the base for those interested academicians to conduct similar study on the subject.

1.6. Scope of the Study

This study focused on integration of ergonomics and work study to redesign J-Bolt production line in Ferric Belt metal Processing and Engineering factory. There are four types of machines on the line namely, Cutting, Lathe, Threading and Bending machines. The study redesigns each of these machines workstations for better ergonomic design that reduce muscle fatigue of workers and improve well-Bing of them and to develop standard operations procedure and standard time of each activity on the line.

Chapter Two

2. Literature Review

2.1. Definition of terms

Ergonomics

Ergonomics is the science of studying people at work and of their working environment. A better match between workers' physical capabilities and limitations and workplace conditions and activities are gained through ergonomics. In reality, most ergonomics programs focus on preventing injury and illness by controlling or eliminating work-related musculoskeletal disorders (MSDs) (Sutton, 2015). Ergonomics can be defined as the study of human capabilities and characteristics that affect the design of equipment, jobs and systems. It is an interdisciplinary activity based on engineering, anatomy, psychology, physiology and organizational studies. Its aims are to improve efficiency, safety and operator well-being (Corlett & Clark, 2009). Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (Bush, 2012). It is concerned with making the workplace as safe, efficient and comfortable as possible. Effective application of ergonomics in work system design can bring a balance between worker characteristics and task demands (Mali & Vyavahare, 2015).

Human factors, a term that is used here synonymously with ergonomics and denoted as human factors ergonomics (HFE), has been evolving as a unique and independent discipline that focuses on the nature of human-artifact interactions, viewed from the combined perspective of the science, engineering, technology, design, and management of human compatible systems, including a variety of natural and artificial products, processes, and living environments (Salvendy, 2012).

Awkward postures: Body positions that deviate from neutral (MacLeod, 2006). Awkward postures may lead to physical stress and health problems (Salvendy, 2012). Awkward posture refers to positions of the body that deviate significantly from the neutral position while performing work activities. When you are in an awkward posture, muscles operate less efficiently and you expend more force to complete the task.

Neutral posture: is achieved when the muscles are at their resting length and the joint is naturally aligned (Moore & Krajewski, 2011).

Traumatic injury. Injuries that are acute, that may result from instantaneous events such as being struck by objects and that often require immediate medical attention. These types of injuries are often sustained through accidents (Moore & Krajewski, 2011).

Musculoskeletal disorders (MSDs). Illnesses and injuries that affect one or more parts of the soft tissue and bones in the body. The parts of the musculoskeletal system are bones, muscles, tendons, ligaments, cartilage, and their associated nerves and blood vessels (Moore & Krajewski, 2011).

Repetitive handling is defined as handling an object more than once every 5 min (Colombini & Waters, 2013)

Work study

Work study is a generic term for the techniques of method study and work measurement. These techniques are used in the examination of human work in all its contexts. They lead systematically to the investigation of all the factors which affect the efficiency and economy at the work place in order to affect improvement (Kesavan & Ramnath, 2009). Work study is the study of human work with a view to increase the effectiveness with which the work is done. Work study is defined as a modern discipline which analyses and evaluates all aspects of a work system in order to enhance effectiveness and functional efficiency (Adithan, 2007).

According to International Labour organization (I.L.O., Geneva, Switzerland), sited in Adithan (2007) work study is defined as a generic term for those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which leads systematically to the investigation of all the factors which affect the efficiency and economy of the situation being reviewed, in order to affect improvements.

Work study is a specific type of operations research used to measure work being performed in order to increase efficiency and productivity. It can also be defined as a generic term for those techniques, particularly method study and work measurement, which are used in the examination of human work in all its contexts, and which lead systematically to the investigation of all factors which affect the efficiency and economy of the situation being reviewed, in order to effect improvement (Megh Patel & Patel, 2015). Work study is generic term for those techniques which are used in the examination of human effort in its entire context and which lead to systematic investigation of all the factors affecting the efficiency and economy of a situation under review in order to effect improvement (Biswas & Bhowmik, 2016). Work study is the systematic examination of the methods of carrying on activities so as to improve the effective use of resources and to set up standards of performance for the activities being carried out.

Work study then aims at examining the way an activity is being carried out, simplifying or modifying the method of operation to reduce unnecessary or excess work, or the wasteful use of resources, and setting up a time standard for performing that activity.

2.2. Economics of Ergonomics

By definition, ergonomics can serve both social goals (well-being) and economic goals (performance). At society level, ergonomics can contribute to the reduction of costs due to avoidable health problems such as WRMSD by improving working conditions. The societal costs include health care costs for the treatment of disorders and costs related to the loss of labor productivity due to absence from work (Dul & Weerdmeester, 2008). According to statistics from the International Labor Organization (ILO), work-related injury and illness costs vary between 1.8 and 6.0% of GDP in country estimates. The number of people needing medical care as a result of poorly designed workplaces is also an issue for society, since so many hospital resources are taken up (Berlin & Adams, 2017). According Katz, (2006) In the United States alone, the annual total cost of LBP was estimated from 100 to 200 billion dollars.

The objective of ergonomics is to design safe and productive jobs and workplaces to protect workers from illness and injury. Similarly, one of the purpose of economics is efficient allocation of resources. Clearly these objectives are in alignment because safe and productive work environment not only protects workers but controls wastage of resources such as compensation expenses, workers' morale and health, and lost time and effort. Appropriate allocation of vital resources also leads to productive efficiency by encouraging more output with fewer resources and at a lower cost (Bhattacharya & McGlothlin, 2012). Human labor is one of the most important factors of a business organization because it is directly related to the productivity of the system. Labor productivity is a key measure of successful business efficiency, particularly for firms in which the production process is labor-intensive (Rahman & Ahmed, 2015).

Where a worker is injured at work the direct cost to the enterprise is usually limited to the workers' compensation premium cost. This is the case even where a worker is permanently disabled as a result of a work injury (Marras & Karwowski, 2006). According to Douphrate & Rosecrance

(2004) direct and indirect costs of injuries in the workplace due to wrong ergonomic workplace design are:

Direct Costs

- Insurance premiums (if insured)
- Lost wages, medical expenses, rehabilitation (if self-insured)

Indirect Costs

- Uninsured costs not covered by insurance (workers' compensation)
- Cost of wages for workers' compensation waiting period
- Time lost on day of injury
- Time spent at, and traveling to and from, doctor visits
- Time spent at, and traveling to and from, rehabilitation
- Reduced output after return to work until 100% performance is achieved
- Cost of overtime to pick up slack of injured worker
- Time lost by non-injured workers
- Reduced output of replacement employee(s)
- Time-cost of supervisor for management of injury
- Time-cost of safety professional for injury investigation and presentation
- Time-cost of human resources to manage injury
- Damage to equipment and/or materials

According to Berlin & Adams (2017) the individual cost to worker with poor ergonomically design work environment are:

- Pain and suffering due to injuries and occupational diseases (including Repetitive Strain Injuries (RSI), Cumulative Trauma Disorders (CTD) and repetitive motion injuries)
- Medical care costs
- Lost work time
- Lost future earning and fringe benefits
- Reduced job security and career advancement
- Lost home production and child care
- Home care costs provided by family members
- Adverse effects on family relations

- Lost sense of self-worth and identity
- Adverse effects on social and community relationships
- Adverse effects on recreational activities

At company level, ergonomics can contribute to the competitive advantage of a company. With ergonomically designed production processes, a company can increase employee performance in terms of productivity and quality, and can realize important cost-reductions. Furthermore, with ergonomically designed products, a firm can deliver benefits to its customers, which exceed those of competing products (Dul & Weerdmeester, 2008)

There are no perfect jobs or perfect workplaces that are free of all work-related hazards and provide ideal psychosocial conditions for complete satisfaction for all employees. Therefore, one must consider the trade-offs between competing needs for ergonomic improvements at the workplace and establish a basis for identifying the most critical workplace characteristics for design or redesign. Such trade-offs between the personal factors, biomechanical factors, and work organizational factors, including work stress, coping strategies, and organizational practices, require one to balance various ergonomic needs to achieve the solution that will have the greatest benefits for employee health and productivity (Salvendy, 2012).

2.3. Principles for Workspace Design

The objective of human factors is to design systems that reduce human error, increase productivity, and enhance safety and comfort. Workplace design is one of the most important areas in which human factors professionals can help improve the fit between humans and machines and environments (Wickens & Gordon-Becker, 2014). People must have sufficient space to be able to easily move around work areas while they do their jobs. While the provision of adequate space does not guarantee proper performance, lack of it almost guarantees reduce performance (Lehto & Landry, 2013). The importance of the design of the workstation, a "system" must be defined that includes not only the hardware but also the worker and the interface between the two (Bhattacharya & McGlothlin, 2012).

The ergonomic approach to workplace design must be known as the most effective and is the first choice for controlling causes of workplace stress. The best fit is achieved by engineering the problems out at the design stage. With the implementation of the ergonomic approach to job design, prevention of injury is achieved as a result of the worker experiencing improved work postures, fewer repetitions, reduced forces, and reduction in overall exposure to risk factors (Bush, 2012).

According to Corlett & Clark, (2009) the workplace design principles are:

- The worker should be able to maintain an upright and forward-facing posture.
- Avoid unbalanced postures (leaning or twisting), and the need for muscle activity to support the legs or upper arms. Small and/or precise movements require support of the limb(s) involved.
- Where vision is a requirement of the task, the necessary work points must be adequately visible with the head and trunk upright or with the head inclined slightly forward.
- All work activities should permit the worker to adopt several different, but equally healthy and safe, postures without reducing capability to do the work.
- Work should not be performed consistently at or above the level of the heart; even the occasional performance where force is exerted above the heart level should be avoided. Where light hand work must be performed above heart level, rests for the upper arms are a requirement.
- Work activities should be performed with the joints at about the mid-point of their range of movement. This applies particularly to the head, trunk and upper limbs.
- Where muscular force has to be exerted it should be by the largest appropriate muscle groups available and in a direction collinear with the limbs concerned.
- Where a force has to be exerted repeatedly, it should be possible to exert it with either of the arms, or either of the legs, without adjustment to the equipment.

2.3.1. Clearance Requirement of the Largest Users

Clearances are an essential component of equipment design. Clearances should facilitate not only easy and ready access to joints, fasteners, and components but sufficient room for manipulation of tools (Mital & Desai, 2014). Less emphasis has been given to clearance (Shahid & Kumar, 2015). Dimensions for the largest individual, the 95th or 99th percentile, are used to determine clearance dimensions. The large individual also determines the necessary width (Bhattacharya & McGlothlin, 2012). The space between and around equipment, the height and width of passageways, and the dimensions provided for the knees, elbows, legs, feet, and head are some examples of clearance design problems. Some workers may not be able to access certain work areas if there is not sufficient clearance provided. Inadequate clearance may also force some workers to adopt an awkward posture, thus causing discomfort and reducing productivity (Wickens & Gordon-Becker, 2014).

2.3.2. Reach Requirements of the Smallest Users

Workers often need to extend their arms to reach and operate a hand-operated device or to use their feet to activate a foot pedal. In opposite to the clearance problem, which sets the design limits at the largest users, reach dimensions should be determined on the basis of the reach capabilities of the smallest users (Wickens & Gordon-Becker, 2014). Dimensions for the smallest person, the 5th or 1st percentile, are used to determine reach dimensions (Bhattacharya & McGlothlin, 2012).

2.3.3. Adjustability Requirements

It is common to address a design range through designing adjustability, usually (but incorrectly) designated as the 5th percentile female through the 95th percentile male. The intention is to make sure a wide range of individuals can make use of the workspace (Delleman & Chaffin, 2004). People vary in many anthropometric dimensions, and their own measurements may change as a function. Because of the inconsistent needs of different people, it is often impossible to have "one size fits all" (Wickens & Gordon-Becker, 2014). Adjustability is an important issue (Hedge, 2017). Adjustability features should be user-friendly (Lehto & Landry, 2013).

Studies have shown that providing adjustable seats increases productivity and reduces complaints of shoulder and back pain. The problem is that workers are usually not aware of the adjustability features available on their chairs and seldom use the ones they know about (Sanders & McCormick, 1993). The problem with adjustability is that users may not use the adjustment facility if they do not expect a product to be adjustable or if they do not recognize the reason for incorporating adjustability into the product (Bridger R. , 2018).

There are many ways in which a workplace can be adjusted. The following summarizes four general approaches to workplace adjustment that should be considered in workplace design (Wickens & Gordon-Becker, 2014).

Adjusting the workplace: To achieve a good fit between the worker and the task the shape, location, and orientation of the workplace may be adjusted.

Adjusting the worker position relative to the workplace: When workplace adjustments are not practicable because they conflict with the requirements of other vital equipment or services or because they exceed budget constraints, designers may consider various ways of adjusting the working position with respect to the workplace. Change in seat height and use of platforms or step-up stools are some of the means of achieving vertical adjustability.

Adjusting the workpiece. Lift tables or forklift trucks can be used to adjust the height of a workpiece. Clamps, Jigs, and other fixtures can be used to hold a workpiece in a position and orientation for easy viewing and operation. Parts bins can help organize items for easier access.

Adjusting the tool: An adjustable-length hand tool can allow people with different arm lengths to reach objects at different distances. In an assembly plant, such tools can allow a worker to access an otherwise unreachable workpiece.

2.3.4. Visibility and Normal Line of Sight

How well something can be seen by the human eye is referred to as visibility. Visibility, therefore, involves human judgment. A human must always be involved in visibility determination; because there is no device that can measure visibility directly. One key factor influencing visibility of a target is how well it stands out from its background (Sanders & McCormick, 1993). The factors that affect good visibility are the same today as they were in 1900. These factors are visual size, color differences, luminance contrast, retinal image quality, and retinal illumination (Stanton & Hendrick, 2005).

A comfortable posture and viewing angle for a range of users in a range of operating postures, seated or standing. A comfortable viewing distance for the size of object and environmental conditions is necessary. Designers should guarantee that the visual displays in a workplace can be easily seen and read by the workers. This requires that the eyes are at appropriate positions with respect to viewing requirements. In this regard, the important concept of “normal” line of sight is of particular relevance (Wickens & Gordon-Becker, 2014). The viewing angle of surface must be approximately 90° to the line of sight and free from obstruction. Consider short and tall users. The display should be clearly and comfortably visible when the corresponding control is operated (Corlett & Clark, 2009). The visual requirements determine the position of the head and, therefore, the posture of the neck. According to Woodson, (1981) sited in Bridger, (2018) the eye is sensitive to stimuli up to 95° to the left and right, assuming binocular vision - 15° either side of the straight-ahead line of sight is the region of binocular overlap. These limits describe a visual field in which objects may be placed such that they can be viewed without moving the head from its comfortable upright position (Bridger R. , 2018).

The visibility of a target should not be a function of the observer; visibility should be a characteristic of the task itself (Sanders & McCormick, 1993). The eyes can comfortably deviate 15º right or left and up or down to direct the fovea to visual targets, providing a 30º visual field cone around the line of sight. If frequent changes of gaze between two equally important visual targets are equally critical, they should be situated within this 30º cone (Eastman Kodak Company[EKC], 2004). There are three aspects to visibility. The first is image clarity. The second aspect of visibility is the position of the display within the operator’s field of vision. The normal line of sight is not directly horizontal from the viewer, but is oriented at a 15° downward slope. The optimal location of a control panel would be a 45° angle to the angle of vision. The latter is the same as a 30° angle relative to the directly horizontal line of sight (Guastello, 2014). When the visibility of the information is inadequate, it is more effective to improve the legibility of the information than to increase the light intensity. Further increases in light intensity are meaningless when lighting is already intense. The legibility of information can be improved by enlarging the details (by using a larger typeface or smaller reading distance) or by increasing the contrast (black letters on a white background) (Dul & Weerdmeester, 2008).

2.3.5. Component Arrangement

To arrange the displays and controls, equipment and tools, and other parts and devices within some physical space is part of a workplace designer’s task. Depending on the capability of the user and the tasks in question, optimum arrangements can help a user access and use these components easily and smoothly (Wickens & Gordon-Becker, 2014). Ideally, we would like to arrange each component in an optimum location for serving its purpose. This optimum would be predicated on human capabilities and characteristics, including sensory capabilities, anthropometric and biomechanical characteristics. The optimum location would facilitate performance of the activities carried out in the space. Unfortunately, it is usually not possible to arrange each component in its optimum location (Sanders & McCormick, 1993). Ideally, work objects such as materials, tools, parts, controls, assemblies, and data input devices should be placed as close to the worker as possible at or near elbow height (Nordin & Pope, 2007). Careless arrangement can confuse the user and make the jobs harder (Wickens & Gordon-Becker, 2014). An important side of design is arranging components within some physical space. We arrange controls and displays on a control panel (Sanders & McCormick, 1993). Our capabilities are also limited by factors such as our size, and strength, reach distances, and so the physical arrangement of tools and other work artifacts is critical if we are to demonstrate maximum performance ability while minimizing the risks of accidents, errors, and injuries (Hedge, 2017). For safe operation of equipment, and to assist in correct posture the appropriate design, selection, arrangement and labeling of displays and control instruments is essential. A sensible layout of both displays and control instruments will make monitoring stress-free, reduce the risk of confusion caused by misreading, and decrease visual and postural strain (MacLeod, 2006). The general issue is to increase total movement efficiency and reduce overall movement distance, whether this is movement of the feet, of the hands, or of the total body through locomotion (Wickens & Gordon-Becker, 2014).

Principles of Arranging Components

List of component arrangement principles in the work place are: (Wickens & Gordon-Becker, 2014; Sanders & McCormick, 1993; Lehto & Landry, 2013)

Frequency of use principle: The most frequently used components should be placed in most convenient locations. Frequently used displays should be positioned in the primary viewing area; frequently used foot pedals should be close to the right foot, and frequently used hand tools should be close to the dominant hand.

Importance principle: Those components that are more important to the achievement of system goals should be located in the convenient locations. Based on their levels of importance for a specific application, displays and controls can be prioritized as primary and secondary. Primary displays should be located close to the primary viewing area, which is the space in front of an operator and 10° to 15° within the normal line of sight.

Sequence of use principle: Components used in sequence should be positioned next to each other, and their layout should reflect the sequence of operation.

Consistency principle. Components should be laid out with the same component placed in the same spatial locations to reduce memory and search requirements. Uniformity should be maintained both within the same workplace and across workplaces designed for similar functions.

Functional grouping principle: Components with closely related functions should be placed close to each other.

2.4. Design of Standing and Seated Work Areas

2.4.1. Choice between Standing and Seated Work Areas

In most job environments, workers either stand or sit during work (Wickens & Gordon-Becker, 2014). It is sometimes necessary to provide the opportunity to perform a job in either a standing or a sitting posture or to permit workers to alternate their postures. In such cases the work-surface height should permit a relaxed position of the upper arm, and the chair and footrest should permit such a posture (Sanders & McCormick, 1993).

Standing is usually used as a working posture if sitting is not possible, because the operator must exert large forces with the hands, the operator has to cover a large work area, or the work area requires mobility (Bush, 2012). Standing workplaces are usually used where the workers need to make frequent movements in a large work area, exert large forces with their hands, or handle heavy or large objects (Wickens & Gordon-Becker, 2014). Standing in one place should only be compulsory for a limited time period. Obliging someone to stand because the work area is placed high above the floor or outside the sitting reach areas is not a good justification (Bush, 2012). Standing operators often work in an area around a machine instead of at a given workplace. Even when the operator is free to move about, all handled items and controls should be positioned to eliminate excessive reaches, twisting the body, stooping and bending, and unnatural head positions because of visual requirements (EKC, 2004).

Prolonged standing is a strainful posture that puts too much load on the body and may lead to body fluid accumulation in the legs, a worker should not be required to stand for long time without taking a rest. Use of floor mats and shoes with cushioned soles may also help increase a standing worker’s comfort (Wickens & Gordon-Becker, 2014). Standing for the largest part of the working day is not advised (Hedge, 2017). According to McCulloch, (2002) sited in Hedge, (2017) shows that working while standing during the largest part of the day increases the risk of vein problems in the legs, lower back and feet problems, and premature birth.

Sitting down is a much less strenuous working posture than standing. Stabilizing the body while sitting down is easier because lesser muscles need to be contracted and the body benefits from the support of the chair. Sitting allows better control of hand movements, but the seated postures mean the capacity for force application with the hands is reduced. Sitting individuals can operate controls with their feet; however, the amount of force that can be exerted is considerably less than when standing (Bush, 2012). Whenever possible, a seated workplace should be used for long-term duration jobs, because a seated posture is much easier to maintain and much less of a strain to the body. It also allows for better controlled arm movements, delivers a stronger sense of balance and safety, and improves blood circulation. Workplace designers must make sure, however, that leg room (leg and knee clearance) is provided for the seated worker. Furthermore, prolonged sitting can be harmful to the lower back (Wickens & Gordon-Becker, 2014).

Humans are not biomechanically adapted for long-term static postures, whether it is sitting or standing. Therefore, sitting for prolonged periods of time can lead to lower back pain and foot swelling. Changing postures throughout the shift will reduce continued compression of the spinal column, as well as muscle fatigue. The ideal working area is right in front of the body at about elbow height, with the upper arms hanging. Visual requirements should also be considered when determining work area height (Bush, 2012).

2.4.2. Work Surface Height

In any workplace, work height is often a trade-off between a close view of the work and the need for precise movements and the freedom to perform gross movement and the capability to generate force (Bhattacharya & McGlothlin, 2012). Work surface heights should approximate the standing elbow height of workers depending on the task when carrying out fine work, a higher work surface is appropriate to reduce the visual distance and permit the worker to stabilize the forearms by resting them on the work surface. When carrying out heavy work, a lower work surface is needed to allow the worker to apply large vertical forces by transmitting part of the body weight through the arms (Bridger R. , 2018).

Appropriate design of the workplace is required to minimize awkward working posture. More specifically, the working surface should be at a height that allows a worker to work with the shoulders at the relaxed posture. It should be noticed here that the working height does not always equate to the work surface height. The former depends on what one is working on while the latter is the height of the upper surface of the table, bench, desk, and so on. Furthermore, to define the appropriate work surface height, one should consider the angle between the elbows and the wrists and the angles between the upper arms and the elbows. To increase comfort and minimize the occupational risks, the second of the two angles should be about 90^o if no force is required and a little bit broader if application of force is required. The wrists should be straight as far as possible in order to avoid carpal tunnel syndrome (Salvendy, 2012).

The nature of the tasks being performed should determine the correct work surface height for standing or seated work. Unless the job requires precise manipulation or great force application a simple but useful rule of thumb to determine the work surface height is to design standing working heights at 5 to 10 cm (2–4 in.) below elbow level and to design seated working heights at elbow level (Wickens & Gordon-Becker, 2014). The arm bent at a right angle at the elbow, is regarded as the best option for light work. If a higher degree of precision is necessary, then the working height should be slightly higher, permitting the worker to see exactly what they are doing without straining their neck. For heavier work containing physical exertion the working height should be lower (Berlin & Adams, 2017). For high precision work, tables should be up to 10 cm (around 4 in.) higher than the normal elbow height and for heavy work as much as 20 cm below normal elbow height (Lehto & Landry, 2013). The normal work height for seated tasks is about 5 cm below elbow height. This clearance provides a reasonably close view of the work while allowing movement not interfered with by obstructions on the work surface. This clearance can then be increased for more movement and force capability, and decreased, even to where work height is above elbow height, for precise physical and visual tasks. In this last case, it may be necessary to provide elbow support for prolonged tasks (Bhattacharya & McGlothlin, 2012).

2.5. Musculoskeletal Disorder

Musculoskeletal disorders (MSD) represent one of the leading causes of occupational injury and disability in the developed and industrially developing countries (Chakravarthy & Shekar, 2015). Studies have shown that workers whose jobs are physically demanding or are poorly designed from an ergonomics perspective are at significantly increased risk of developing work-related musculoskeletal disorders (WMSDs), such as low-back pain (LBP) and distal upper-extremity musculoskeletal disorders (MSDs) (Bhattacharya & McGlothlin, 2012). Musculoskeletal disorders (MSDs) are disorders and injuries that affect the musculoskeletal system of human body. Various musculoskeletal disorder (MSD) symptoms are experienced by the workers performing their activities in bad work postures which are largely static and consequently these are associated with long term risks and injuries. The disorder occurs when the body part is called on to work harder in bad work postures (Rahman & Ahmed, 2015). Musculoskeletal disorders (MSDs) is a health disorder caused by repetitive motion, inadequate working posture, excessive exertion of strength, body contact with sharp surface, vibration, temperature, etc (Inaki, 2011). Ergonomics seeks to prevent Work-Related Musculoskeletal Disorders (WMSDs) by applying principles to identify, evaluate, and control physical workplace risk factors (Stack & Wilhelmsen, 2016).

Musculoskeletal disorders (MSDs) are a class of disorders involving damage to muscles, tendons, ligaments, peripheral nerves, joints, cartilage (including vertebral discs), bones, and/or supporting blood vessels (Stack & Wilhelmsen, 2016). Occupationally related musculoskeletal disorders have been associated with exposure to excessive physical loads, repetitive movements, awkward postures, and vibration (Bhattacharya & McGlothlin, 2012). Work-related musculoskeletal disorders (WMSD) related with repetitive and demanding working conditions (Nunes, 2012). WMSDs are MSDs aggravated by working conditions. WMSDs are not typically due to acute events but occur slowly over time due to repeated wear and tear or microtraumas to the tissue (Stack & Wilhelmsen, 2016).

The World Health Organization (WHO), recognizing the impact of “work-related” musculoskeletal diseases, has characterized WMSDs as multifactorial, indicating that a number of risk factors contribute to and exacerbate these maladies (Bush, 2012; Nunes, 2012). The two most prevalent musculoskeletal problems are low back pain and upper-extremity (fingers, hands, wrists, arms, and shoulders) cumulative trauma disorders (Wickens & Gordon-Becker, 2014). WMSDs are also known as cumulative trauma disorders (CTDs), repetitive strain injuries (RSIs), repetitive motion trauma (RMT), repetitive motion injuries (RMI) or occupational overuse syndrome (Nunes, 2012; Stack & Wilhelmsen, 2016).

2.6. Work Study

2.6.1. Method study

Method study/Methods analysis focuses on how a task is accomplished. Whether controlling a machine or making or assembling components, how a task is done makes a difference in safety, performance, and quality. Using knowledge from ergonomics and methods analysis, methods engineers are charged with safeguarding that quality and quantity standards are achieved efficiently and safely (Heizer & Munson, 2017). Method study is a systematic approach to finding the best method (Slack & Johnston, 2013). Methods analysis is the study of how a job is done. Methods analysis is used by companies when developing new products or services and for improving the efficiency of methods currently in use (Reid & Sanders, 2013).

Methods analysis is done for both existing jobs and new jobs. For a new job it is needed to establish a method. The procedure usually is to have the analyst observe the job as it is currently being performed and then devise improvements for an existing job. The analyst must rely on a job description and an ability to visualize the operation for a new job (Stevenson, 2015).

A method is a prescribed procedure for performing a task or a job. It is a behavioral description of precisely what one does. Once the work requirements and purpose of a job are known, ergonomic specialists typically recognize what is done and record it. Photographs and/or videotapes frequently accompany method descriptions. Once the job is studied and a particular method is developed, that method is known as the standard method for a company. Ideally that method is the easiest to perform and teach to new personnel, requires the least time, results in the fewest errors, and provides the maximum safety. But methods that are optimal for all desirable criteria are rare, if they ever exist at all (Lehto & Landry, 2013).

2.6.2. Work measurement

Work measurement/time study is concerned with determining the length of time it should take to complete the job. Job times are vital inputs for capacity planning, workforce planning, scheduling, budgeting, estimating labor costs, and designing incentive systems. Moreover, from the workers' standpoint, time standards reflect the amount of time it should take to do a given job working under certain conditions. The standards include expected activity time plus allowances for probable delays (Stevenson, 2015). A time standard is defined as the time required to produce a product at a workstation with the following three conditions: (1) a qualified, well-trained operator; (2) working at a normal pace; and (3) doing a specific task (Stephens & Meyers, 2013). The standard time is the time it should take a qualified worker, operating at a sustainable pace and using the appropriate tools and process, to do the job. The standard time is the sustainable time it takes to do either a whole job or a portion or element of a job (Reid & Sanders, 2013). Time studies are the most widely used labor standard method (Heizer & Munson, 2017). A trained and experienced person can establish a standard by following these seven steps (Reid & Sanders, 2013; Heizer & Munson, 2017):

Step 1. Choose the job for the time study.

Step 2. Tell the worker whose job you will be studying.

Step 3. Break the job into easily recognizable units.

Step 4. Calculate the number of cycles you must observe. $n \geq \left[\left(\frac{Z}{a}\right)\left(\frac{s}{\bar{x}}\right)\right]^2$

Where n = the number of observations of an element that are needed

z = the number of normal standard deviations needed for desired confidence

s = the standard deviation of the sample

a = the desired accuracy or precision

x = the mean of the sample observations

Step 5. Time each element, record the times, and rate the worker’s performance.

Step 6. Compute normal time. NT = (MOT) (PRF) (F)

Step 7. Compute the standard time. ST = (NT) (AF)

Where:

MOT = Mean Observed Time

NT = Normal Time

AF = Allowance Factor

PRF =Performance Rating Factor

F = Frequency of Occurrence

2.7. Ergonomics and Work Study Relationship

Work study is based on principles and techniques of scientific management developed by Fredrick Taylor. It is based on the analysis of operations using method-time- motion study on elements of the task/activity. Fatigue factor is provided by standard allowance to develop the production rate whereas ergonomics/human factors approach uses physiology & biomechanics to identify fatigue factors that are neutralized by engineering & administrative controls. The approach of human factors is the systematic application of relevant information about human capabilities, characteristics, limitations, behavior, and motivation to the design of things and procedures people use and the environment in which they use them. This involves scientific investigation to discover relevant information about human beings and their responses to things, procedures, equipment, and work environments, etc. The human factors approach also involves the evaluation of the things designed to ensure that they satisfy their intended purpose (Iqbal & Samsuzzoha, 2011).

The job may be restudied, comparing the initial standard to alternative methods and either the initial standard is retained or a new standard is developed. Restudies take place when new equipment is purchased that alters one or more tasks. The personnel who perform the jobs normally suggest many potential methods, and many companies encourage such suggestions with financial rewards commensurate with the cost savings. Other possible methods are generated by the ergonomics personnel. Since the same staff often evaluates all of the alternative methods, it is important that the staff exercises professional ethics and evaluates all proposed methods with objective fairness. These evaluations typically need empirical tests to be run on the various methods and measurements to be made on each criterion of concern (Lehto & Landry, 2013).

2.8. Summary of literatures

Table 2. 1: Summary of key articles on the Ergonomics and work study

S/N	Authors	Title	Problem	Objective	Methods	Finding
1	Poh Kiat Ng and Kian Siong Jee (2016)	Design and Development of an Ergonomic Milling Machine Control Knob using TRIZ Principles	It is Difficult to Turn the Milling Machine Control Knob	aim of the study is to generate a solution for this problem and occupational injuries and reduce occupational musculoskeletal	Theory of Inventive Problem Solving (TRIZ) and new ergonomic knob is designed and developed	new ergonomic milling machine control knob was able to reduce the amount of pinch force by about 72% for males and 55% for females compared to the original knob

				disorders of the users and increase their productivity		
2	Aide Maldonado-Macias, Maria Guadalupe Ramírez, Jorge Luis García, Juan José Díaz, and Salvador Noriega (2009)	Ergonomic Evaluation of Work Stations Related With the Operation of Advanced Manufacturing Technology Equipment: Two cases of study	presence of pain and discomfort among workers is observed when this equipment is operated	To apply anthropometric and ergonomic principles and methods in two work stations	video camera was used to record and take photos to the worker to identify stressful body postures; also a measurement tape and a computer to run REBA commercial software	risk level is medium for both operations (lathe and Milling) the milling machine workstation, the right wrist is the most affected the lathe workstation most affected body parts are the trunk and legs
3	Jerzy Józwik1, Paweł Pietras (2013)	Investigation and assessment of occupational risk On the metal cutting machine tool stand	increasing risk of accidents at turning, milling, drilling and grinding stands	to minimize hazards at the turning, milling, drilling and grinding stands	qualitative and quantitative	lack of protection against chips and fast rotating elements breaking off a machine or tool, which can cause grave injuries, cuts, or even death
4	Isa Halim, Ab. Rahman Mahmood, Hazmilah Hasan, Haeryip Sihombing, Adi Saptari, Baharudin Abu Bakar, Syaheera Ahmad (2014)	Ergonomic Design of CNC Milling Machine for Safe Working Posture	the existing CNC milling machine has contributed to ergonomics-related problems such as awkward working posture	to redesign the existing CNC milling machine by considering working posture of the machinist	The study is performed using questionnaire survey to determine ergonomics feature requirements from the machinist	this study pointed that the Machinists wanted adjustable facilities for working platform, control panel, and tool holder in the future design of CNC milling machine.
5	Aman Sachdeva, B.D.Gupta, Sneh Anand (2011)	Minimizing Musculoskeletal Disorders in Lathe Machine Workers	various musculoskeletal disorders within the workers	minimizing musculoskeletal disorders for lathe machine workers of automobile industry	the minimization of musculoskeletal disorders problem has been formulated using fuzzy technique	The ligaments of the shoulder muscle as well as of the low back muscles are the major effected muscles among lathe machine workers
6	Cengiz Duran, Aysel Cetindere, Yunus Emre Aksu (2015)	Productivity improvement by work and time study technique for	Sources declined with each passing day, constantly increasing needs.	To determine whether or not the molds used for producing glass cups comply with	Observational method is used to collect data	waiting time cause inefficiency in the work of molder and in the content of work/time, efficiency is increased 53 percent

		earth energy-glass manufacturing company		efficiency principles		
7	Sujay Biswas, Abhijit Chakraborty, Nabanita Bhowmik (2016)	Improving Productivity Using Work Study Technique	The company cannot reach at the deadline of the customers	To reduce work in progress inventories and also to diminish the waste of available resources	The research method is observation	Standard times and standard method
8	Megh Patel, Nisarg Patel, Harsh Patel, Yash Patel (2015)	A Review on concepts of Work-Study for Productivity Improvement	Challenge of competing with respect of productivity, quality, cost, delivery and so on.	To present an overview on various methodologies which can be used for improvement of productivity in small and medium scale industries.	Work-study concepts with Lean manufacturing tools, kaizen problem solving concept and cell manufacturing technique	These would result more effective for controlling various aspects in an industry with assured profit margins
9	M. P. Singh, Hemant Yadav (2016)	Improvement In Process Industries By Using Work Study Methods: A Case Study	great challenge to the Indian small industries in respect of productivity, quality, cost, delivery etc.	To reduce in process time, labour cost and production cost	Observation	The plant is not using optimum layout
10	Prathamesh P. Kulkarni, Sagar S. Kshire, Kailas V. Chandratre (2014)	Productivity Improvement Through Lean Deployment & Work Study Methods	Less productivity	To present an overview on a new combined methodology for the efficient improvement in productivity with the help of various Work Study Methods associated with Lean Manufacturing Principles & Tools.	Work Study Methods associated with Lean Manufacturing Principles & Tools	Critical lean tools when effectively combined with Work Study Methods, a unique leaner system can be formed which will be the universal solution for any type of industry having any sort of problem regarding the productivity.
11	Md. Abdul Moktadir, Sobur Ahmed,	Productivity Improvement by Work Study	Bottleneck	To identify the bottleneck and suggest	Direct observation, critical questioning technique	Increase productivity to 12.71% with reduction of work

	Fatema-Tuj-Zohra1 and Razia Sultana (2017)	Technique: A Case on Leather Products Industry of Bangladesh		appropriate system to improve productivity.		content and line balancing.
12	Mohd Razali Muhamad & Wan Hasrulnizzam Wan Mahmood (2005)	Productivity Improvement Through Motion and Time Study	Inconsistent production volume, High operator turnover, Resource constraint, and Workers' skill and attitude	To discuss related issues of motion and time study implementation and its influence toward productivity improvement.	This study was undertaken by semi-structured interviews and questionnaire survey.	The companies implementing motion and time study face many challenges such as cooperation from workers, followed by inexperienced project leader, unavailability of relevant consultant, staff training and lack of inter departmental cooperation

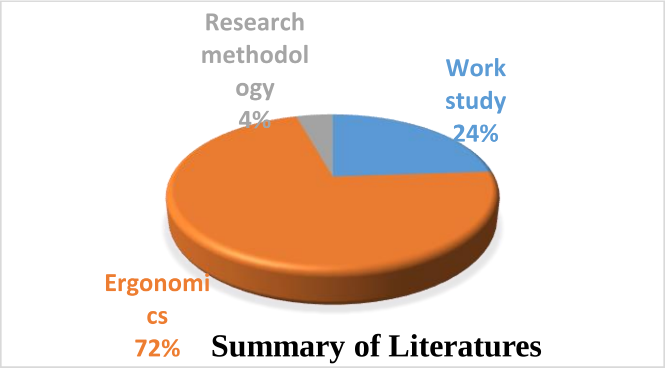

Figure 2. 1: Reviewed literatures based on titles

The reviewed literatures are form ergonomic 72% from work study 24% and from research methodology4% as shown in figure 2.1.

2.9. Literature Gaps

Regarding workplace design redesign lathe and milling workstation there are some researches. Their findings show that ergonomic designing of workstation improves productivity, quality and well-being of operators. Few researches on this example Józwik1& Pietras, (2013); Sachdeva et al., (2011); Maldonado-Macias (2009); Kiat Ng and Siong Jee, (2016). Conducted on lathe and milling. Accordingly by, example, Józwik1& Pietras, (2013) deals with Investigation and assessment of occupational risk on the metal cutting machine tool stand. Sachdeva et al., (2011) focuses on Minimizing Musculoskeletal Disorders in Lathe Machine Workers. Maldonado-Macias (2009) Ergonomic Evaluation of Work Stations Related with the Operation of Advanced

Manufacturing Technology Equipment: CNC lathe and milling machines. Kiat Ng and Siong Jee, (2016). Give attention on Design and Development of an Ergonomic Milling Machine Control Knob using TRIZ Principles. Their findings indicate that lack of protection against chips and fast rotating elements breaking off a machine or tool, which can cause grave injuries, cuts, or even death.(Józwik1& Pietras, 2013), The ligaments of the shoulder muscle as well as of the low back muscles are the major effected muscles among lathe machine workers (Sachdeva et al., 2011), risk level is medium for both operations (lathe and Milling) the milling machine workstation, the right wrist is the most affected the lathe workstation most affected body parts are the trunk and legs (Maldonado-Macias, 2009) and new ergonomic milling machine control knob was able to reduce the amount of pinch force by about 72% for males and 55% for females compared to the original knob (Kiat Ng & Siong Jee, 2016). This implies that the workstations have ergonomic problems that lead Work-related musculoskeletal disorders. On the other hand others did on work study like Improving Productivity Using Work Study Technique by (Sujay Biswas et al., 2016) and Productivity improvement by work and time study technique for earth energy-glass manufacturing company (Cengiz Duran, et al., 2015).

The present topic is on Integration of Ergonomic and Work Study to Redesign J-Bolt Production Line. From these none of them integrate ergonomics and work study, some of them worked on ergonomics of machines and the other worked on work study so the difference exist is that they do not integrate ergonomics and work study, similarly they did on single machine this one is on production line including transporting, the other is that the objective and tools are also different. For these above reasons the researcher was motivated to conduct the study on the integration of ergonomic and work study and to propose possible recommendation.

Chapter Three

3. Research Design and Methodology

Ferric belt metal processing and engineering factory is located in the south-western of the capital city of Ethiopia; Addis Ababa, in a town called Alemgena, which is 20Kms from Addis Ababa.

The factory is established in 2009 with an initial capital of 12 million Birr and built in an area of 5000 m^2. It starts production in full capacity in 2011. It processes different metals lime steel structure, steel bridges, steel reservoirs and etc.

3.1. Research Design

Research design is a master plan that specifies the methods and procedures for collecting and analyzing the needed information. A research design provides a framework or plan of action for the research (Zikmund & Griffin, 2009).

There are different research designs. For this study, a descriptive case study design was used. According to Kothari, (2004), a descriptive design is a type of research design which is description of the state of affairs as it exists at present. To get full information and understanding of the work area and working life of the workers, mixed method of data collection and analysis that is qualitative and quantitative data was collected and analyzed.

3.2. Participants of the Study

For this study, the participants were selected from Ferric Belt Metal Processing and Engineering Factory. The reason for making them participants was that they were working on the line. Therefore, they were expected to provide relevant data.

3.3. Sample Size and Sampling Techniques

3.3.1. Sample size determination

At the J-Bolt manufacturing line, there were a total of 150 workers (employees) from whom the researcher selected the participants. Sample size was determined based on the following formula.

$$n = \frac{z^2 \times p \times q \times N}{e^2(N-1) + z^2 \times p \times q}$$

Where

N = size of population

n = size of sample

e = acceptable error (the precision)

p = sample proportion, q = 1 – p;

z = the value of the standard variate at a given confidence level

N = 150

e = 5% = 0.05

z = 1.96 (as per table of area under normal curve for the required confidence level of 95%)

Taking the value of P = 0.5 in which case ‘n’ be the maximum and the sample yield at least the desired precision. This is the most conservative sample size (Kothari, 2004).

$$n = \frac{z^2 \times p \times q \times N}{e^2(N-1) + z^2 \times p \times q} = \frac{1.96^2 \times 0.5 \times 0.5 \times 150}{0.05^2(150-1) + 1.96^2 \times 0.5 \times 0.5}$$

$$= 108.08 = 109 \; sample\ size$$

Thus, according to the above formula the number of respondents was 109. Those 109 respondents were selected randomly by using simple random sampling technique based on the proportionality to their population size from sections. Accordingly, from cutting section 24, machining section 11, welding section 53, and from assembling section 19 respondents were selected respectively.

3.4. Types and sources of data

For this study both qualitative and quantitative data types were employed from both primary and secondary data sources.

3.4.1. Primary data sources

The primary data were collected from shop floor workers, and direct observation of the work flow.

Here the primary data had been checked against the secondary data and vice versa in addition to bringing forward new and supplementing information.

3.4.2. Secondary data sources

The required secondary data were collected from diverse sources: those were from ferric belt metal processing and engineering factory records, literatures and websites etc.

3.5. Tools and methods of data collection

3.5.1. Questionnaire

A questionnaire is a list of questions presented to prospective respondents. The purpose is to collect information and sometimes to measure statistical accuracy. Since a large number of questionnaires can be distributed and the results can be easily summarized, the principal appeal of this technique is relatively low cost in quickly gaining access to many people.

The researcher prepared the questionnaire and distribute to the shop floor workers to get the response of them on theirs working activity, working condition and on degree of pain (WMSD) at different parts of their body. The purposes of the questionnaire were to assess the awkward postures, material handling conditions, environmental problem and degree of pain at different body parts.

3.5.2. Direct Observation

One of the most useful data collection methods is to observe operators at the existing working condition. The researcher used observation to record the sequence of activities, duration of activities, frequency of activities, and movement of the operators' body. And also to map the flow of work using process flow chart similarly to conduct time study using stopwatch the researcher used observation. This method was also used to take photo/video of operators' during operation of the machines for ergonomic analysis of the tasks. To measure the anthropometric dimension and the size of the workstation the researcher used measuring tape.

3.5.2.1. Tools for observation

Stopwatch: is used to develop a time standard based on observations of one worker taken over a number of cycles.

Video/photo camera: used to take photo/record working postures of operators for ergonomic analysis and the working procedure of the work to analysis the process flow.

Measuring tape: is used to measure different dimensions of the work area as well as operators.

3.5.2.2 Formulas for observation

Calculate the number of cycles you must observe. $n \geq \left[\left(\frac{Z}{a}\right)\left(\frac{s}{\bar{x}}\right)\right]^2$

Where n = the number of observations of an element that are needed

z = the number of normal standard deviations needed for desired confidence

s = the standard deviation of the sample

a = the desired accuracy or precision

x = the mean of the sample observations

Normal time. NT = (MOT) (PRF) (F)

Standard tune. ST = (NT) (AF)

$$ST_{each\ work\ element} = NT\left(\frac{1}{1-0.15}\right)$$

3.6. Method of Data Analysis

In this study, both qualitative and quantitative data collected were analyzed by using statistical tools such as tables, percentages, and graphs. Besides that, to compare the existing and proposed working system Arena simulation software was used. Finally, the data were interpreted in order to draw conclusion and to offer recommendations.

3.7. Research Methodology Framework

Research methodology and procedure that this study followed is illustrated in figure 3.1. The process starts with defining the problem and ends with conclusion and recommendation.

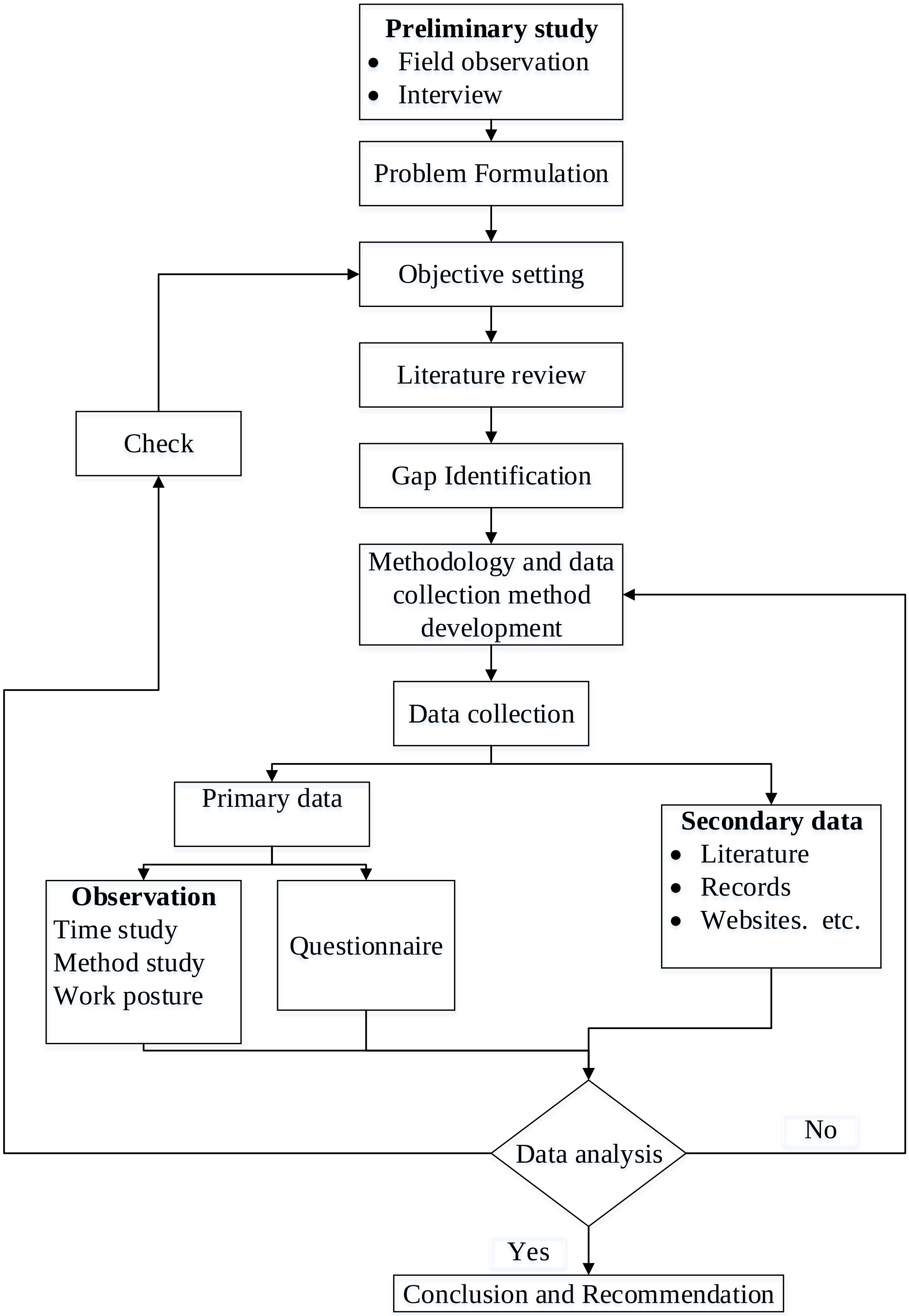

Figure 3. 1: Research methodoldogy framework

Chapter Four

4. Result and Discussion

The chapter presents the background information about respondents, analyze and discuss the data obtained through direct observation at shop floor and through questionnaire from the shop floor workers. Accordingly, the chapter is divided into four sections. The first section deals with the background information of the respondents. The second section is about awkward working postures at the work area. The third section deals with the workers injury at work or WRMSD. The fourth section is about work study that is standard working method and standard time.

4.1. Background Information of the Respondents

The researcher was designed questionnaires to assess the ergonomic problem workers are facing in their work area. The questionnaires was distributed to 109 shop floor workers of Ferric Belt metal processing and engineering factory out of which 94 questionnaires were retuned.

Table 4. 1: Response rate of questionnaire for each section

Sections	No. distributed	No. returned	% response
Cutting section	24	20	83.33%
Machining section	11	9	81.81%
Welding section	53	47	88.67%
Art metal section	21	18	85.71%
Total	109	94	86.24%

Source: respondents result

As can be observed from table 4.1 the response rate of questionnaire for cutting section 83.33% for machining section 81.81%, for welding section 85.71% and for 86.24%. So the total response rate is 86.24% that is very good response rate so it is representative.

4.2. Awkward working postures

4.2.1. Cutting machine workstation

Operation of line starts when the worker grasp the bar on the ground. The input for the cutting machine is reinforcement bar. There are two workers in cutting workstation. One to peak and setup workpiece on the machine and the other operate the machine. This bar is cut to required length (45± 4 cm) to be turned on lathe. To cut it the worker picks the bar that is laying over each other irregularly on floor as shown in figure 4.1. The worker stands over the laid bar and lean forward all the time to grasp and pick it this have negative effects on the worker physical workload, health and overall performance. Leaning forward cause tension in the lower back muscles as they act to maintain equilibrium. As the operator bend forward the neck bend backward that causes pain on the neck, shoulder and back due to awkward working posture.

Figure 4. 1: when worker picks the work piece (Filed survey)

The second worker operate the cutting machine that is performed by sitting on the chair as we can see from figure 4.2 most of the time operator's hand is above the Shoulders to grasp and drop down the cut workpiece. As we can observe from figure 4.2 (left) the chair seat is not comfortable.

Figure 4. 2: Cutting station operator on chair (Left) and Cutting station chair (Right) (Filed survey)

The worker working area is 66 cm forward to reach the working area which is above the maximum working area recommended for right hand that is 50.8cm according to [EKC] 2004) so to reach this area the worker should bend forward. All of the working time of a day the worker is bend forward this lead to adoption of static postures, sitting and forward bending positions for long periods of time that straining muscles, ligaments, and discs, which are also well-known risk factors for low back pain. When forward bending the backrest of the chair is no longer used. Also the hands of the worker stretches forward that makes the hand straight which makes the angle at elbow more than 90^0 which is awkward and exposes forearm and upper arm for more fatigue and that reduce productivity of the worker. Prolonged sitting or forward bending leads to increased risk of low back pain and muscle fatigue.

Table 4. 2: Cutting machine workstation dimensions

No.	Items Measured	Height above the floor
1	Chair seating height	46 cm
2	Working height	95 cm
3	Forward reach distance	66 cm

***Source*:** Measurement taken at cutting workstation by the researcher

The working height of cutting station is 95 cm which is above the 95th percentile working height of men that is 91 cm and the average of seating working height is 83 cm.

4.2.2. Transporting from cutting to Lathe station

As anyone can understand from Figure 4.3 when the worker grasp and pick the workpieces placed on ground at cutting workstation to transport to lathe workstation. As we can observe from the figure the worker leans forward until reaching the ground. The worker neck bends backward. This is the awkward the worker is facing. This reduces productivity, comfort and wellbeing of the operator as the works performing the activity regularly. The worker is support equilibrium by placing his left hand on left leg. In this activity there is repetitive movement, this obviously increases the stress on these muscles and joints that can cause WRMSD. As worker leans forward postural stress like compression of abdominal contents and intervertebral discs and stretching of the posterior spinal ligaments this lead to fatigue.

Figure 4. 3: Worker grasping the material from cutting station (Field survey)

This production line has no mechanical material handling device due to this the workers transport materials on shoulder as we can see on figure 4.4 when transporting from Cutting station to Lathe station. During this transporting carry on his right shoulder and his neck bends to the left away from normal and the left and right hands come the right shoulder which is awkward posture and trunk also twist from normal.

Figure 4. 4: Worker transporting material from cutting to lathe station (Field survey)

This type of transporting material exposes to wastage of time and energy as well as reduce productivity of the worker due to fatigue and loss of time. This expose the works for MSD. Compered to mechanical material handling tools transporting on shoulder like this is smaller quantity. For the three lathes the average transporting distance 10.67m due to low quantity carried at a time is small this activity is repetitive. As this activity is repetitive and awkward causes ergonomic problem and consumes more time relative to mechanical handling.

4.2.3. Lathe machine workstation

The existing lathe machine control switch height is 77 cm, Spindle clutch lever is 66 cm high, carriage handwheel lever is 67 cm and Cross slide handwheel is 90 cm high. All of these dimensions are lower than the minimum height for the work surface during standing tasks that is 100 cm, according to [EKC] 2004 and also below elbow height of average man and woman which is 109 cm and 100.5 cm respectively. Due to this the operator of the machine bends forward all the working time. In principle to visualize controls of a machine the head and trunk upright and forward facing. When the worker stands at the middle he should bend lateral to left and right to reach the Spindle clutch lever and control switch. Which exposes the worker for ergonomic rick because it involves lateral bending and twisting of the trunk.

Table 4. 3: Lathe machine workstation dimensions

No.	Items measured	Height above the floor
1	Control switch height	77 cm
2	carriage handwheel	67 cm
3	Spindle clutch lever	66 cm
4	Cross slide handwheel	90 cm
5	Material to be process storage table	72 cm
6	Processed Material storage table	23 cm

Source**:** Measurement taken at lathe workstation by the researcher

The working height 5-10 cm blow elbow height is optimal working height.

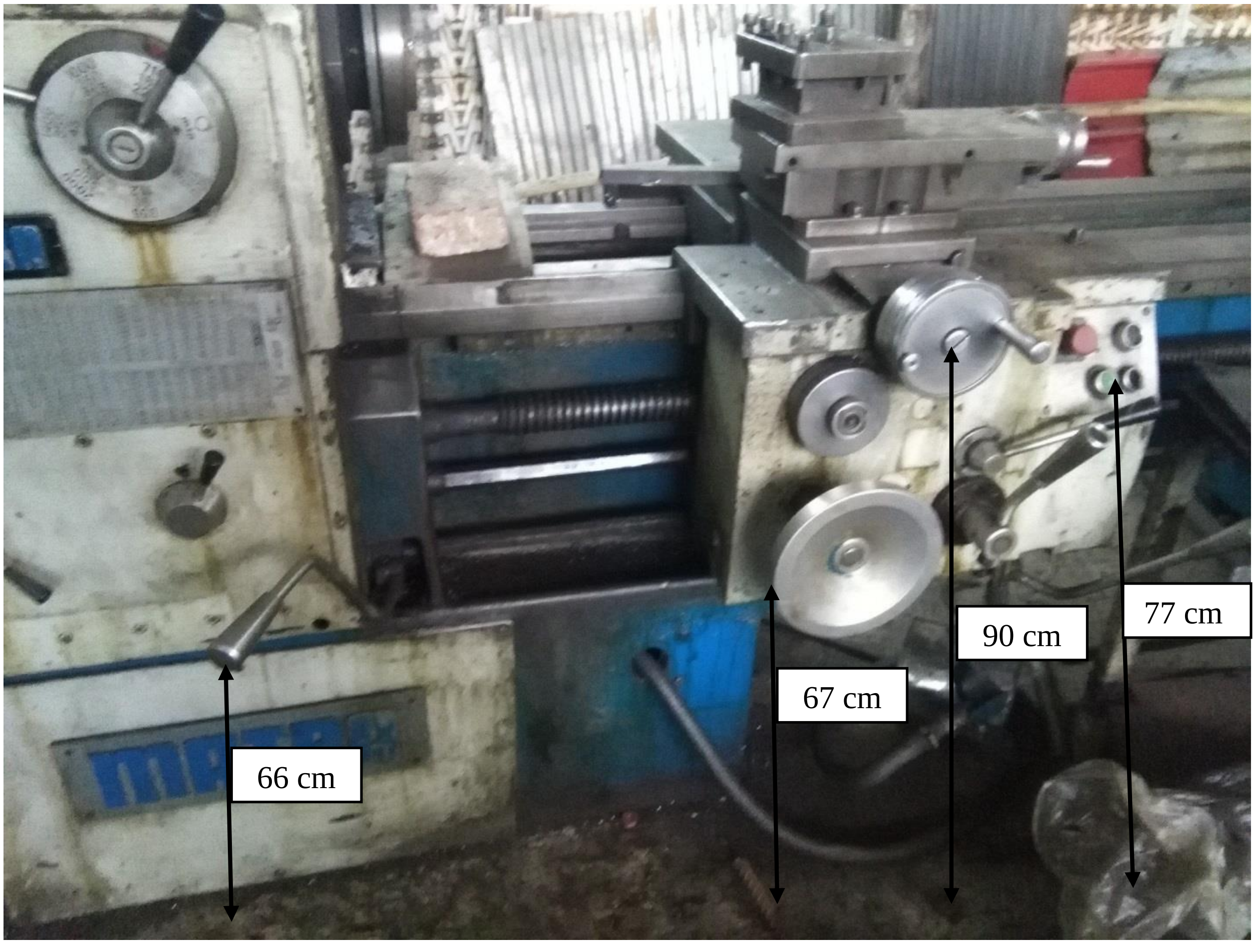

Figure 4. 5: Existing lath working height (Field survey)

At lathe station the cut workpiece is turned one of its end to be ready for threading. During this operation the worker take the workpiece from table 72 cm high, turn the workpiece on the lathe and bends side ward to place the turned workepiece under table that is 23 cm high as can be observed from Figure 4.6. The operator perform this work cycle at least 250 per day that is bend side way at least 250 time a day. Bending side increases the risk for injury. During this lateral bending to reach the lower height the operators stand on one foot or twist their trunk.

Figure 4. 6: worker puts turned workpiece on lower table (Field survey)

This work method exposes the workers for WRMSD that is health and comfort of operators. That also reduce productivity of the workers due to fatigue and wastage of time and energy for bend side for long reach. Lateral bending, or twisting increases muscle stress and intervertebral disc pressure. Lateral bending produced more discomfort and appears to be the least well-tolerated posture.

The rotating parts of the machine, chuck has no guard. The chips from the machine hits the operator and burn the operator skin and creates minor injury and reduce the comfort and safety of the operator.

4.2.4. Transporting from Lathe to Threading station

In transporting from lathe station to threading station as there is no mechanical material handling human labor is used for carrying the material as can be view from figure 4.7. As we can observe and understand from the figure the load is on the right hand than left hand and to support the left hand turned to right that cause trunk to twist.

Figure 4. 7: worker transporting material from lathe to threading station (Field survey)

4.2.5. Threading workstation

At this workstation the turned end of the bar is threaded. During this operation the operator takes the workpiece from the coolant under the machine by bending lateral left, twisting and setup the workpiece on the machine and make ready for the operation as shown on figure 4.8. Side bending and twisting is major source of lower back pain and intolerable awkward posture. At this workstation work is conducted by sitting on not adjustable chair. Trunk rotation (twisting) or lateral bending should be avoided when lifting as it increases the risk for injury.

Table 4. 4: Threading machine workstation dimensions

No.	Items measured	Height above the floor
1	Chair height	56 cm
2	Working height	85 cm
3	Material delay in coolant	40 cm
4	Forward reach distance	72 cm
5	WIP storage table	72 cm
6	Control switch height	45 cm

***Source*:** Measurement taken threading workstation by the researcher

At this work station the seat chair height is 56 cm and not adjustable, working height is 85 cm which is 50th percentile working height and forward reach distance is 72 cm which is beyond the maximum reach distance that is 50.8cm. Similarly the work station has no room for worker knee due to this the worker should bend forward.

Figure 4. 8: worker operate threading machine (Field survey)

Control switch

The control switch of the threading machine is located at 45 cm above the floor which is blow chair height of the working station that is 56 cm. due to this the worker should bend to side and stretch his hand to reach the control switch blow his knee which is awkward so it leads the workers to WRMSD which reduce productivity and comfort of worker.

As we can observe from figure 4.9 the stop and Revers control switch of the machine have the same color that is red. This led the worker to confusion and can cause error that can lead to product frailer or worker injury. Which have negative effect on quality and productivity of the station.

As the control switch is located below the working table and below the height of the seating chair it is not visible to the worker because it is located out of prime operating space, which is out of a 30º visual cone.

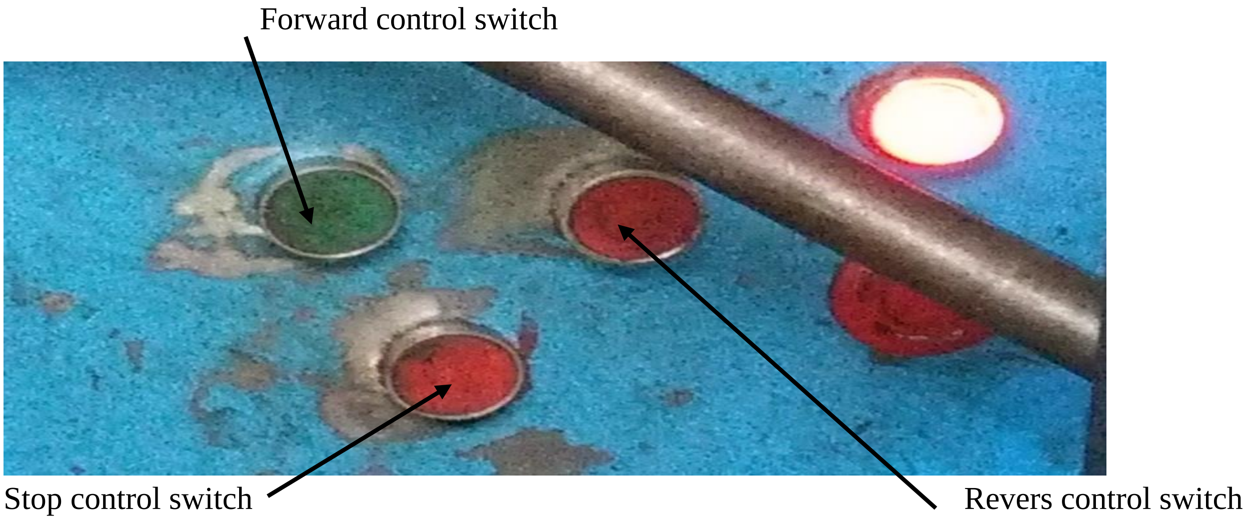

Figure 4. 9: Threading machine control switch (Field survey)

4.2.6. Bending workstation

At this bending workstation the cut, turned and threaded bar is bent as J to make J-bolt. This workstation is a seat work station that is it performed by seating on chair.

As can be viewed from figure 4.10 even though the workstation is seated workstation it has no clearance for leg for the operator. Due to this the operator bends forward because he knee pushes the machine body.

The seat chair height is 68 cm and is not adjustable this is above the maximum siting height/Popliteal height of the 95th percentile man which is 49 cm. As the height of the seat increases beyond the popliteal height of the user, pressure will be felt on the underside of the thighs. This resulting in reduction of circulation to the lower extremities may lead to ‘pins and needles’, swollen feet and considerable discomfort. As can be observed from figure 4.11 the chair is not suitable for siting for long time because it is not comfortable due to the sitting surface is flat wood only and the back support is flat strip welded on round pipe.

The working height is 75 cm above the floor which is 9 cm above chair height which is 3.5 cm below 5th percentile women that is 12.5 cm above seating height of this class and 20.5 cm below 95th percentile men that is 29.5 cm above seating height. As we can understand from this, this workstation is not designed ergonomically. Similarly the forward reaching distance of this work station is 70 cm which is above the maximum allowed reach distance that is 50.8 cm this lead the worker to bend forward and over stretch forward.


[redacted]

Figure 4. 10: Worker operating bending machine (Field survey)

Table 4. 5: Bending machine workstation dimensions

No.	Items measured	Height above the floor
1	Chair height	68 cm
2	Working height	75 cm
3	Forward reach distance	70 cm
4	WIP storage table	72 cm
5	Control switch height	58 cm

Source**:** Measurement taken bending station

Figure 4. 11: Bending workstation chair (Field survey)

Control switch

Figure 4.12 is the photo of control switch of bending machine. As can be viewed forward and revers control switch color is the same which is green that can cause confusion to the operator which lead to error. This error can cause product defect and also human injury that affect negatively the productivity and quality of the work station.

The control switch of this machine is 58 cm height above the floor which is 10 cm below the chair height of the work station. Due to this the worker should bend forward and stretch his hand below knee that is awkward working posture. As this activity is performed for all the time during the working hours this can lead to WRMSD.

The control switch of this machine is under the working table and out of visual cone of 30^0 but in principle control switches should be placed in front of the operator in forward facing at prime operating region.

Figure 4. 12: Bending machine control switch (Field survey)

4.2.7. Assembly workstation

There are two workers employed for assembling the bolt and nut. At this assembly station the manufactured J-Bolt and the purchased nut is assemble with the workers manually. At this workstation the workers are sitting on a chair that is shown in figure 4.13 which is 28 cm high above floor which is below 5th percentile women popliteal height that is 35.5 cm. As sitting height decreases the user will (1) tend to flex the spine more (due to the need to achieve an acute angle between thigh and trunk); (2) experience greater problems in standing up and sitting down, due to the distance through which his or her center of gravity must move; and (3) require greater leg room.

Figure 4. 13: Assemble area Chair (Field survey)

The work is preformed through taking J-bolt and nut placed on the ground so the worker should bend forward frequently. This lead to lower back pain as it is repetitive and awkward that is the angle between trunk and thigh is acute that is it is not normal, the seating height is low, and the parts are taken from the ground this causes to fatigue and reduce productivity and also the well-being of the workers is in risk.

Taking the parts through bending forward from ground takes longer time so that it reduces productivity of workers. The working method has ergonomic and method problem that has avoidable waste and considerable ergonomic problem that require the redesign of the workstation for better work method and ergonomic postures that can improve productivity and wellbeing of the works.


[redacted]

Figure 4. 14: Assembly workstation and workers on assembling (Field survey)

Response from questionnaire

Table 4. 6: Workers response on working postures

Questions	**Yes**		**No**	
	Number	**Percentage**	**Number**	**Percentage**
Is there frequent or prolonged bending down where your hands pass below mid-thigh height?	80	85.11	14	14.89
Is there frequent or prolonged reaching above your shoulder?	76	80.85	18	19.15
Is there frequent or prolonged bending due to an extended reach forward?	78	82.98	16	17.02
Is there frequent or prolonged twisting of your back?	84	89.36	10	10.64
Are awkward postures assumed frequently or over prolonged periods, that is, postures that are not forward facing and upright?	94	100	-	0
Do you have a way of operating the machine by alternate position siting, standing/walking?	34	36.17	60	63.83
Do the workstations have way of adjusting for different body sizes? E.g. Height	-	0	94	100

Source: Respondents result

Table 4.7 indicate that 80(85.11%) of the respondents respond that they bend down their hand pass blow mid-thigh height and 14(14.89%) of them respond that they do not bend down during their work. In addition 76(80.85%) of the respondents responds that during their work there is frequent or prolonged reaching above their shoulder and 18(19.15%) of them respond that during their activity there is no frequent and prolonged reaching above their shoulder.

Similarly, 78(82.98%) of the respondents respond that there is frequent or prolonged bending due to extended forward reach and 16(17.02%) respond that there is no frequent or prolonged bending due to extended forward reach. In addition 84(89.36%) is the respondents respond that there is frequent or prolonged twisting of their back and 10(10.64%) of them responded that there is not frequent or prolonged twisting of their back.

All of them (94) respond that there is awkward postures at their work area. Again 60 (63.83%) of the respondents respond that they cannot work by alternating position of work sitting, standing and walking and 34(36.17%) respond that they can perform their activity in alternate position. Then the other is that 94 (100%) of the respondents respond that their work area is not adjustable for different body size workers. This show that there is awkward posture that lead to fatigue and WRMSD.

Table 4. 7: Response of respondents on Material handling

Questions	Yes		No	
	Number	**Percentage**	**Number**	**Percentage**
Is manual handling performed frequently or for long time periods by you?	70	74.47	24	25.53
Are loads moved or carried over long distance?	72	76.60	22	23.40
Is the weight of the object:				
More than 4.5 kg and handled from a seated position?	72	76.60	22	23.40
More than 16 kg and handled in a working posture other than seated?	60	63.83	34	36.17
More than 55kg?	68	72.34	26	27.66
For pushing, pulling or other application of forces, are large pushing/pulling forces involved?	78	82.98	16	17.02
Is the load difficult or awkward to handle, for example, due to its size, shape, temperature, instability or unpredictability?	54	57.45	40	42.55
Is it difficult or unsafe to get adequate grip of the load?	64	68.09	30	31.91

Source: Respondents result

Table 4.8 is the response of workers on the material handling. As shown in the table 70 (74.47%) of them respond as they handle manually materials frequently or for long time and 24 (25.53%) respond as they did not handle material manually. On the other hand 72 (76.60%) carried load over a long distance and the rest 22 (23.40%) did not move materials over long distance.

Similarly 72 (76.60%) of workers respond that they handle a load more than 4.5Kg on seated position, 60 (63.83%) respond as they handle 16Kg load at working posture other than seated and 68 (72.34%) respond that they handle material more than 55 Kg.

In addition 78 (82.98%) as they exert larger force for pushing, pulling or other application of force on the other hand 54 (57.45%) respond that the load handled is awkward to handle due to its size, temperature, shape etc. and the rest 40 (42.55%) respond that they did not handle a load that is difficult or awkward to handle. Similarly 64 (68.09%) respond that the load handled is difficult or unsafe to get adequate grip and the rest 30(31.91%) respond that the load handled is not difficult or un safe to get adequate grip. From this we can understand that the workers carry a large load over long distance that its handling is difficult this can lead to injury of workers.

Table 4. 8: Response of respondents on Work environment

Questions	**Yes**		**No**	
	Number	**Percentage**	**Number**	**Percentage**
Is the task performed in a confined space?	46	48.94	48	51.06
Is the lighting inadequate for safe manual handling and working?	64	68.09	30	31.91
Is the work environment particularly cold or hot?	76	80.85	18	19.15
Are the floor working surfaces cluttered, uneven, slippery or otherwise unsafe?	28	29.79	66	70.21
Is the sound in the working area is disturbing?	86	91.49	8	8.51
Is there disturbing smell in the working area?	76	80.85	18	19.15

Source: Respondents result

Table 4.9 show that 46 (48.94%) of workers are working in confined space and 48 (51.06%) of them work in non-confined space. The other is 64 (68.09%) work at inadequate light and 30 (31.91%) work at adequate light working environment. In addition 76 (80.85%) of workers respond that as they are working in unfavorable working temperature that is cold or hot and the rest 18 (19.15%) respond as they are working in neither cold or hot temperature environment.

Similarly 28 (29.79%) of the workers work at floor working surface that is not good and 66 (70.21%) work at good floor surface. The other is 86 (91.49%) respond that at their work area there is disturbing sound and 8 (8.51%) respond that there is no disturbing sound in their working area. Similarly 76 (80.85%) of them respond that as there is disturbing smell in their working environment and 18 (19.15%) of them respond that there is no disturbing smell in their working environment.

This show that not working in good working environment that is there is disturbing smell, sound, unsuitable temperature and inadequate light that can lead to permanent or temporary disability.

Table 4. 9: Response of respondents on duration of awkward

Questions	Yes		Duration (hours)	No	
	Number	**Percentage**		**Number**	**Percentage**
Are you standing and bending forward during work?	80	85.11	4-8	14	14.89
Are you sitting and bending forward during working?	40	42.55	3-8	54	57.45
Do you have break in between your work?	84	89.36	15-20 minutes per shift	10	10.64

Source: Respondents result

Table 4.10 show that the response of workers on duration of their work that is 80 (85.11%) of the workers respond that they standing and bending forward for at least 5 – 8 hours per day and on the other hand 40 (42.55%) sitting and bending forward for 3 – 8 hours per day which is awkward for long time and the workers have 15 – 20 minutes rest per shift. From this we understand that workers are bending forward, according to Dul & Weerdmeester (2008) upper body part of an adult weighs about 40 kg on average, so during forward bending stress is particularly large in the lower back.

Most of the workers are bending forward for a long time of their work, forward bending creates large stress at lower back.

4.3. Workers injury

Table 4. 10: Response of respondents on body parts pain

Body parts	Degree of pain					
	Low		Moderate		High	
	Number	Percentage	Number	Percentage	Number	Percentage
Shoulders	30	31.91	28	29.79	36	38.30
Arm	38	40.43	16	17.02	40	42.55
Forearm	26	27.66	36	38.30	32	34.04
Wrist	26	27.66	34	36.17	34	36.17
Hand	16	17.02	42	44.68	36	38.30
Half back	20	21.28	24	25.53	50	53.19
Neck	18	19.15	50	53.19	26	27.66
Lower back	18	19.15	24	25.53	52	55.32
Knee	34	36.17	28	29.79	32	34.04
Hip	34	36.17	30	31.91	30	31.92
Mid Back	14	14.89	42	44.68	38	40.43
Elbow(s)	32	34.04	34	36.17	28	29.79
Thigh(s)	34	36.17	28	29.79	32	34.04
Lower Leg(s)	24	25.53	30	31.92	40	42.55
Foot/Ankle(s)	28	29.79	32	34.04	34	36.17

Source: Respondents result

As we can see from the table 4.11 from 94 respondents 36 (38.30%) of the face high degree of pain in their Shoulder, 28 (29.79%) of them moderate and 30 (31.91%) of them low. Similarly, 40 (42.55%) of the face higher degree of pain at their Arm, 16 (17.02%) of them moderate and 38(40.43%) of them low. At their Forearm 32 (34.04%) of them face high degree of pain, 36 (38.30%) of them moderate and 26 (27.66%) of them low. In Wrist 34(36.17%) of them face higher pain, 34 (36.17%) of them moderate and 26 (27.66%) of them low pain. On Hand 36 (38.30%) of them face high pain, 42 (44.68%) of the moderate and 16 (17.02%) of them face low degree of pain.

At Half back 50 (53.19%) of them face high pain, 24 (25.53%) of the face moderate and 20 (21.28%) of them face lower degree of pain. At Neck 26 (27.66%) of them face high degree of pain, 50 (53.19%) of them moderate and 18 (19.15%) of them lower pain. At lower back 52 (55.32%) of them face high degree of pain, 24 (25.53%) of them moderate and 18 (19.15%) of them lower pain. At knee 32 (34.04%) of them face high degree of pain, 28(29.79%) of them face moderate of pain and 34 (36.17%) of the lower pain. At Hip 30 (31.92%) of them face higher degree of pain, 30(31.91%) of them moderate and 34 (36.17%) of them lower pain.

At Mid back 38 (40.43%) of them face higher degree of pain, 42 (44.68%) of them face moderate and 14 (14.89%) of them face lower pain. At Elbow(s) 28 (29.79%) of them face higher degree of pain, 34 (36.17%) of them face moderate and 32 (34.04%) of them face lower pain.At Thigh(s) 32 (34.04%) of them face higher degree of pain, 28 (29.79%) of them face moderate and 34 (36.17%) of them face lower pain. At Lower Leg(s) 40(42.55%) of them face higher degree of pain, 30 (31.92%) of them face moderate and 24 (25.53%) of them face lower pain. At Foot/Ankle(s) 34 (36.17%) of them face higher degree of pain, 32 (34.04%) of them face moderate and 28 (29.79%) of them face lower pain.

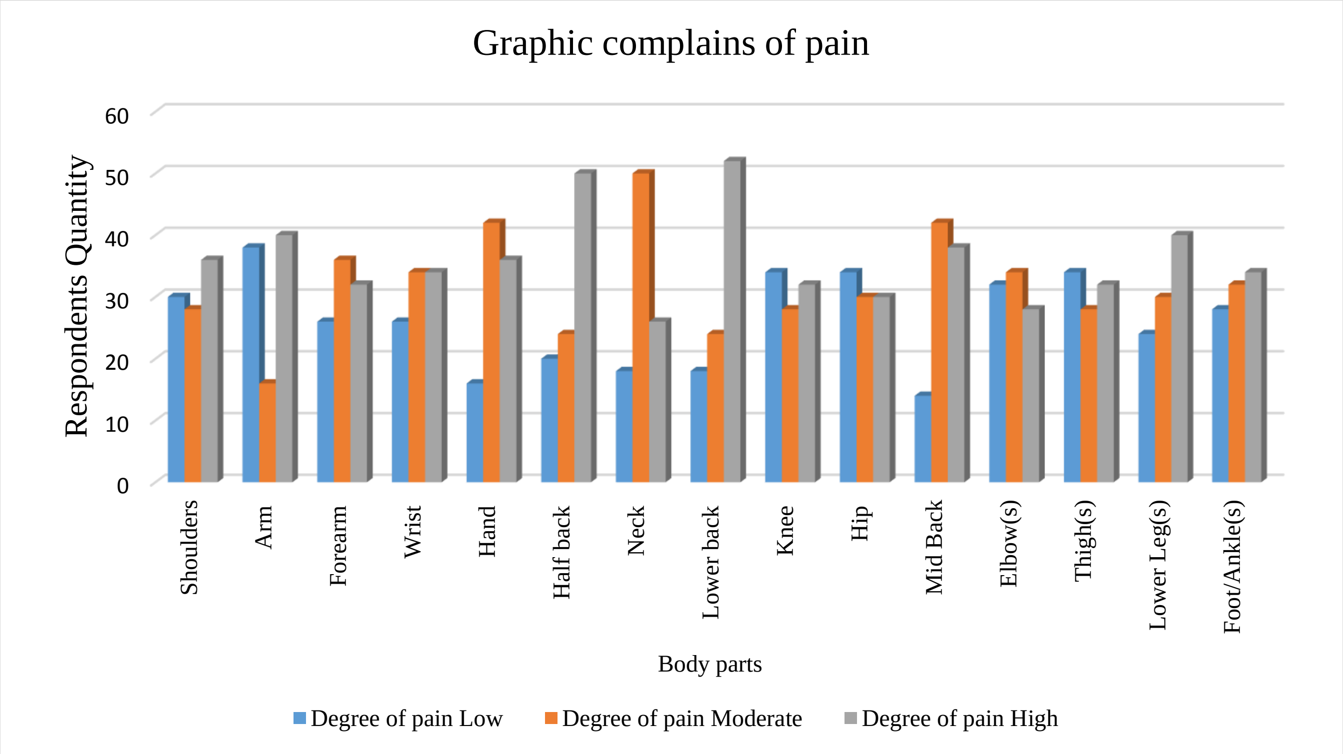

Figure 4. 15: Degree of pain of body part of workers in graph (Respondents result)

The result of this show that more than 55% of workers face high degree of pain at low back similarly, according Wickens & Gordon-Becker (2014) low-back pain may affect as much as 50 to 70 percent of the general population due to occupational and other unknown factors.

From the record of the ferric belt metal processing and engineering factory in the last three years there are 22 minor injuries and 5 major/higher injuries.

Table 4. 11: Response of respondents on Psychology of workers

Questions	**Yes**		**No**	
	Number	**Percentage**	**Number**	**Percentage**
Are you satisfied in the work you are performing in this station?	34	36.17	60	63.83
Are you happy when coming to this workstation for work?	62	65.96	32	34.04
Due to working in your workstation do you have concern of your healthy?	78	82.98	16	17.02
	Increase		Decrease	
Is your performance is ______________from Monday to Friday	28	29.79	66	70.21

Source: Respondents result

Table 4.12 show that the respondents response on the psychological condition of their works. On this 34 (36.17%) are satisfied in their workstation and 60 (63.83%) are not satisfied in their workstation and also 62 (65.95%) respondents respond that they are happy when they come to area and 32 (34.04%) respond that they are not happy when they coming to workstation.

In addition 78(82.98%) of the respondent respond that they have concern of their health due to working in their workstation and 16 (17.02%) have no concern of their healthy due to working in their station.

The other is that 28 (29.79%) of them think that their performance is increasing from Monday to Friday and the rest 66 (70.21) say that their performance is decreasing from Monday to Friday.

Most of the works of the factory are not satisfied with their workstation and in addition they have concern of their health due to working in the work area.

4.4. Standard working method and standard time

4.4.1. Method study

The distance the material moves between each successive processing machines were shown in table 4.13. The first processing machine is cutting and the next processing machines lathe. There is one cutting machine and three lathe machines. From the cutting machine to the first lathe machine is 9.80m, from cutting to the second lathe machine is 11.00m and from the cutting machine to the third lathe machine is 11.20m. After lathe the next processing machine is threading. There are two threading machines.

The distance from the first lathe to the first threading machine is 2.20m and from the first lathe to the second threading machine is 8.20m. The distance from the second lathe machine to the first and second threading machines are 3.10 m and 9.40 m respectively. Similarly the distance from the third lathe machine to the first threading machine is 2.30 m and from this third lathe to the second threading machine is 10.10 m.

The next processing machine to threading is bending machine and its quantity is one. The distance from the first threading machine to bending machine 2.20 m and from the second threading machine to bending machine is 5.00 m. the last process is assembling and the distance from bending to assembly area is 4.00 m.

Table 4. 12: Distance between each machine

Between machines	**Distance**
Cutting Machine – Lathe Machine 1	9.80m
Cutting Machine – Lathe Machine 2	11.00m
Cutting Machine – Lathe Machine 3	11.20m
Lathe Machine 1 – Threading Machine 1	2.20m
Lathe Machine 1 – Threading Machine 2	8.20m
Lathe Machine 2 – Threading Machine 1	3.10m
Lathe Machine 2 – Threading Machine 2	9.40m
Lathe Machine 3 – Threading Machine 1	2.30m
Lathe Machine 3 – Threading Machine 2	10.10m
Threading Machine 1 – Bending Machine	2.20m
Threading Machine 2 – Bending Machine	5.00m
Bending Machine – Assembly area	4.00m

Source: Measurement at the production line by researcher

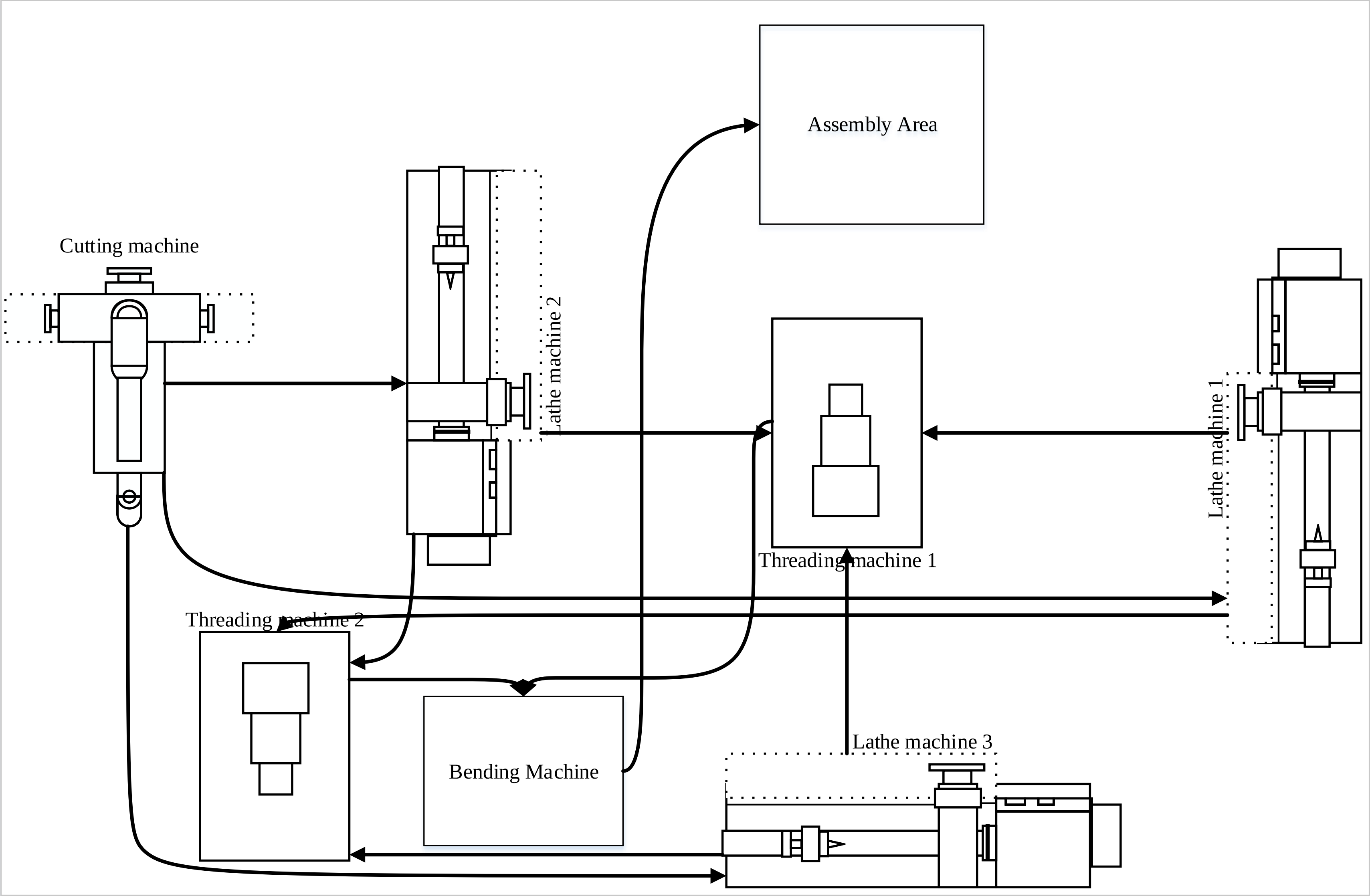

Figure 4. 16: Existing layout of the J-Bolt manufacturing line (Field survey)

As we can see from figure 4.16 the existing process flow of material is exposed to forth and back movement many times. This shows that the material is moving long distance. In principle transporting material does not add value so it must be kept to minimal as much as possible. In this layout the material transported a longer distance than necessary that is it increases processing cost and also it consumes human labor and time that lead to muscular fatigue as it is transported by human labor.

To make this excessive transport clear, let us see one line of movement that is picked from figure 4.16 and indicated in figure 4.17.

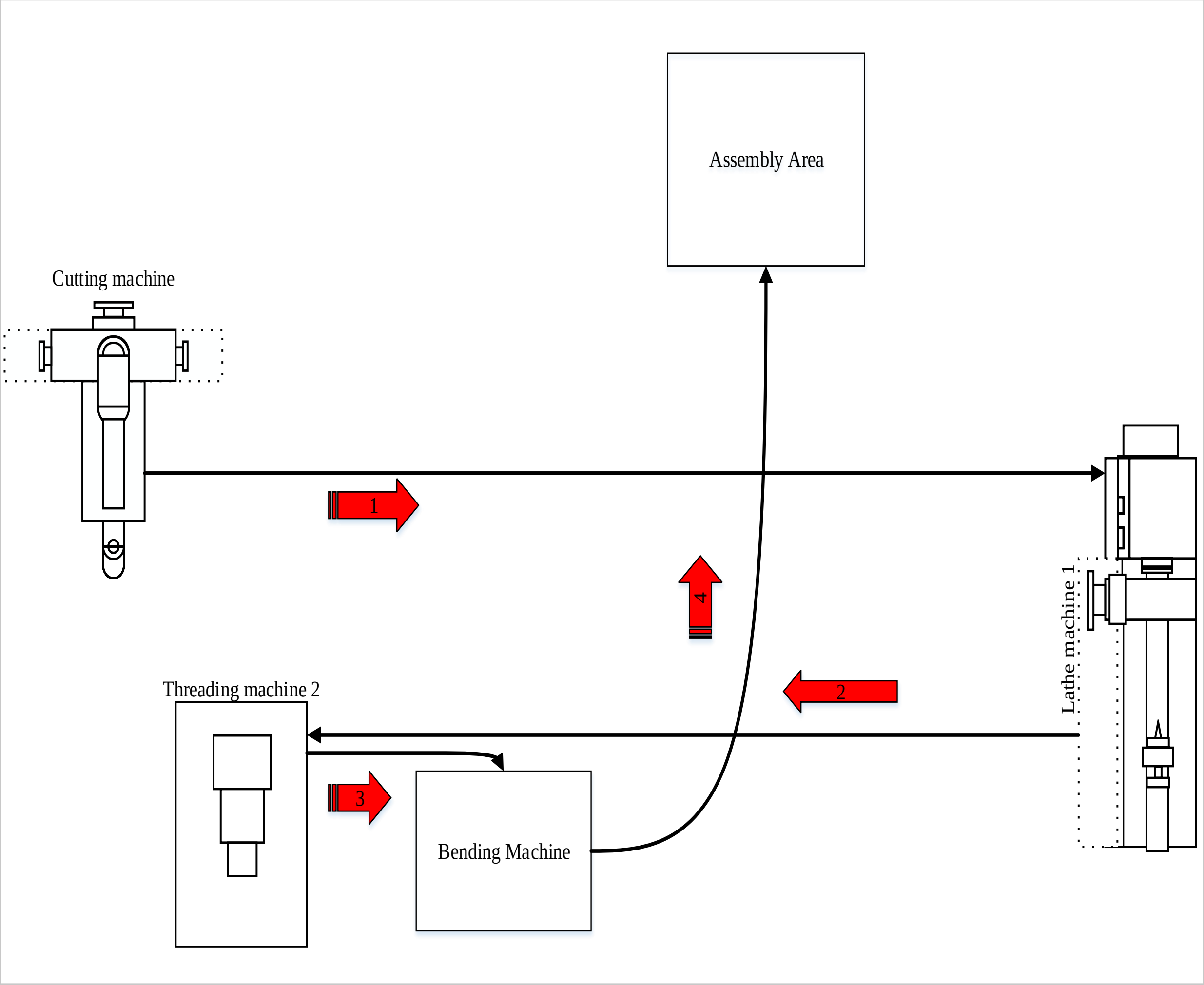

Figure 4. 17: Sample existing flow line of the J-bolt manufacturing line (Field survey)

As we can observe from figure 4.17 the workpiece is cut on cutting machine and transported to Lathe machine through path 1 shown on the figure; then turned on lathe machine and move to threading station through path 2 and thread is cut on this machine; after that transported to bending machine through path 3 to be bent as J on bending machine then transported to assembly area through path 4 and assembled and for transport to storage area loaded to hand truck. During this movement the material transported totally between these work stations 30.30 meter.

In the existing layout, if the material moves from lathe 1 to threading 1 and then go to bending and then to assembly it moves 18.20m that is the minimum distance the material to move.

The line is producing J-bolt of different diameters but the process is the same so that product layout is selected for this because one type of product is manufactured in larger volume.

The processes of the line are:

Figure 4. 18: Processes of manufacturing J – bolt (Field survey)

Cutting: the reinforcement bar is cut to required size at this workstation

Turning: the cut bar is turned one of its end for preparing to thread

Threading: thread is cut at the turned end

Bending: the threaded bar is bent as J at this process

Assembly: threaded and bended bolt is assembled to nut on this process

Table 4. 13: Existing flow working method process flowchart

Details of method	Operation ○	Movement ⇨	Inspection □	Delay D	Storage ▽
Waiting for process start				●	
Grasp workpiece	●				
Pick from ground		●			
Cut on cutting machine	●				
Throw on ground		●			
Waiting for the next transport to lathe station				●	
Pick from ground	●				
Transport on shoulder		●			
Release on table		●			
Waiting for the next process				●	
Pick from table and mount on lathe	●				
Turn on lathe	●				
Remove from lathe and place on table		●			
Waiting for the next transport to threading station				●	
Pick from table	●				
Transport to threading station		●			
Place in coolant on the ground				●	
Pick from coolant and setup on threading machine	●				
Threading operation	●				
Remove from threading machine and place on table		●			
Waiting for the next transport to bending station				●	
Pick from table and transport to bending station		●			
Setting bending machine	●				
Bending operation	●				
Pick from bending machine and Throw to ground		●			
Waiting for transport to assembly area				●	
Moving to assembly station		●			
assemble J-bolt and Nut	●				
Waiting for transport to store station				●	
Pick from ground and mount on hand truck	●				
Transport to store	●				
Store					●

Source: Filed observation

4.4.2. Time study

Time study is conducted on J-bolt manufacturing line of Ferric Belt metal processing and engineering factory. The steps followed for the study are:

- Choose the job for the time study.
- Break the job into easily understandable units.
- Ten sample number of sample observation was taken for each job unit
- Number of cycles observation was Calculated for each
- The maximum number of observation was taken i.e. (51)
- Time study was conducted
- Mean observation was calculated
- Workers' performance was rated.
- Normal time was computed
- Standard time was computed

Table 4. 14: Sample observed time, mean and standard deviation of observed time

JOB ELEMENT	**Number of Observation (Time in seconds)**										**Average**	**Standard deviation**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**		
Waiting for process start												
Grasp workpiece	6.90	9.21	14.04	9.87	6.60	8.11	6.93	6.78	6.92	7.70	8.306	2.1812
Pick raw material from ground	5.08	5.22	5.01	4.35	5.34	8.04	6.84	9.07	4.54	8.60	6.209	1.6834
Cut on cutting machine	4.72	3.55	6.70	4.34	7.41	5.99	9.94	2.12	3.64	9.74	5.815	2.5034
Throw on ground	2.06	2.32	1.40	1.19	1.65	1.24	1.77	1.75	1.29	1.45	1.612	0.3520
Waiting for the next transport to lathe station												
Pick from ground from cutting station	38.52	31.74	34.97	22.88	25.51	30.30	21.97	34.97	35.42	33.46	30.974	5.4065
Transport on shoulder	8.74	11.60	11.84	8.62	10.78	12.16	9.45	14.05	18.94	18.34	12.452	3.4752
Release on table	1.69	1.94	2.07	1.98	1.90	1.51	1.67	1.73	2.02	1.68	1.819	0.1767
Waiting for the next process												
Pick from table and mount on lathe	20.72	28.89	33.39	31.81	12.44	18.55	15.05	18.48	32.79	16.92	22.904	7.5705
Turn on lathe	31.91	35.02	40.36	44.81	31.46	35.94	28.31	29.94	38.56	39.93	35.624	5.0137
Remove from lathe and place on table	20.72	20.37	15.83	14.42	12.44	10.01	10.41	11.79	20.21	17.77	15.397	3.9831
Waiting for the next transport to threading station												
Pick from table	7.05	7.51	8.82	4.22	9.66	9.77	12.5	15.55	11.12	9.15	9.535	2.9451
Transport to threading station	11.12	11.36	12.55	12.61	12.02	12.68	8.36	14.83	12	12.35	11.988	1.5395

Place in coolant on the ground	6.55	4.04	5.43	6.27	3.33	5.99	5.55	5.04	6.43	5.27	5.39	0.9895
Pick from coolant and setup on threading machine	6.89	10.31	6.19	7.17	5.80	7.37	7.32	3.75	6.74	9.67	7.121	1.7591
Threading operation	62.61	50.16	54.76	56.20	52.11	50.60	54.70	54.22	56.27	52.33	54.396	3.4109
Remove from threading machine and place on table	1.78	1.83	2.46	2.34	2.15	1.64	1.85	1.73	1.87	1.79	1.944	0.2611
Waiting for the next transport to bending station												
Pick from table and transport to bending station	24.98	28.80	31.61	28.84	26.23	24.15	30.55	28.27	28.33	28.02	27.978	2.1939
Setting bending machine	8.65	7.66	9.67	8.44	11.14	8.94	9.59	8.88	8.69	12.47	9.413	1.3438
Bending operation	8.67	13.74	7.23	7.70	7.26	7.46	7.83	7.40	11.15	7.53	8.597	2.0466
Pick from bending machine and Throw to ground	1.47	2.04	3.00	2.72	2.42	2.48	2.21	2.26	2.25	2.30	2.315	0.3847
Waiting for transport to assembly area												
Transport to assembly station	13.57	12.03	14.03	9.68	15.50	16.69	9.25	8.82	4.95	6.96	11.148	3.6295
Pick from ground J-bolt and Nut	4.05	6.52	3.43	6.56	8.33	3.61	4.48	4.43	4.73	4.90	5.104	1.4732
Assemble J-bolt and Nut	8.8.31	15.69	8.89	9.20	14.64	11.51	9.85	13.51	12.29	14.12	12.1889	2.3452
Through to ground	1.13	1.20	1.06	1.66	1.34	1.57	0.95	0.97	1.22	1.01	1.211	0.2331
Waiting for transport to store station												
Pick from ground and mount on hand truck	3.93	6.15	3.57	3.68	4.02	3.62	5.64	4.17	3.13	5.73	4.364	1.0101
Transport to store												
Store												

Source: Filed observation

To know how many time we must observe the worker to ensure the results wanted in conducting time study the following formula was used for each activity.

Ten sample cycle time is observed then mean and standard deviation of these observed samples is calculated using Microsoft Excel and shown in table 4-15. Using the result from the table calculate the number of cycles must be observed using the following formula.

Calculate the number of cycles must observe. $n \geq \left[\left(\frac{Z}{a}\right)\left(\frac{s}{\bar{x}}\right)\right]^2$

All non-integer solutions are rounded up

Taking the desired confidence percentage as 90, from standard table Z value is = 1.65

Confidence level more than 90% is incurs more cost and time consuming.

Grasp workpiece

Calculate the number of cycles must observe. $n \geq \left[\left(\frac{Z}{a}\right)\left(\frac{s}{\bar{x}}\right)\right]^2$

$$n \geq \left[\left(\frac{1.65}{0.1}\right)\left(\frac{2.1812}{8.306}\right)\right]^2 = [4.333]^2 = 18.7749 = 19\ observations$$

Table 4. 15: Sample observed time, mean and standard deviation of observed time

JOB ELEMENT	**Average** ($\bar{x}$)	**Standard deviation (S)**	**z**	**α**	$n \geq \left[\left(\frac{Z}{a}\right)\left(\frac{s}{\bar{x}}\right)\right]^2$
Waiting for process start					
Grasp workpiece	8.306	2.1812	1.65	0.1	19
Pick raw material from ground	6.209	1.6834	1.65	0.1	21
Cut on cutting machine	5.815	2.5034	1.65	0.1	51
Throw on ground	1.612	0.3520	1.65	0.1	13
Waiting for the next transport to lathe station					
Pick from ground from cutting station	30.974	5.4065	1.65	0.1	9
Transport on shoulder	12.452	3.4752	1.65	0.1	22
Release on table	1.819	0.1767	1.65	0.1	3
Waiting for the next process					
Pick from table and mount on lathe	22.904	7.5705	1.65	0.1	30
Turn on lathe	35.624	5.0137	1.65	0.1	6
Remove from lathe and place on table	15.397	3.9831	1.65	0.1	19
Waiting for the next transport to threading station					
Pick from table	9.535	2.9451	1.65	0.1	26
Transport to threading station	11.988	1.5395	1.65	0.1	5
Place in coolant on the ground	5.39	0.9895	1.65	0.1	10

Pick from coolant and setup on threading machine	7.121	1.7591	1.65	0.1	17
Threading operation	54.396	3.4109	1.65	0.1	2
Remove from threading machine and place on table	1.944	0.2611	1.65	0.1	5
Waiting for the next transport to bending station					
Pick from table and transport to bending station	27.978	2.1939	1.65	0.1	2
Setting bending machine	9.413	1.3438	1.65	0.1	6
Bending operation	8.597	2.0466	1.65	0.1	16
Pick from bending machine and Throw to ground	2.315	0.3847	1.65	0.1	8
Waiting for transport to assembly area					
Transport to assembly station	11.148	3.6295	1.65	0.1	29
Pick from ground J-bolt and Nut	5.104	1.4732	1.65	0.1	23
Assemble J-bolt and Nut	12.1889	2.3452	1.65	0.1	11
Through to ground	1.211	0.2331	1.65	0.1	11
Waiting for transport to store station					
Pick from ground and mount on hand truck	4.364	1.0101	1.65	0.1	15
Transport to store					
Store					

Source: Author’s computation

Normal and standard time for each element

Compute normal time. NT = (MOT) (PRF) (F)

To calculate the standard time for each work element as follows.

Compute the standard tune. ST = (NT) (AF)

Where ST = standard time

NT = normal time

AF = allowance factor

$$ST_{each\ work\ element} = NT\left(\frac{1}{1-0.15}\right)$$

Normal time and standard time for each element is shown in table 4.16.

Table 4. 16: Normal time and standard of each activity

JOB ELEMENT	Mean Observed Time	Performance Rating Factor	Normal Time	standard Time
Waiting for process start				
Grasp workpiece	7.79	0.90	7.01	8.25
Pick raw material from ground	6.86	0.95	6.52	7.67
Cut on cutting machine	7.12	1.00	7.12	8.38
Throw on ground	1.52	1.00	1.52	1.79
Waiting for the next transport to lathe station				
Pick from ground from cutting station	37.13	0.95	35.27	41.50
Transport on shoulder	13.34	0.95	12.68	14.91
Release on table	1.54	1.00	1.54	1.81
Waiting for the next process				
Pick from table and mount on lathe	21.77	1.00	21.77	25.61
Turn on lathe	31.28	1.00	31.28	36.80
Remove from lathe and place on table	15.98	1.00	15.98	18.80
Waiting for the next transport to threading station				
Pick from table	11.56	0.95	10.98	12.92
Transport to threading station	12.00	1	12.00	14.11
Place in coolant on the ground	5.45	1	5.45	6.41
Pick from coolant and setup on threading machine	6.23	0.95	5.92	6.96
Threading operation	43.49	1.00	43.49	51.16
Remove from threading machine and place on table	2.39	1.00	2.39	2.81
Waiting for the next transport to bending station				
Pick from table and transport to bending station	21.26	0.95	20.20	23.77
Setting bending machine	7.14	0.95	6.78	7.98
Bending operation	7.18	1.00	7.18	8.44
Pick from bending machine and Throw to ground	2.38	1.00	2.38	2.80
Waiting for transport to assembly area				
Transport to assembly station	10.57	1.00	10.57	12.44
Pick from ground J-bolt and Nut	5.12	0.95	4.86	5.72
Assemble J-bolt and Nut	13.44	0.90	12.10	14.23
Through to ground	1.17	1.00	1.17	1.37
Waiting for transport to store station				
Pick from ground and mount on hand truck	7.84	1	7.84	9.22
Transport to store				
Store				

Source: Researcher's computation from time study

Chapter Five

5. Proposed Workplace Design

5.1. Proposed framework for integration of ergonomics and work study

When method study only focuses on improving the working process without considering ergonomic issues, new ergonomic problems may be created. Even well-designed manufacturing workstations can present ergonomic risks to the operators. These ergonomic risks can cause work-related musculoskeletal disorders (WMSDs) such as repetitive motion injuries, carpal tunnel syndrome, cumulative trauma disorders, low back pain, tension neck syndrome, and soft tissue disorders. Workplace ergonomics and work study are highly inter-related. Ergonomic risks can lead to working method problem and vice versa. Furthermore, ergonomics can support Work study and work study can lead to ergonomic risk reduction. High ergonomic risk can be used as an indicator of the existence of one or more working method problem. For example, awkward postures and poor design of tools and equipment can lead to wasted motions that increase the time to perform tasks and reduce the quality of work. On the other hand, safe workplace can improve employee talent. Working Method problem can also create ergonomic risk factors. For example, defects can create fatigue to the operators and increase the overtime.

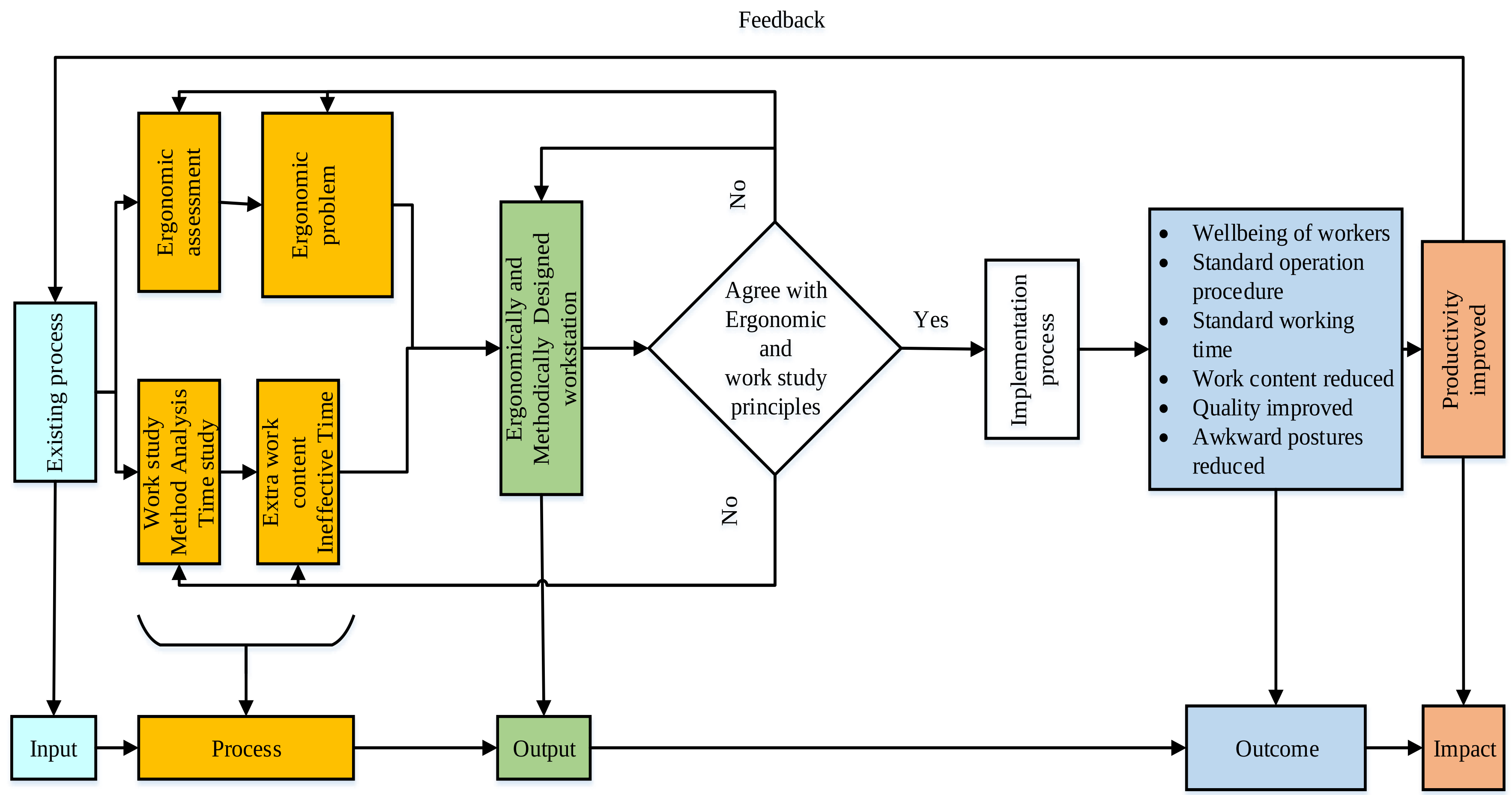

Figure 5. 1: Ergonomics and work study integration

Existing process: - the previously implemented working condition and working method on the line

Work study: is the systematic examination of the methods of carrying on activities so as to improve the effective use of resources and to set up standards of performance for the activities being carried out.

Method Analysis: - determines the methods and activities to be included in jobs

Time study: - is concerned with measuring the time that should be taken for performing jobs

Extra work content: activity that consumes time and energy without adding value

Ineffective Time: time consumed in non-value adding activity

Ergonomic assessment: Check the ergonomic fitness of the workstation

Ergonomic problem: like Repetitive Strain Injury and Carpal Tunnel Syndrome are the frequent repetitive motion tasks, awkward posture, vibrations, forceful movements, stress at workplace, poor workplace setup.

Ergonomically and methodically designed workstation: - comfortable and that can reduces non value adding activities and that can match with human capability.

Ergonomic principles: maintain neutral posture, work in the comfort zone, allow for movement and stretching, reduce excessive force, reduce excessive motions, minimize contact stress, reduce excessive vibration and provide adequate lighting

Work study principles: reduce the work content to value adding activities

Implementation process: process of implementing the designs ergonomically and systematically designed working conditions

5.2. Proposed layout

As discussed above the existing layout of the J – Bolt production line many ergonomic and working method problems. To improve this the researcher decided to rearrange the layout, if the layout of the production line is arranged as shown on figure 5.2. The maximum distance the material move is 9.50m so the layout reduces the transport distance by three times of the maximum of the existing layout which is 30.30m and about two times of the minimum of it which is 18.20m. Similarly the area used in existing layout about 52.5m^2 but the proposed layout uses 41m^2.

The proposed layout reduces back and forth movement of workers which reduces works fatigue and increases productivity by reducing non-value adding activates and waste time for transport. Simultaneously it improves the working condition of works through minimizing awkward postures.

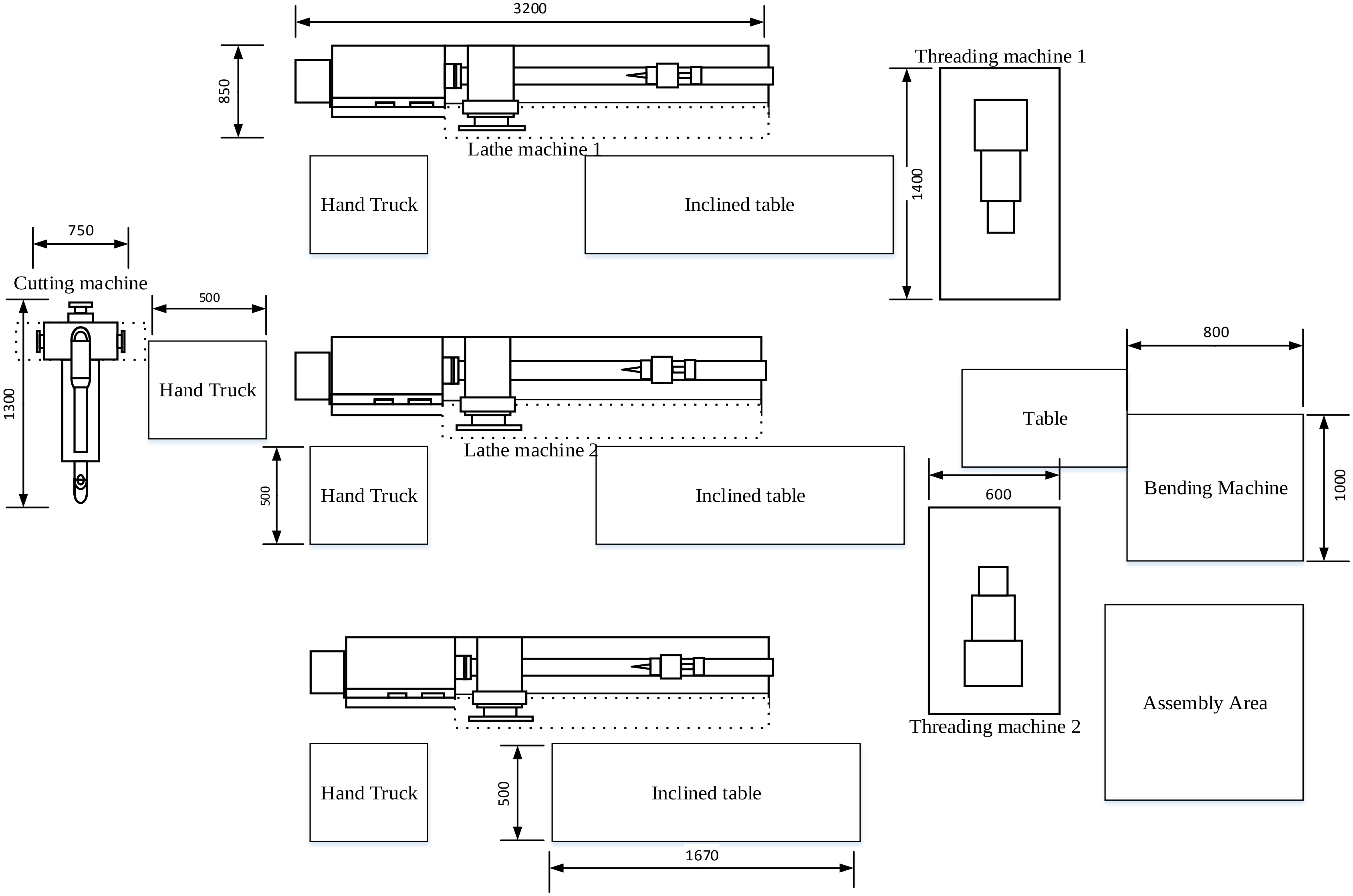

Figure 5. 2: Improved layout of J-bolt Production line (Researcher’s design)

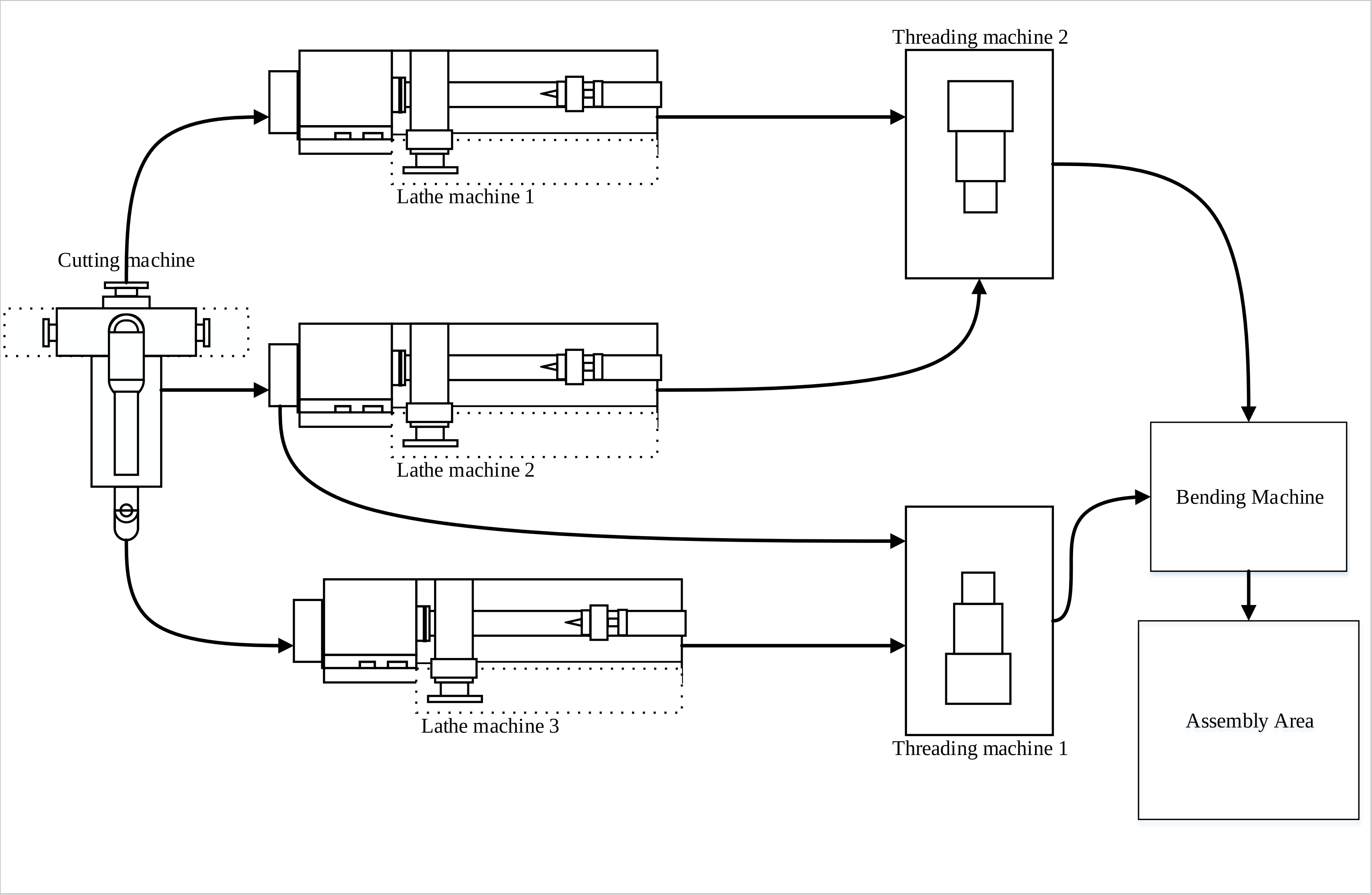

Figure 5. 3: Improved layout of J-bolt manufacturing line with flow directions (Researcher's design)

As can be observed from figure 5.3 the material cut at cutting station go to either of the three lathe stations using proposed hand truck that is less distant than the existing layout and clear way of movement. Then the turned material transported to threading station by inclined table that reduce the movement of workers and time between stations. The threaded material moves to Bending similarly through other inclined table. From Bending to assembly station the bended bolt removed from bending should be placed on proposed assembly table. The worker at assembly assembles the J – Bolt and nut and place on the truck for transporting of the finished material to store.

5.3. Cutting workstation

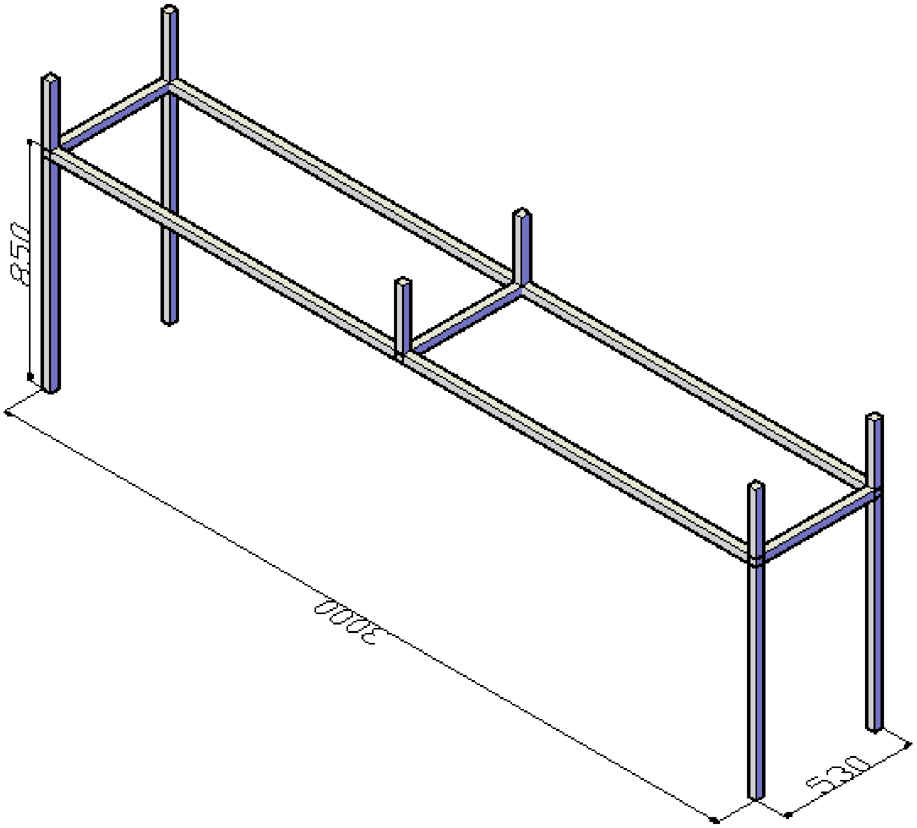

Figure 5. 4: Proposed rack for placing raw material at cutting (Researcher's design)

As viewed the worker bends forward to grasp a work pieces overlaid on the ground. To avoid this the researcher designed this rack that can avoid forward bending of the operator, improve productivity and wellbeing of the worker. This rack's height is 10 cm blow the working height of the worker because when the bars overlay it near to the working height. Due to this the worker draw the bars properly laid over this rack and without bending forward and better ergonomically working condition. The rack can be manufactured in the company at low cost and it has no operational cost.

5.4. Ergonomic chair design considerations for seating workstation

The chair for this workstation is 46cm high not adjustable and discomfort. As standard, the chair height should be equal to the vertical distance from the sole of the foot to popliteal height. The researcher propose a chair that can be adjustable height between 38 cm to 62 cm to accommodate 5th percentile women and 95th percentile men.

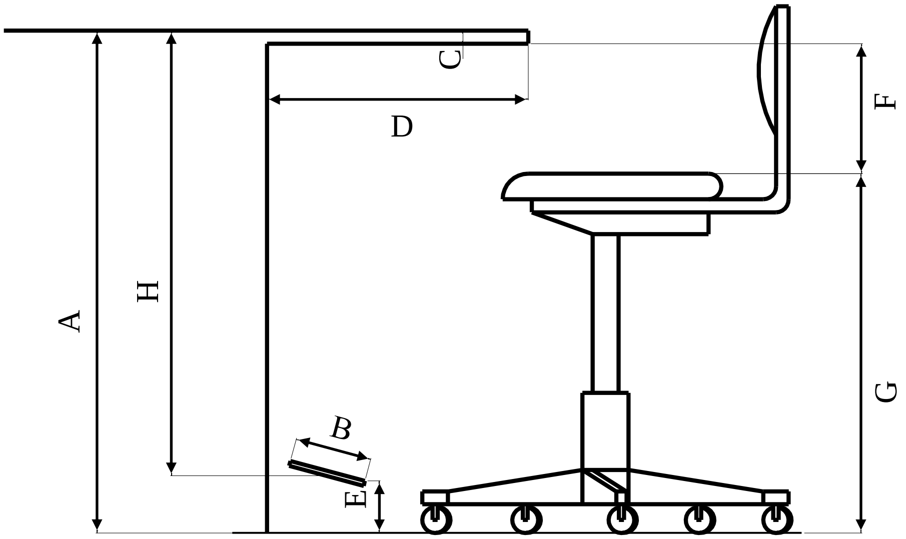

Figure 5. 5: Recommended Chair for sitting work (Researcher's design)

A = work surface height

B = Footrest depth 30 cm

C= work surface thickness 5 cm Maximum

D = leg clearance 46 – 66 Cm

E = Adjustable footrest height 2 – 23 cm

F = Thigh clearance 20 cm Minimum

G = Adjustable seat height 38 – 62 cm

H = footrest to underside of table knee clearance 46 cm

Seat size

- Depth = 41 cm
- Width = 43 cm
- Backrest Width 30 Cm
- Backrest height 20 cm

The heights, clearances, and work surface thickness of a seated workplace with a footrest and an adjustable chair are given. These design guidelines ensure that most people that is 5th percentile women to 95th percentile man will be able to work comfortably at the workplace. Based on the work surface height the chair and footrest heights should be adjustable to provide adequate thigh clearance and leg comfort. Forward leg clearances: leg clearance is the recommended distance under the work surface. Seat and footrest adjustability are important in accommodating differences in size of people using a seated workplace

The chair is proposed for seating workstations those are cutting workstation, threading workstation, bending workstation, and assembly workstation. This chair can help the worker to work at comfortable height through adjusting the chair for different worker height. Similarly due to clearance of leg provided the worker work without bending forward that can reduce the awkward postures and WRMSD. Due to comfortable workstation the fatigue reduce which improves productivity of workers.

5.5. Cutting to lathe workstations transport

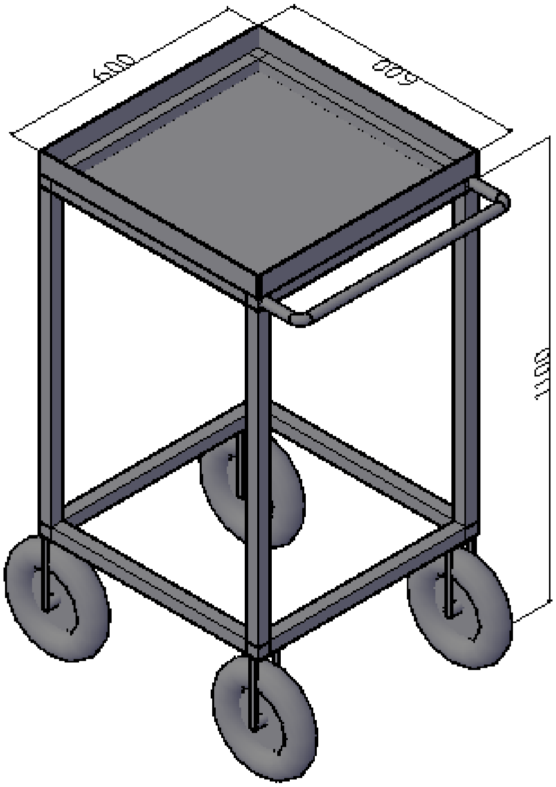

Figure 5. 6: Proposed hand truck for transporting from cutting station to lathe station (Researcher's design)

To solve the transportation problem from cutting workstation to lathe workstation the researcher proposes hand truck that help in transporting materials from cutting station to lathe station. At cutting station instead of throwing the workpiece to ground after cut the worker places on this hand truck. Then any one can push this truck to the lathe station without bending to ground to pick the workpiece that create awkward posture and consumes production time that reduce productivity. Using this hand truck reduce awkward posture and transporting time because it can handle more quantity than human at a time. The workpiece length is 45 ± 4 cm to handle this hand truck has 60 cm × 60 cm and the height is 110 cm that is 10 cm blow average standard elbow height of human. The optimum working height for standing work is 5 – 10 cm below elbow height. In this design the researcher selected the maximum because when the workpieces are accumulated on the hand truck the height increase and when the workpieces depleted from the truck the height come to the minimum that is 10 cm below the elbow height so the hands stay more of their time in between the optimal working height that is 10 – 5 cm below the elbow height. This hand truck can be manufactured in the company from scrap at small cost and the operational cost is almost none because it does not consume energy and not require lubrication.

5.6. Lathe machine workstation

As we observed from the lathe in the shop the lathe height is shorter than the 5th women's acceptable working height. To make the machine convenient for average height worker the proposed solution is to move the working levers of the machine to slightly below elbow height. That is making all the levers between acceptable working heights 94 cm to 109 cm. the average man elbow height is 109 cm.

For incoming and processed material storage instead of using the one table it is better to use two tables which height is 10 cm below the elbow height. The optimal working height is between 5cm and 10 cm below elbow height. Using 10 cm below elbow height in this cause is that the material stored on the table increases the height and so the hand of the operator stay most of the time above 10 cm below elbow height and below 5 cm the height.

The other is that to cover the chuck the chuck guard should be installed. Similarly to prevent the chips from hitting the operators transparent cover that is attached to the carriage should be used.

5.7. Transporting materials from lathe to threading stations

The lathe station is a standing workstation and the threading workstation is a sitting workstation so to transport the materials from lathe to threading station the researcher proposed an inclined table which height is at the lathe end equal to the 5 cm below the elbow height of the standing operator (average man elbow height i.e. 109 cm) and at the threading end the height of the table equal to elbow height of average person (i.e. 83 cm). The drawing of this table is shown in figure 5.7. The cost of this mechanical material handling is only initial cost because it did not consume energy and it has no moving part its operational cost it zero the initial cost is also small because it can be manufactured in the company from scrap. But it reduces the repetitive movement of operators, manual currying of material on shoulder and simultaneously reduces fatigue. As material handling is non-value adding activity it should be kept as minimum.

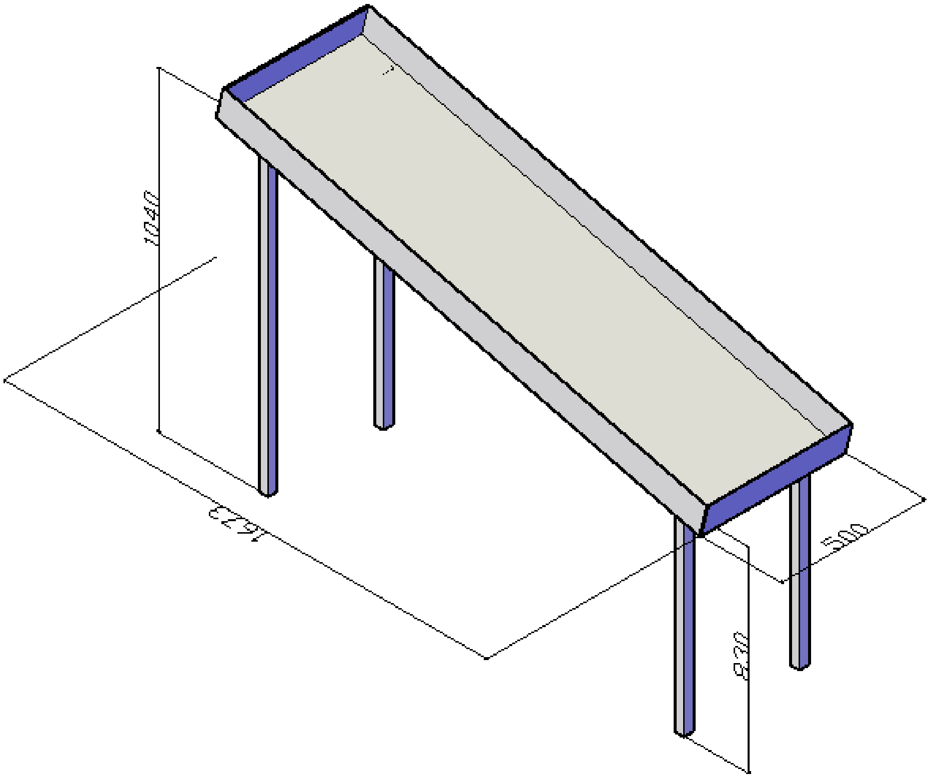

Figure 5. 7: Proposed inclined table to transport from lathe to threading station (Researcher's design)

5.8. Threading workstation

The control switch of the threading machine should be placed in front of the operator at primer visual cone and at about elbow height of the operator that is 83 cm. The colors of the control switch should also be different to avoid confusion and working error so the revers switch should be changed to black instead if red. Similarly the arrangements of theses switch should be in sequence of the operations that is first forward then stop and then revers as indicated on the figure 5.8.

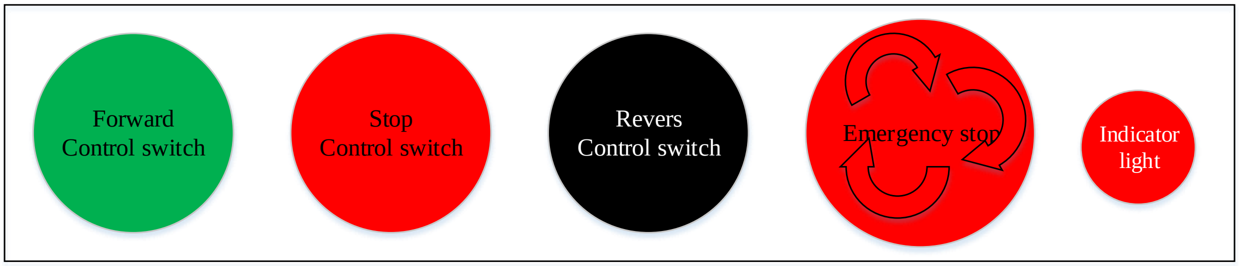

Figure 5. 8: Proposed control switch color and arrangement for threading machine (Researcher's design)

5.9. Bending workstation

The working height of this work station should be designed to the average working height that is about 83 cm instead of 75 cm to avoid forward bending and reduce forward starching to recommended forward reach that is 50 cm instead of 70 cm.

The control switch of this bending machine should have different color for forward and reverse operation. That is green for forward and black for revers operation to avoid operator confusion and error that reduce productivity and safety of the workstation as can be observed from figure 5.9.

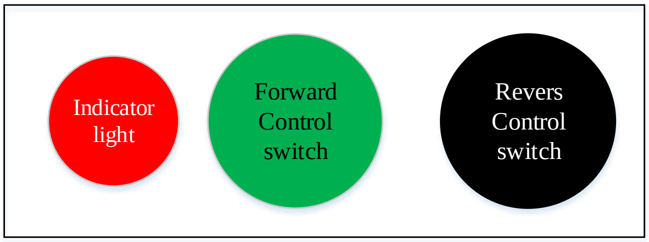

Figure 5. 9: Proposed control switch color for bending machine (Researcher's design)

Leg clearance should be provided as chair on figure 5.5 to avoid forward bending and improve comfort

5.10. Assembly workstation

At the assembly station instead of assembling J-Bolt and nut through picking from the ground the researcher propose assembly table. The height of the table should be equal to the seating elbow height of average human that is 83 cm above floor. So for this the chair is the one that is proposed on this paper at for seating works on figure 5.5.

5.11. Proposed standard working method and time

Table 5. 1: Proposed flow working method process flowchart and standard time

Details of method	Operation ○	Movement ⇨	Inspection □	Delay D	Storage ▽	**standard Time**
Waiting for process start				●		
Grasp workpiece set on machine	●					4.25
Cut on cutting machine		●				8.38
Place on hand truck		●				1.79
Waiting for the next transport to lathe station				●		
Transport using hand Truck to lathe station		●				14.91
Waiting for the next process Turning				●		
Pick from Truck and mount on lathe	●					18.80
Turn on lathe	●					36.80
Remove from lathe and place on inclined table		●				18.80
Place in coolant at a height of elbow				●		2.48
Pick from coolant and setup on threading machine	●					2.48
Threading operation	●					49.16
Remove from threading machine and place on inclined table		●				2.81
Setting bending machine	●					7.98
Bending operation	●					8.44
Pick from bending machine and place on assembly table		●				2.80
assemble J-bolt and Nut	●					14.23
Place on hand truck	●					1.37
Transport to store		●				
Store					●	

Source: researcher's result

5.12. Comparison of existing and proposed working system

Table 5. 2: Qualitative and quantitative compression of existing and proposed system

S/N	**Parameters**	**Existing**	**Proposed**	**Remark**
1	Maximal length material move	30.30m	9.50m	
2	Minimum length material move	18.20m	7.50m	
3	Area occupied	52.5m^2	41m^2	
4	Worker at assembly	2	1	
5	Processing time	208.83s	178.48s	14.53%
6	Mechanical material handling	Not exist	Proposed	Can be manufactured in the factory from scrap
7	Muscle fatigue	High	Reduce	
8	Worker comport	Low	Improve	
9	Worker wellbeing	Low	Improve	
10	Chair cost	Low	Higher	
11	Chair Comfort	Low	Higher	
12	Chair adjustability	Not adjustable	Adjustable	
13	Awkward postures	Higher	Low	
14	Repetitive movement	Higher	Low/ no	
15	Chair cost	800	7000	
16	Average number of Minor injures	7.33 per year	Reduce	
17	Average number of major injuries	1.66per year	Reduce	
18	Mechanical material handling cost	-		Initial cost only

To compare the existing and proposed designed system Arena simulation is used as we can observe from the simulation model at figure 5.10.

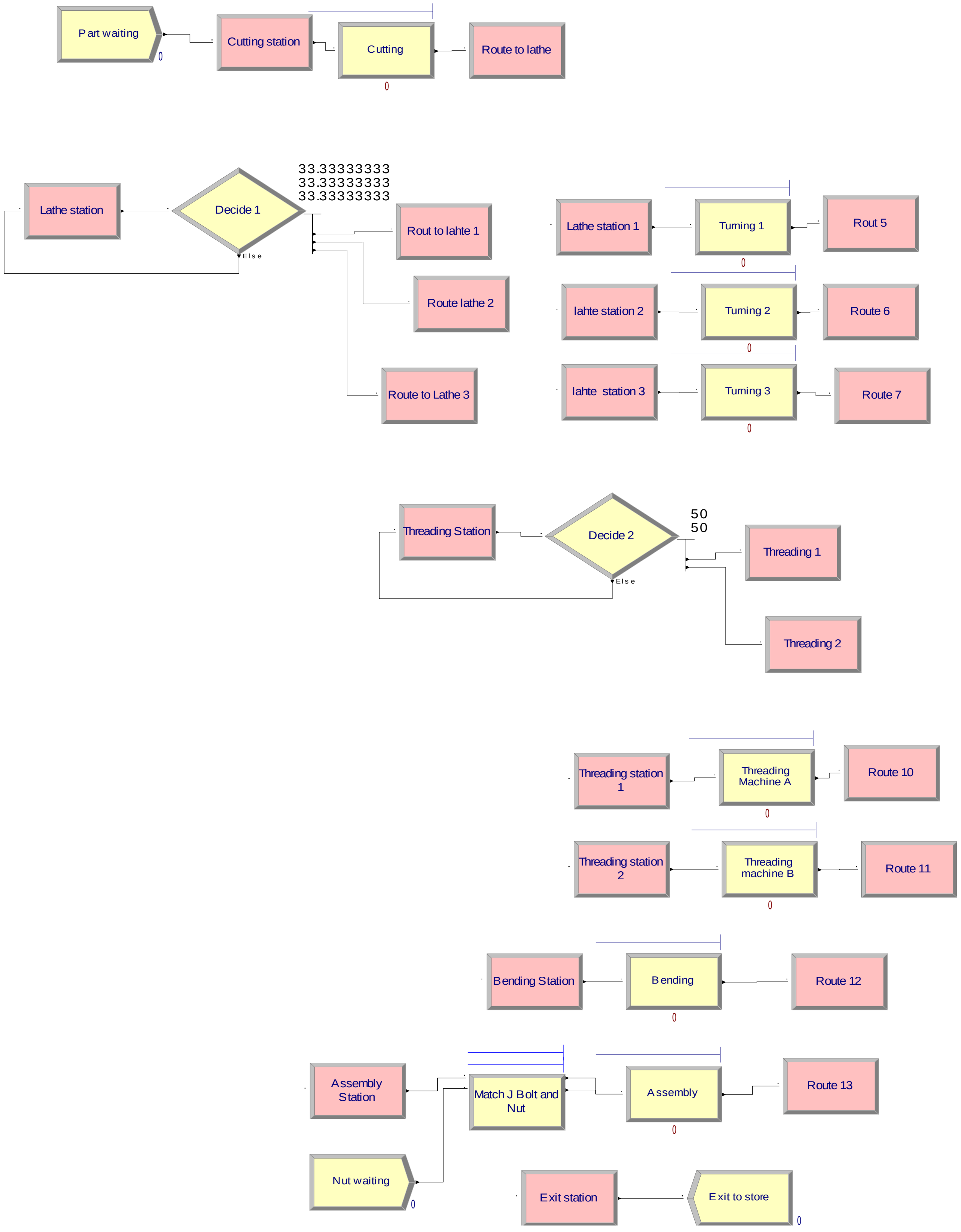

Figure 5. 10: J – Bolt existing production simulation model (Researcher’s simulation model development)

Scheduled Utilization is the time-average number of units of the Resource that are busy (taken over the whole run), divided by the time-average number of units of the Resource that are scheduled (over the whole run).

Table 5. 3: Simulation result comparison for existing and proposed system

Recourses	**Existing**		**Proposed**	
	Scheduled utilization (average)	**No. waiting**	**Scheduled utilization (average)**	**No. waiting**
Bending machine	0.5994	0.1418	0.6524	0.1295
Cutting machine	0.6138	0.3627	0.6802	0.6036
Lathe machine 1	0.9769	20.6381	0.9906	15.3736
Lathe machine 2	0.9872	24.5984	0.9979	23.3736
Lathe machine 3	0.9912	16.4949	0.9832	28.7134
Threading machine 1	0.9580	6.8727	0.9826	3.3324
Threading machine 2	0.9683	3.9877	0.9689	9.4349
Worker at assembly	0.6594	0.053494	0.9633	0.2640

Source: arena simulation result

As we can see from Table 5.3 the bottle neck workstation is lathe workstation so it has high scheduled utilization both at existing and proposed system. The least utilize machine is bending machine in both system but it has 8.8% improvement. In the existing system at the assembly station there was two workers and the utilization is 0.6594 but in proposed system one worker is reduce and the utilization is improved to 0.9633 that is 46.09% improvement. This show that one can handle the workstation.

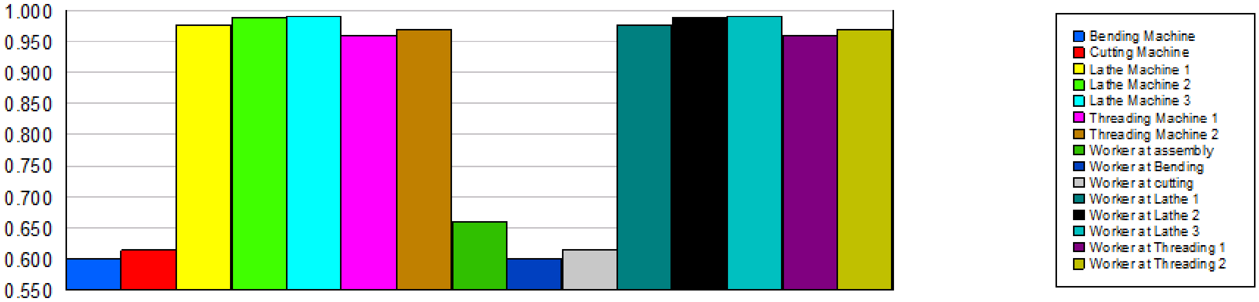

Figure 5. 11: Existing system scheduled utilization (arena simulation result)

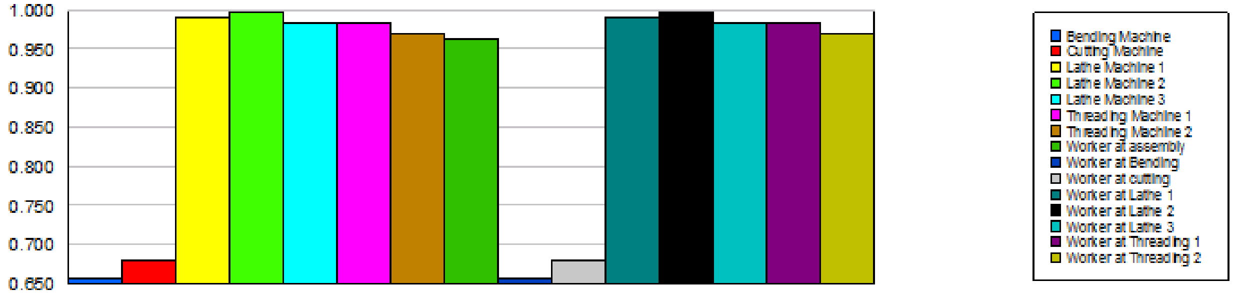

Figure 5. 12: Proposed system scheduled utilization (arena simulation result)

From the arena simulation result graph figure 5.11 and figure 5.12 we can observe that bending machine and cutting machine have low scheduled utilization i.e. both stations have higher capacity so they have lower processing time. The scheduled utilization is better for propose system than existing system in all the stations.

Chapter Six

6. Conclusion and Recommendation

In this chapter the conclusions and recommendations of the whole research are explained in detail. It includes two main parts. The first part discusses about the conclusions of the research. The second parts discuss about the recommendations.

6.1. Conclusion

The finding of direct observation and questionnaire show that there are awkward postures on the J-Bolt production line that lead to WRMSD. These are sitting and forward bending, standing and forward bending, siting and lateral bending, siting lateral bending and twisting of the trunk, standing and lateral bending, sitting on a chair below and above Popliteal height. There is also extended forward reach. These lead to workers fatigue and can reduce productivity.

The machines did not ergonomically designed i.e. at the bending and threading the designers did not provide leg clearance that lead to forward bending and discomfort. The control switches are located out of prime operating space i.e. 11 cm below chair for threading and 10 cm below chair height for bending. The colors of the control switches for revers and forward have the same color this can lead to confusion and error. The working height of lathe machine is below the working height of 5th percentile women. The line have no mechanical material handling equipment so the transportation of materials between work stations is conducted by human shoulder and hand.

According to findings of the study the main muscular-skeletal injures indicate that most of workers high degree of pain at their low back, records of the company show that on average 7.3 workers face minor and 1.66 workers face major injures each year.

The existing layout of the J-Bolt manufacturing line is exposed to forward and backward movement that is lead the material to move longer distance and consumes human resource than necessary similarly exposed to waste of motion and time.

6.2. Recommendation

Based on the major findings and conclusions, the following recommendations are drawn

The layout of the J-Bolt manufacturing line in Ferric Belt metal processing and engineering factory should be rearranged in such a way that reduce wastage of motion, transportation and time as well as ergonomically reduce fatigue.

The workstations of the line should be designed in such a way that it is adjustable to accommodate different body sizes.

The machineries at seating workstation Threading and Bending Machines should be designed in a way that provide leg clearance to avoid forward bending and improve worker comfort.

Mechanical material handling equipment should be provided to transport materials from workstation to workstation that can improve productivity and reduce workers fatigue.

The control switch should have different colors for deferent operation to avoid confusion and work error and also placed at primer operation space (30^0 cone).

The workstations should be designed in such a way that the working height of the work is at elbow height of for seating workstations and 5 – 10 cm below elbow height for standing workstations.

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Appendix A: Questionnaire

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

School Of Mechanical and Industrial Engineering

Graduate School Study in Industrial Engineering

Questionnaire

Dear Sir/ Madam,

Mr Wakweya Tolera, a M.Sc. student is conducting a research entitled “***Integration of Ergonomic and Work Study to Redesign J-Bolt Production Line: The Case of Ferric Belt Metal Processing and Engineering Factory”*** in partial fulfillment of a M.Sc. degree in Industrial Engineering in the School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology, Addis Ababa University.

The purpose of this questionnaire is to gather ergonomic problems in the work area at Ferric Belt Metal Processing and Engineering Factory. To come up with important results, your support in providing reliable information regarding existing phenomena on Ergonomics will be instrumental. The result of this research will help to redesign the workstations for better ergonomic and standard working method. The collected data will only be used for academic purpose, and it will not be disclosed to third party nor presented at any level. Thank you for your cooperation!

Personal Details

1. Sex Male ☐ Female ☐
2. Age less than 25 ☐ 25-35 ☐ 35-45 ☐ 45-55 ☐ Above 55☐
3. Academic Qualification

Certificate ☐

Diploma/TVET ☐

First degree ☐

Second Degree ☐

4. Years of experience in this company _______________ Total years of experience__________

A Questionnaire to be filled by operators

Direction: 1. No need of writing your name

2. Put a tick "√" mark where it corresponds with your response on the space provided

3. When written responses are required, please, make brief statements

4. Respond to all questions precisely

Questionnaires

Working Postures

1. Is there frequent or prolonged bending down where your hands pass below mid-thigh height?
   Yes ☐ No ☐
2. Is there frequent or prolonged reaching above your shoulder? Yes ☐ No ☐
3. Is there frequent or prolonged bending due to an extended reach forward? Yes ☐ No ☐
4. Is there frequent or prolonged twisting of your back? Yes ☐ No ☐
5. Are awkward postures assumed frequently or over prolonged periods, that is, postures that are not forward facing and upright? Yes ☐ No ☐
6. Do you have a way of operating the machine by alternate position siting, standing/walking? Yes ☐ No ☐
7. Do the workstations have way of adjusting for different body sizes? E.g. Height
   Yes ☐ No ☐

Material handling

8. Is manual handling performed frequently or for long time periods by you? Yes ☐ No ☐
9. Are loads moved or carried over long distance? Yes ☐ No ☐
10. Is the weight of the object:
    a) More than 4.5 kg and handled from a seated position? Yes ☐ No ☐
    b) More than 16 kg and handled in a working posture other than seated? Yes ☐ No ☐
    c) More than 55kg? Yes ☐ No ☐
11. For pushing, pulling or other application of forces, are large pushing/pulling forces involved? Yes ☐ No ☐
12. Is the load difficult or awkward to handle, for example, due to its size, shape, temperature, instability or unpredictability? Yes ☐ No ☐

13. Is it difficult or unsafe to get adequate grip of the load? Yes ☐ No ☐

Work environment

14. Is the task performed in a confined space? Yes ☐ No ☐

15. Is the lighting inadequate for safe manual handling and working? Yes ☐ No ☐

16. Is the work environment particularly cold or hot? Yes ☐ No ☐

17. Are the floor working surfaces cluttered, uneven, slippery or otherwise unsafe? Yes ☐ No ☐

18. Is the sound in the working area is disturbing Yes ☐ No ☐

19. Is there disturbing smell in the working area Yes ☐ No ☐

Duration of awkward

20. How much time you are working in the Production shop per day? ___________hour

21. From working time how many hours you are standing _______________hour

22. From working time how many hours you are sitting? ____________hour

23. Are you standing and bending forward during work? Yes ☐ No ☐

If yes for how much time ____________ per day

24. Are you sitting and bending forward during working? Yes ☐ No ☐

If yes for how much time ____________ per day

25. Do you have break in between your work? If yes in what interval of time?

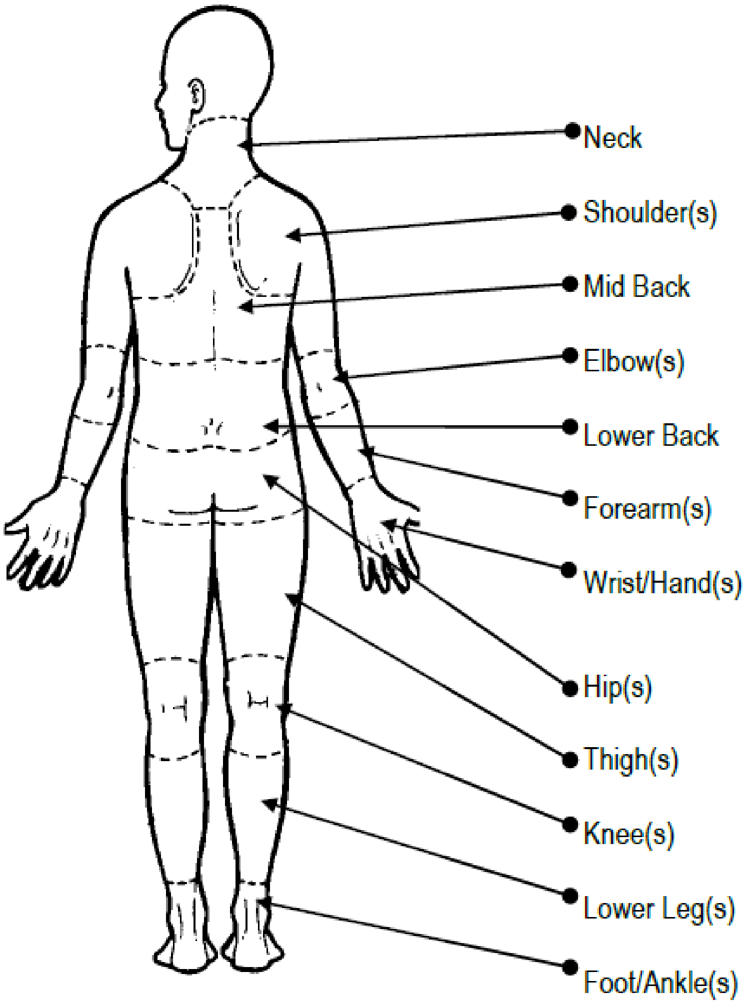
Physical injury/pain

26. Do you face pain in your muscles? Yes ☐ No ☐

If yes at what part and at what degree? Show in the table blow

	Body part	Degree of pain			
		No	Low	Moderate	High
1	Shoulders				
2	Arm				
3	Forearm				
4	Wrist				
5	Hand				
6	Half back				
7	Neck				
8	Lower back				
9	Knee				
10	Hip				
11	Mid Back				
12	Elbow(s)				

13	Thigh(s)				
14	Lower Leg(s)				
15	Foot/Ankle(s)				



Psychology

27. Are you satisfied in the work you are performing in this station?

Yes ☐ No ☐

28. Are you happy when coming to this workstation for work? Yes ☐ No ☐

29. Due to working in your workstation do you have concern of your healthy?

Yes ☐ No ☐

30. Is your performance is ______________from Monday to Friday

A. Increase B. Decrease

Appendix B: Time study Record

Time study Record (Part 1)

JOB ELEMENT	**Number of Observation (Time in seconds)**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Waiting for process start															
Grasp workpiece	6.90	9.21	14.04	9.87	6.60	8.11	6.93	6.78	6.92	7.70	7.4	3.83	2.74	6.96	6.04
Pick raw material from ground	5.08	5.22	5.01	4.35	5.34	8.04	6.84	9.07	4.54	8.60	11.58	5.42	4.52	6.36	10.09
Cut on cutting machine	4.72	3.55	6.70	4.34	7.41	5.99	9.94	2.12	3.64	9.74	38.61	5.10	7.02	9.04	17.13
Throw on ground	2.06	2.32	1.40	1.19	1.65	1.24	1.77	1.75	1.29	1.45	1.30	1.34	1.29	1.39	1.13
Waiting for the next transport to lathe station															
Pick from ground from cutting station	38.52	31.74	34.97	22.88	25.51	30.30	21.97	34.97	35.42	33.46	37.07	46.24	18.60	26.95	18.62
Transport on shoulder	8.74	11.60	11.84	8.62	10.78	12.16	9.45	14.05	18.94	18.34	17.35	15.84	12.16	23.82	11.66
Release on table	1.69	1.94	2.07	1.98	1.90	1.51	1.67	1.73	2.02	1.68	2.01	1.38	1.44	1.56	1.53
Waiting for the next process															
Pick from table and mount on lathe	20.72	28.89	33.39	31.81	12.44	18.55	15.05	18.48	32.79	16.92	17.09	15.67	20.44	20.55	21.70
Turn on lathe	31.91	35.02	40.36	44.81	31.46	35.94	28.31	29.94	38.56	39.93	36.54	32.19	30.84	35.01	31.64
Remove from lathe and place on table	20.72	20.37	15.83	14.42	12.44	10.01	10.41	11.79	20.21	17.77	13.52	11.86	16.86	20.74	11.53
Waiting for the next transport to threading station															
Pick from table	7.05	7.51	8.82	4.22	9.66	9.77	12.5	35.55	11.12	9.15	7.05	7.51	8.82	35.55	11.12
Transport to threading station	11.12	11.36	12.55	12.61	12.02	12.68	8.36	14.83	12	12.35	12.68	8.36	14.83	12	12.35
Place in coolant on the ground	6.55	4.04	5.43	6.27	3.33	5.99	5.55	5.04	6.43	5.27	6.01	5.46	4.04	5.43	6.27
Pick from coolant and setup on threading machine	6.89	10.31	6.19	7.17	5.80	7.37	7.32	3.75	6.74	9.67	7.96	8.44	7.05	7.51	8.05
Threading operation	62.61	50.16	54.76	56.20	52.11	50.60	54.70	54.22	56.27	52.33	54.47	58.91	56.74	61.57	66.80
Remove from threading machine and place on table	1.78	1.83	2.46	2.34	2.15	1.64	1.85	1.73	1.87	1.79	1.48	2.59	1.87	1.94	1.59
Waiting for the next transport to bending station															
Pick from table and transport to bending station	24.98	28.80	31.61	28.84	26.23	24.15	30.55	28.27	28.33	28.02	20.90	15.38	15.10	18.99	18.53
Setting bending machine	8.65	7.66	9.67	8.44	11.14	8.94	9.59	8.88	8.69	12.47	8.57	8.97	9.23	8.03	8.40
Bending operation	8.67	13.74	7.23	7.70	7.26	7.46	7.83	7.40	11.15	7.53	7.28	8.00	8.16	7.54	7.79
Pick from bending machine and Throw to ground	1.47	2.04	3.00	2.72	2.42	2.48	2.21	2.26	2.25	2.30	3.57	3.63	3.83	3.31	2.72

Waiting for transport to assembly area															
Transport to assembly station	13.57	12.03	14.03	9.68	15.50	16.69	9.25	8.82	4.95	6.96	7.49	9.21	5.02	3.37	10.26
Pick from ground J-bolt and Nut	4.05	6.52	3.43	6.56	8.33	3.61	4.48	4.43	4.73	4.90	4.40	4.90	6.28	2.29	3.82
Assemble J-bolt and Nut	8.8.31	15.69	8.89	9.20	14.64	11.51	9.85	13.51	12.29	14.12	14.01	10.40	17.85	20.03	17.33
Through to ground	1.13	1.20	1.06	1.66	1.34	1.57	0.95	0.97	1.22	1.01	1.10	1.09	1.02	1.12	0.95
Waiting for transport to store station															
Pick from ground and mount on hand truck	3.93	6.15	3.57	3.68	4.02	3.62	5.64	4.17	3.13	5.73	2.88	2.85	3.72	5.84	4.34
Transport to store															
Store															

Time study Record (continued)

JOB ELEMENT	**Number of Observation (Time in seconds)**														
	16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Waiting for process start															
Grasp workpiece	15.84	2.86	7.1	7.61	7.90	8.21	13.04	8.87	8.60	9.11	7.93	5.78	7.92	6.70	7.4
Pick raw material from ground	12.57	5.48	4.45	7.38	6.08	4.22	4.01	5.35	5.37	6.04	8.84	6.07	7.54	7.60	9.58
Cut on cutting machine	3.53	3.87	5.81	7.65	8.69	19.75	9.46	16.59	3.32	3.26	3.29	9.31	9.48	4.79	8.06
Throw on ground	0.94	2.03	2.36	2.32	1.10	1.49	1.25	1.64	1.67	1.85	1.49	1.25	1.40	1.24	1.34
Waiting for the next transport to lathe station															
Pick from ground from cutting station	31.85	23.32	48.44	35.45	51.18	78.72	76.25	35.52	52.46	37.12	35.52	34.74	30.97	26.88	27.51
Transport on shoulder	10.26	14.3	15.32	15.51	12.34	16.4	7.94	15.79	10.34	9.95	9.74	11.60	11.84	9.62	10.78
Release on table	1.51	1.06	1.34	1.25	0.94	1.09	1.35	1.54	1.1	1.23	1.99	1.64	2.03	1.98	1.94
Waiting for the next process															
Pick from table and mount on lathe	18	18.40	16.61	16.25	15.63	19.15	20.15	17.15	18.00	17.26	18.04	18.14	17.43	15.39	14.90
Turn on lathe	28.23	24.08	26.68	27.1	28.64	34.59	28.16	33.33	26.28	28.01	30.26	36.67	25.85	35.54	28.96
Remove from lathe and place on table	21.48	19.09	19.87	15.7	21.61	15.42	13.45	29.63	16.7	15.49	18.74	13.32	17.41	18.64	14.2
Waiting for the next transport to threading station															
Pick from table	9.15	4.22	9.66	9.77	12.5	7.05	9.15	9.51	11.12	8.82	12.5	9.75	8.74	12.85	13.4
Transport to threading station	11.12	11.36	12.55	12.61	12.02	12.68	8.36	14.83	12	12.35	11.12	11.36	12.55	12.61	12.02
Place in coolant on the ground	3.33	5.99	5.55	5.04	6.43	5.27	6.01	5.46	6.55	4.33	5.99	5.55	5.14	6.43	5.27

Pick from coolant and setup on threading machine	7.64	7.78	7.51	5.42	4.32	5.5	6.84	5.61	4.91	5.61	4.49	3.99	5.05	4.22	4.69
Threading operation	45.65	42.37	38.27	45.61	38.19	40.76	40.48	41.91	41.26	41.66	37.56	36.21	37.79	39.17	36.35
Remove from threading machine and place on table	2.58	2.08	4.22	1.4	4.69	2.98	2.36	2.27	1.47	1.58	2.37	2.38	2.66	3.39	1.93
Waiting for the next transport to bending station															
Pick from table and transport to bending station	18.75	17.73	27.01	13.97	15.56	11.18	15.68	29.92	33.53	14.58	16.36	17.6	22.5	12.26	26.27
Setting bending machine	6.14	13.53	5.61	6.06	6.89	5.49	5.74	7.79	6.34	5.99	5.6	5.72	5.52	5.69	6.62
Bending operation	7.43	7.50	5.88	6.69	6.32	6.14	5.46	6.6	8.01	6.47	5.94	6.55	7.6	6.37	5.95
Pick from bending machine and Throw to ground	2.00	2.35	2.28	2.21	1.64	2.06	2.58	2.25	2.11	1.93	1.98	2.27	2.95	2.13	2.16
Waiting for transport to assembly area															
Transport to assembly station	9.54	6.59	8.23	15.04	11.88	6.21	7.22	10.63	6.40	8.16	5.38	12.34	6.02	6.21	8.42
Pick from ground J-bolt and Nut	3.65	2.98	5.73	3.95	6.93	3.38	5.9	5.67	3.77	9.84	5.3	3.51	4.03	12.26	11.11
Assemble J-bolt and Nut	9.06	15.34	10.28	13.24	16.39	11.56	13.59	11.53	12.43	19.26	10.4	16.92	8.64	4.66	3.87
Through to ground	1.22	1.17	1.05	0.95	1.23	1.20	1.16	1.26	1.14	1.47	1.35	1.07	1.25	1.07	1.12
Waiting for transport to store station															
Pick from ground and mount on hand truck	5.82	6.41	14.21	14.74	12	9.39	15.58	11.72	9.52	10.78	9.31	13.32	13.55	20.58	10.8
Transport to store															
Store															

Time study Record (continued)

JOB ELEMENT	**Number of Observation (Time in seconds)**														
	31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**
Waiting for process start															
Grasp workpiece	5.83	4.74	4.96	9.34	12.84	5.86	8.1	6.61	7.90	9.21	12.04	11.87	7.60	7.11	7.93
Pick raw material from ground	8.42	6.52	6.56	8.09	9.57	8.48	5.45	6.38	5.68	5.22	5.51	5.35	6.34	8.04	6.84
Cut on cutting machine	3.33	6.49	4.00	9.64	5.14	4.67	2.92	5.27	3.36	5.03	4.46	3.40	3.49	4.78	3.54
Throw on ground	1.35	1.18	0.97	2.03	2.26	2.42	1.30	1.49	1.45	1.44	1.57	1.55	1.49	1.45	1.30
Waiting for the next transport to lathe station															
Pick from ground from cutting station	28.30	25.97	30.97	33.42	35.46	36.27	44.04	21.60	23.95	21.62	26.85	28.32	43.44	40.45	59.18
Transport on shoulder	12.16	10.45	14.05	15.94	18.34	17.35	15.84	15.16	20.82	12.66	10.66	14.3	15.32	15.51	12.34
Release on table	1.51	1.67	1.73	2.02	1.68	1.96	1.43	1.44	1.56	1.53	1.51	1.06	1.34	1.25	0.94

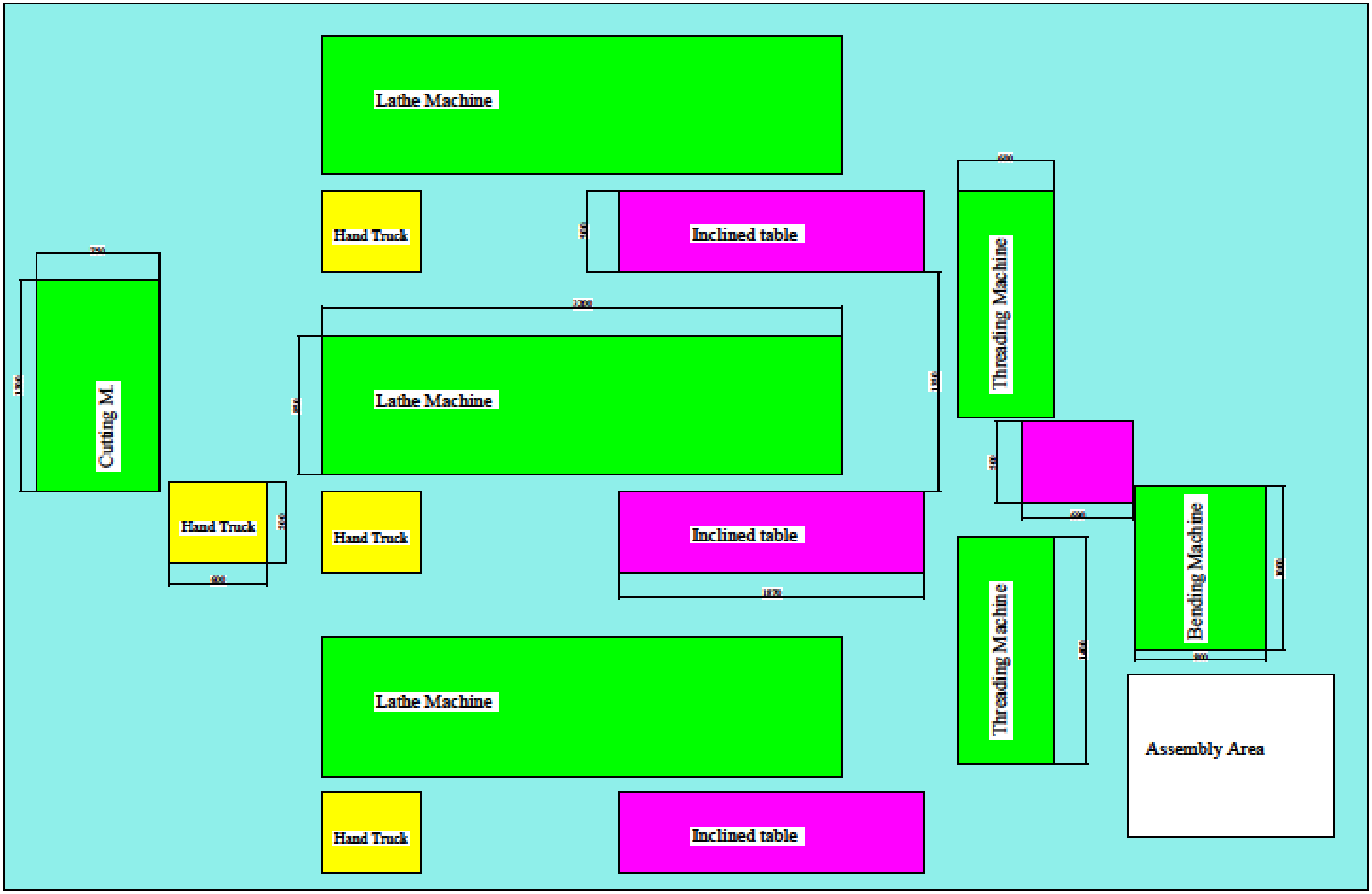
Waiting for the next process															
Pick from table and mount on lathe	25.84	16.56	20.92	21.52	23.77	24.2	43.1	16.56	30.32	20.76	28.52	30.04	25.92	21.43	23.23
Turn on lathe	33.28	25.91	38.74	30.48	25.5	28.76	35.18	26.59	33.62	29.71	25.97	36.68	29.97	28.28	33.68
Remove from lathe and place on table	13.44	14.48	13.52	22.06	13.38	17.44	14.18	16.34	17.11	18.29	13.08	13.63	15.87	13.06	16.34
Waiting for the next transport to threading station															
Pick from table	11.78	17.45	13.72	9.83	8.89	14.12	13.73	15.23	11.41	12.58	8.49	14.56	9.48	14.42	8.15
Transport to threading station	11.36	12.55	12.61	12.02	12.68	8.36	14.83	12	12.35	11.89	12.35	11.12	11.36	12.55	12.61
Place in coolant on the ground	6.01	5.46	4.74	5.43	6.55	4.43	5.99	5.65	5.04	6.43	5.27	6.01	5.46	4.34	5.43
Pick from coolant and setup on threading machine	14.89	4.66	2.6	6.58	6.18	8.11	5.49	5.33	4.57	5.57	5.82	6.74	6.07	5.2	4.81
Threading operation	40.16	37.24	37.5	38.96	35.85	35.52	36	37.36	34.78	39.85	38.25	38.76	40.07	35.02	32.54
Remove from threading machine and place on table	2.28	1.63	2.45	2.27	2.63	7.61	3.08	1.95	1.55	1.53	2.11	2.47	2.88	2.5	3.24
Waiting for the next transport to bending station															
Pick from table and transport to bending station	27.33	25.02	21.90	18.38	19.10	18.59	18.93	23.75	17.73	24.01	14.97	16.56	12.18	16.68	25.92
Setting bending machine	5.3	5.39	5.62	6.07	5.75	5.86	4.6	5.62	5.6	5.57	4.55	6.98	5.84	6.2	6.27
Bending operation	6.57	6.95	6.75	6.6	6.67	7.08	6.24	7.09	8.66	7.46	6.59	6.62	6.22	5.6	7.11
Pick from bending machine and Throw to ground	2.99	2.17	2.03	1.91	3.25	1.75	2.38	1.87	2.5	2.61	2.9	2.7	2.89	1.98	2.5
Waiting for transport to assembly area															
Transport to assembly station	13.40	14.15	7.98	10.81	12.28	9.14	12.24	10.83	12.18	8.39	14.02	17.68	22.11	19.83	13.07
Pick from ground J-bolt and Nut	5.33	2.63	3.77	5.64	2.5	3.37	5.04	3.28	4.91	8.36	4.49	4.33	9.97	3.29	3.77
Assemble J-bolt and Nut	13.32	14.77	9.13	10.46	19.06	11.88	16.88	11.8	15.79	13.33	16.21	14.33	18.19	13.6	30.5
Through to ground	1.19	1.22	1.32	0.95	1.02	1.07	1.15	1.05	1.12	1.15	1.15	1.13	1.25	1.06	1.36
Waiting for transport to store station															
Pick from ground and mount on hand truck	8.08	28.24	5.93	7.15	4.57	5.68	5.02	5.62	4.64	5.17	4.13	5.73	4.88	5.85	4.72
Transport to store															
Store															

Time study Record (continued)

JOB ELEMENT	**Number of Observation (Time in seconds)**						**Averages**
	46	**47**	**48**	**49**	**50**	**51**	
Waiting for process start							
Grasp workpiece	5.78	7.92	6.80	5.45	6.83	7.74	7.79
Pick raw material from ground	9.07	5.54	8.60	11.58	6.42	5.52	6.86
Cut on cutting machine	5.76	6.75	7.45	6.34	7.52	8.12	7.12
Throw on ground	1.34	1.29	1.39	1.13	1.04	2.03	1.52
Waiting for the next transport to lathe station							
Pick from ground from cutting station	70.72	68.25	43.52	47.46	42.12	38.45	37.13
Transport on shoulder	16.4	7.94	15.79	10.34	11.95	10.15	13.34
Release on table	1.09	1.35	1.54	1.1	1.23	1.61	1.54
Waiting for the next process							
Pick from table and mount on lathe	24.79	25.02	18.41	28.84	32.98	22.88	21.77
Turn on lathe	25.47	26.45	31.25	27.13	29.53	28.39	31.28
Remove from lathe and place on table	14	12.95	15.25	15.05	13.32	13.02	15.98
Waiting for the next transport to threading station							
Pick from table	11.76	13.45	9.49	12.76	11.89	12.74	11.56
Transport to threading station	12.02	11.36	10.79	12.61	12.02	12.68	12.00
Place in coolant on the ground	6.55	4.04	5.43	6.27	3.33	6.49	5.45
Pick from coolant and setup on threading machine	5.94	5.07	6.37	4.25	4.65	4.97	6.23
Threading operation	36.32	37.56	33.12	35.03	38.02	34.37	43.49
Remove from threading machine and place on table	2.86	1.45	1.73	4.19	2.5	1.83	2.39
Waiting for the next transport to bending station							
Pick from table and transport to bending station	31.53	16.58	16.36	18.6	22.5	16.26	21.26
Setting bending machine	6.69	6.35	7.28	7.28	6.29	8.79	7.14
Bending operation	6.57	5.69	7.19	6.84	6.87	6.91	7.18
Pick from bending machine and Throw to ground	1.82	2.06	1.78	1.85	2.06	2.15	2.38
Waiting for transport to assembly area							
Transport to assembly station	11.03	12.03	9.60	10.58	13.69	9.15	10.57
Pick from ground J-bolt and Nut	5.47	4.1	3.57	3.29	8.81	4.43	5.12

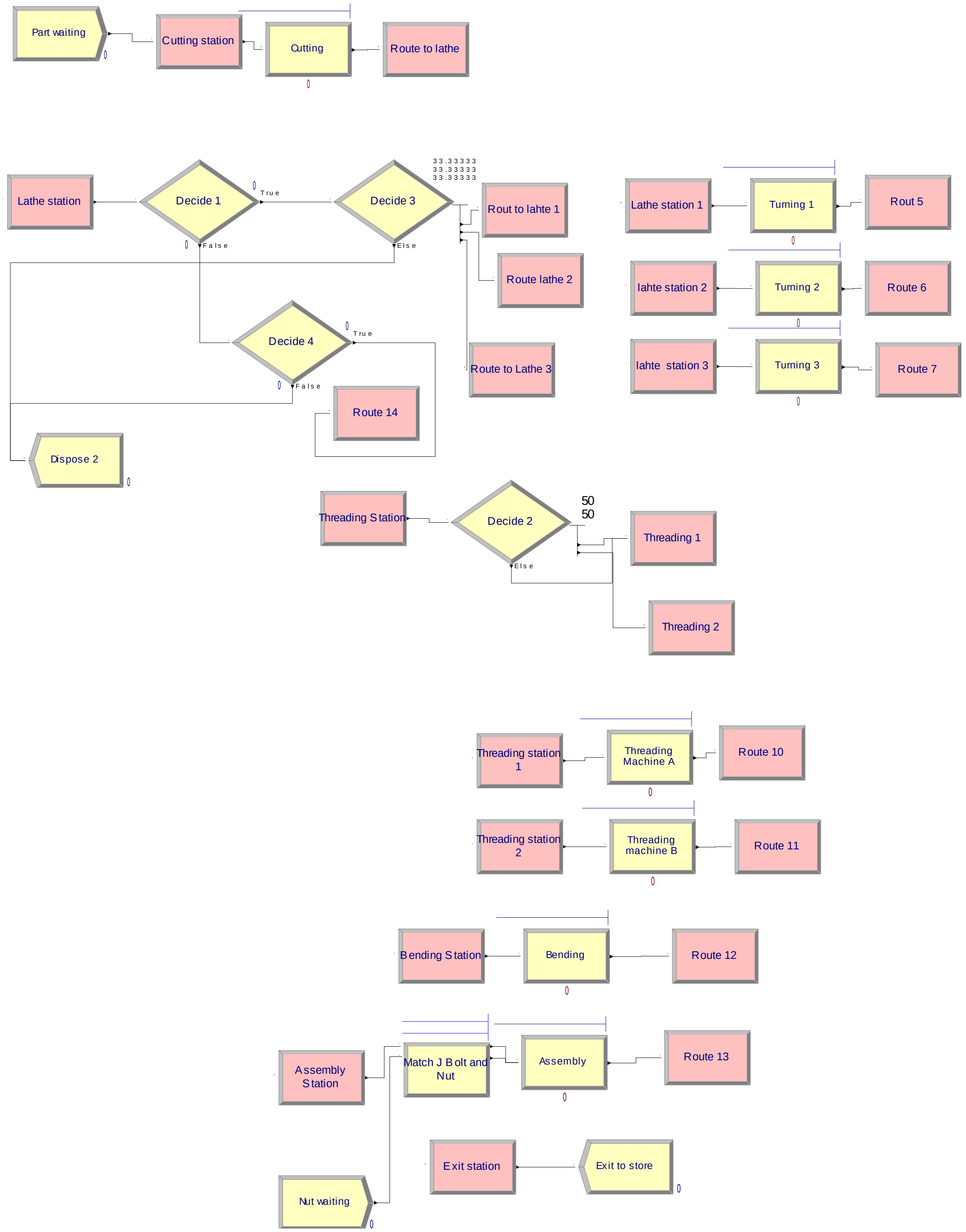
Assemble J-bolt and Nut	11.98	10.18	15.58	15.96	8.41	14.25	13.44
Through to ground	1.04	1.37	1.33	1.17	1.22	1.17	1.17
Waiting for transport to store station							
Pick from ground and mount on hand truck	5.84	5.34	6.82	6.41	14.21	14.74	7.84
Transport to store							
Store							

Appendix C: Proposed layout with dimensions



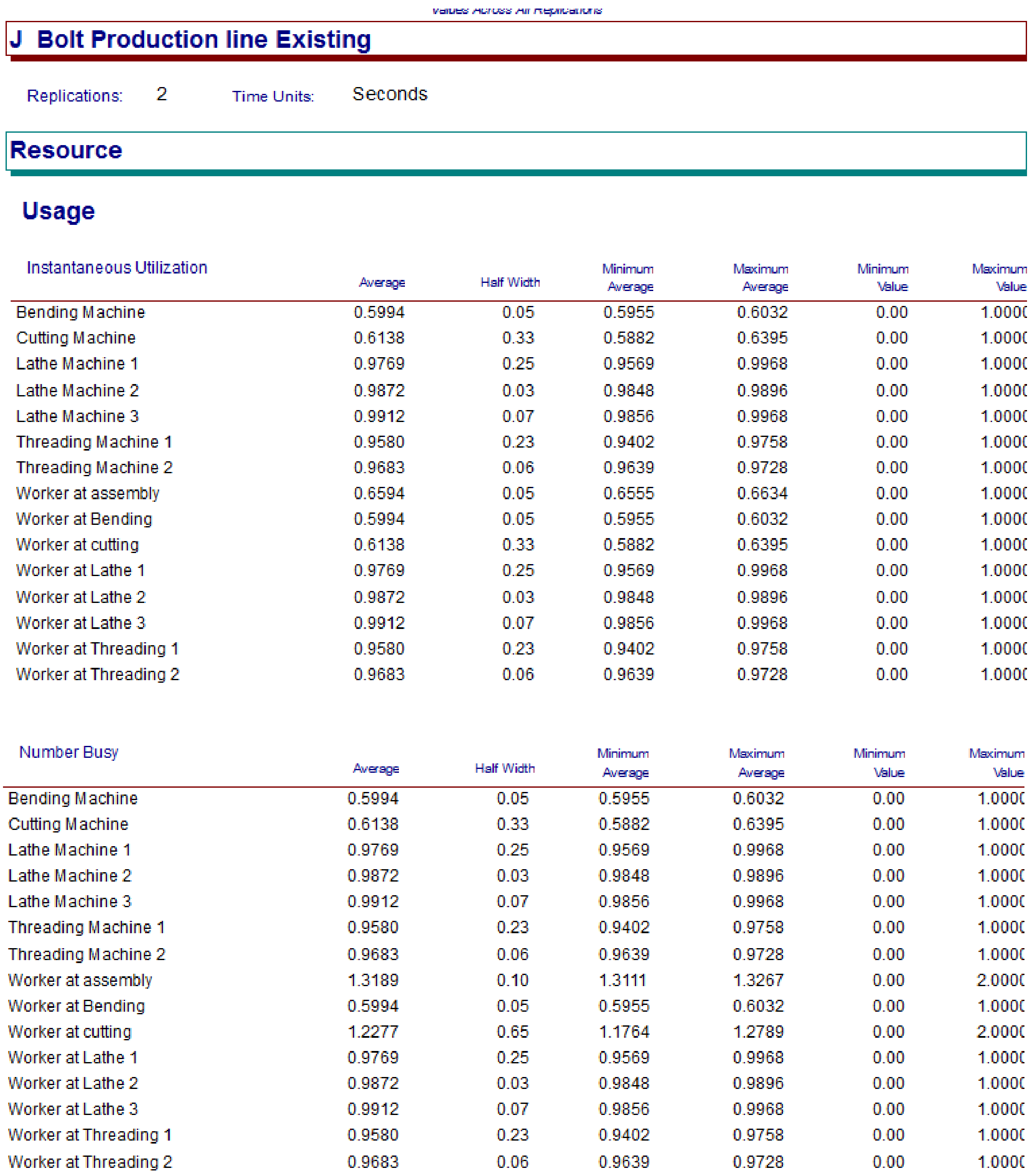
Layout of the J – Bolt manufacturing line

Appendix D: Proposed system arena simulation model



Appendix E: Sample Arena simulation result

Existing system



Values Across All Replications

J Bolt Production line Existing

Replications: 2 Time Units: Seconds

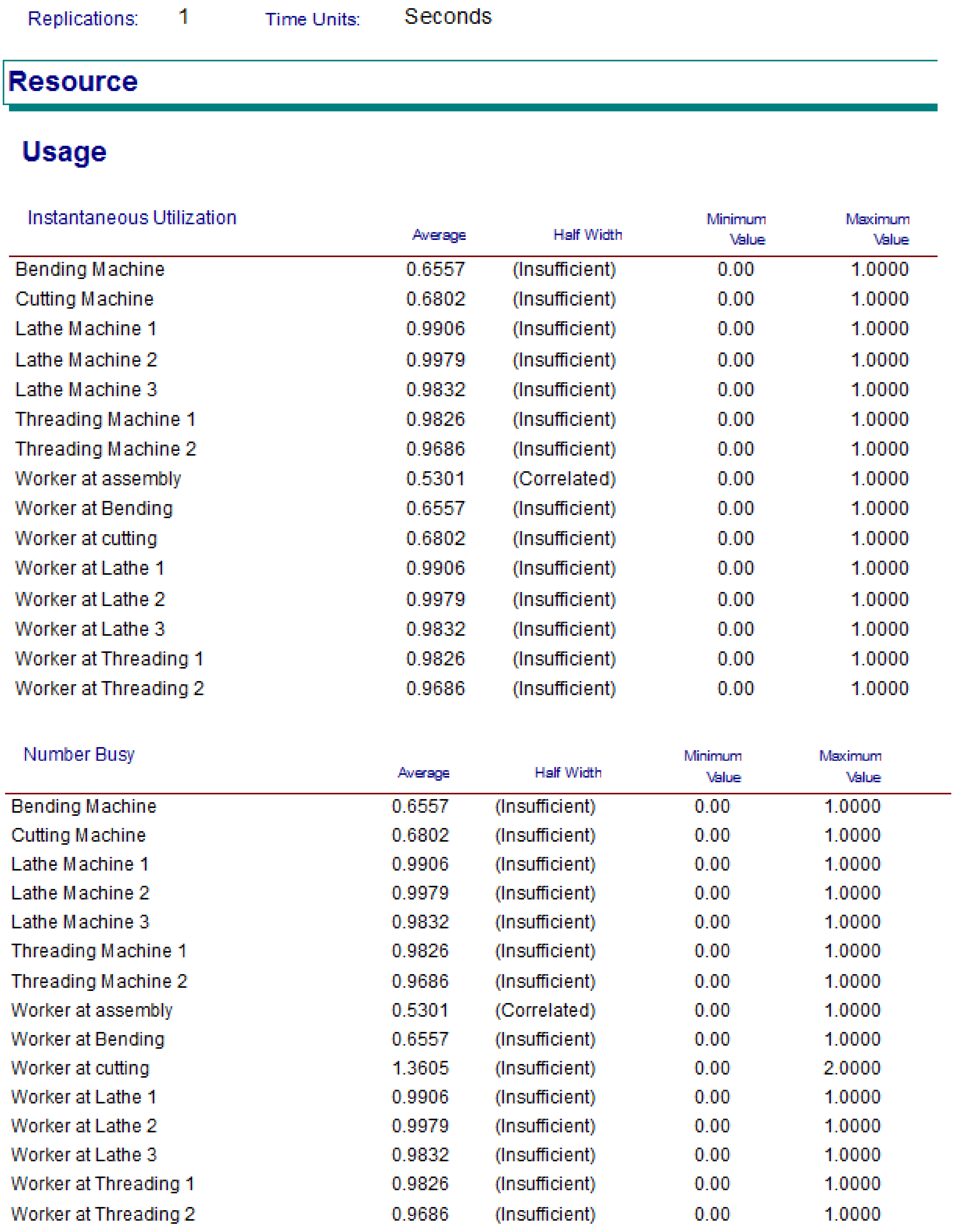
Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Bending Machine	0.5994	0.05	0.5955	0.6032	0.00	1.0000
Cutting Machine	0.6138	0.33	0.5882	0.6395	0.00	1.0000
Lathe Machine 1	0.9769	0.25	0.9569	0.9968	0.00	1.0000
Lathe Machine 2	0.9872	0.03	0.9848	0.9896	0.00	1.0000
Lathe Machine 3	0.9912	0.07	0.9856	0.9968	0.00	1.0000
Threading Machine 1	0.9580	0.23	0.9402	0.9758	0.00	1.0000
Threading Machine 2	0.9683	0.06	0.9639	0.9728	0.00	1.0000
Worker at assembly	0.6594	0.05	0.6555	0.6634	0.00	1.0000
Worker at Bending	0.5994	0.05	0.5955	0.6032	0.00	1.0000
Worker at cutting	0.6138	0.33	0.5882	0.6395	0.00	1.0000
Worker at Lathe 1	0.9769	0.25	0.9569	0.9968	0.00	1.0000
Worker at Lathe 2	0.9872	0.03	0.9848	0.9896	0.00	1.0000
Worker at Lathe 3	0.9912	0.07	0.9856	0.9968	0.00	1.0000
Worker at Threading 1	0.9580	0.23	0.9402	0.9758	0.00	1.0000
Worker at Threading 2	0.9683	0.06	0.9639	0.9728	0.00	1.0000

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Bending Machine	0.5994	0.05	0.5955	0.6032	0.00	1.0000
Cutting Machine	0.6138	0.33	0.5882	0.6395	0.00	1.0000
Lathe Machine 1	0.9769	0.25	0.9569	0.9968	0.00	1.0000
Lathe Machine 2	0.9872	0.03	0.9848	0.9896	0.00	1.0000
Lathe Machine 3	0.9912	0.07	0.9856	0.9968	0.00	1.0000
Threading Machine 1	0.9580	0.23	0.9402	0.9758	0.00	1.0000
Threading Machine 2	0.9683	0.06	0.9639	0.9728	0.00	1.0000
Worker at assembly	1.3189	0.10	1.3111	1.3267	0.00	2.0000
Worker at Bending	0.5994	0.05	0.5955	0.6032	0.00	1.0000
Worker at cutting	1.2277	0.65	1.1764	1.2789	0.00	2.0000
Worker at Lathe 1	0.9769	0.25	0.9569	0.9968	0.00	1.0000
Worker at Lathe 2	0.9872	0.03	0.9848	0.9896	0.00	1.0000
Worker at Lathe 3	0.9912	0.07	0.9856	0.9968	0.00	1.0000
Worker at Threading 1	0.9580	0.23	0.9402	0.9758	0.00	1.0000
Worker at Threading 2	0.9683	0.06	0.9639	0.9728	0.00	1.0000

Proposed system



Replications: 1 Time Units: Seconds

Resource

Usage

Instantaneous Utilization	Average	Half Width	Minimum Value	Maximum Value
Bending Machine	0.6557	(Insufficient)	0.00	1.0000
Cutting Machine	0.6802	(Insufficient)	0.00	1.0000
Lathe Machine 1	0.9906	(Insufficient)	0.00	1.0000
Lathe Machine 2	0.9979	(Insufficient)	0.00	1.0000
Lathe Machine 3	0.9832	(Insufficient)	0.00	1.0000
Threading Machine 1	0.9826	(Insufficient)	0.00	1.0000
Threading Machine 2	0.9686	(Insufficient)	0.00	1.0000
Worker at assembly	0.5301	(Correlated)	0.00	1.0000
Worker at Bending	0.6557	(Insufficient)	0.00	1.0000
Worker at cutting	0.6802	(Insufficient)	0.00	1.0000
Worker at Lathe 1	0.9906	(Insufficient)	0.00	1.0000
Worker at Lathe 2	0.9979	(Insufficient)	0.00	1.0000
Worker at Lathe 3	0.9832	(Insufficient)	0.00	1.0000
Worker at Threading 1	0.9826	(Insufficient)	0.00	1.0000
Worker at Threading 2	0.9686	(Insufficient)	0.00	1.0000

Number Busy	Average	Half Width	Minimum Value	Maximum Value
Bending Machine	0.6557	(Insufficient)	0.00	1.0000
Cutting Machine	0.6802	(Insufficient)	0.00	1.0000
Lathe Machine 1	0.9906	(Insufficient)	0.00	1.0000
Lathe Machine 2	0.9979	(Insufficient)	0.00	1.0000
Lathe Machine 3	0.9832	(Insufficient)	0.00	1.0000
Threading Machine 1	0.9826	(Insufficient)	0.00	1.0000
Threading Machine 2	0.9686	(Insufficient)	0.00	1.0000
Worker at assembly	0.5301	(Correlated)	0.00	1.0000
Worker at Bending	0.6557	(Insufficient)	0.00	1.0000
Worker at cutting	1.3605	(Insufficient)	0.00	2.0000
Worker at Lathe 1	0.9906	(Insufficient)	0.00	1.0000
Worker at Lathe 2	0.9979	(Insufficient)	0.00	1.0000
Worker at Lathe 3	0.9832	(Insufficient)	0.00	1.0000
Worker at Threading 1	0.9826	(Insufficient)	0.00	1.0000
Worker at Threading 2	0.9686	(Insufficient)	0.00	1.0000