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كلية الدراسات العليا

Productivity Improvement of Industrial Pipes Insulators

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Thesis submitted to Postgraduate College Sudan University of Science and Technology in Partial fulfillment of the Requirements for the Degree of M.Sc. in Mechanical Engineering (Production)

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Dedications:

This work is dedicated to my family and friends.

To my dear wife, my brothers and sisters.

A special feeling of gratitude to my loving parents, whose words encourage and push me to be better.

Also, I dedicated this work to my friends, who have supported me throughout the research. I will always appreciate their effort and help.

I dedicate this work to (XY) insulator company family,

where this research is done.

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Abstract

The production processes of heat insulation are studied in order to improve the productivity of the production plant. It has been found that to increase the productivity an improvement in the manual processes to a more efficient processes, equipment and tools should be done. The DMAIC methodology was used. Based on this methodology a tool was designed to simplify two processes (cutting and rolling process). Therefore, the cutting room was dispensed and the number of workers were reduced by two workers which was 11.1% of the total number of workers. The new model was designed and simulated by the **Solid Work** program. Based on simulation the time used for cutting and rolling to produce one piece with the new tool is estimated to be 3 minutes instead of 8 minutes and the new takt time was 5.53 minutes instead of 8.58 minutes.

The previous production rate is 38 units per day (10,000 units per year), The new production rate is 59 units per day (15,500 units per year), the increase percentage of production is 55% more.

مستخلص

تم دراســـة عمليات إنتاج العازل الحراري للانابيب الصـــناعية من أجل تحســـين الإنتاجية وإجراء تحسـينات في العمليات اليدوية لتصـبح العمليات والمعدات والأدوات أكثر كفاءة. في هذا البحث ، تم اسـتخدام منهجية (DMAIC). بناءً على هذه المنهجية تم تصــميم أداة لتبسـيط عمليتين (عملية القطع واللف). حيث تم الاســتغناء عن غرفة القطع وتقليص عدد العمال بعدد عاملين والتي تمثل نســبة 11.1 % من العدد الكلي للعمال. تم تصــميم نموذج الأداة الجديدة ورســمها وعمل محاكاة لها بواسـطة برنامج Solid Work . بناءاَ علي المحاكاة تم تقدير الوقت المستخدم لعملية القطع واللف لإنتاج وحدة واحدة باستخدام الأداة الجديدة بـــ 3 دقائق بدلاً من 8 دقائق والمدة الزمنية الجديدة لانتاج الوحدة الواحدة 5.53 دقيقة بدلاً من 8.58 دقيقة.

معدل الإنتاج الســابق هو 38 وحدة في اليوم (10000 وحدة في الســنة) ، ومعدل الإنتاج الجديد 59 وحدة في اليوم (15500 وحدة في السنة) ، وزيادة نسبة الإنتاج بــ 55 ٪.

Chapter One
Introduction

Chapter one

1. Introduction

1.1. Background:

In industrial field, fluid with high temperature flow through pipes from one machine to others. Thus, appears the need for insulation of pipes with high heat. This heat insulation is produced in several layers with many steps some of them are manual. The annual capacity of the available production lines is 10,000 elements per year with 18 workers. The production period to produce batch of 500 heat insulation elements (with length one meter for each element) is 71.5 hours.

1.2. Problem Definition:

In the (XY) pipe insulator company, some of the production steps are done manually by utilizing a large number of workers which consume a lot of time.

1.3. Objective of the Research:

The objective of this research is to study the production processes of heat insulation and improve it to reduce the manpower and production time.

1.4. Scope of the Research:

The research focuses on the improvement in the manual processes by using more efficient processes, equipment and tools.

1.5. Layout of the Research:

This Research consists of five chapters. The first chapter is introduction consisting of the background, problem, objectives, and scope of the research. The second chapter is literature review consisting of the theoretical background and previous studies. The third chapter is methodology which explain the method used in carrying out the research. The forth chapter is result and discussions. The fifth chapter is conclusion and recommendations.

Chapter Two
Literature Review

Chapter Two

2. Literature Review

2.1. Previous study:

1. Wan Hasrulnizzam, Wan Mahmood and Mohd Nizam Ab Rahman (2010) develop three alternatives in order to enhance the production line; reducing the quantity of idle machines, reorganize tasks for operators, reduce operators, and add a new workstation at the bottleneck area. To enhance the current production line productivity, the company can implement one of the alternatives: alternative 1, reduces the number of run-in machines from 8 units to 2 units; this can be the proposal for ramping up a new production line. Alternative 2, can increase the production output by 9.58% and reduce the production cost by reducing the number of operators from 13 to 12, saving costs of machines and space. Alternative 3, by adding a machine can increase the productivity as much as 28.06%. The experiments on simulated and real data clearly indicate that the productivity improvement on the current performance can be achieved by reallocating the number of operators or machines effectively [1].

2. Md. Abdul Muktadir, Sobur Ahmed, Fatema Tuj-zohra and Razia Sultanan (2017) succeed in increase the productivity in leather product industry of Bangladesh 12.71% more by reducing the time of the critical operation [2].

3. Dr. V SASIREKHA, Mr. GAUTAM KUMAR TRIPATHI (2013) Work study analysis was conducted at the audio division of Hyundai Mobis India ltd to improve the operational and production efficiency. Existing audio production per hour is 60 audio units. By implementing the suggestions offered the division can increase 12 audio productions in one shift and 36 audio units (in three shifts) in a day (20% increase) [3].

4. Tang Saihong, Ng Tanching, Chong Weijian and Chen Kahpin (2016) Lean Manufacturing is a popular tool to be implemented in printing industry fields for the purpose of achieving the successful production goals and it is a well-organized method used to eliminate the waste or nonvalue-added activities. the researcher identifies the problem faced in company's production line and implement lean tools in order to improve the productivity. The result was simulated by using Flexsim and shows that 7.59 seconds was saved in producing one piece of calendar. At the end, the result shows that OEE increase from 34.3% to 60% and the company total save around 6 hours per month by implement one-piece flow [4].

5. Nourhan Hassan, Lina Hamdan, Noor Khourshed, Walid Smew (2018) Company XYZ has been suffering from about 22% waste in the usage of its insulation material that corresponded to an average of more than $42,000 per year. This study presents the impact of the Lean Six Sigma DMAIC on the company which will carry out a reduction in waste by 50% [5].

2.2. Insulation:

Insulation is well known to humans from a long time. Egyptians used earth as an insulator for their comfort [6]. The first use of insulation using cellulose was patented in England in 1893. It is reported that more applications of insulation started from the 1920's [7].

Insulation is the process of keeping heat, sound, or electricity from spreading. The act of protecting something with a material that prevents heat, sound, electricity, etc. from passing through. The materials used for this or material that is used to stop heat, sound, or electricity from escaping or entering [8].

2.3. Pipe insulation:

Pipe Insulation is thermal or acoustic insulation used on pipework. Insulated pipes (called also preinsulated pipes or bonded pipe) are widely used for district heating and hot water supply. It consists of a steel pipe, an insulating layer, and an outer casing. The main purpose of such pipes is to maintain the temperature of the fluid in the pipes. A common application is the hot water from district heating plants. [9]

2.4. Thermal insulation:

Thermal insulation is the reduction of heat transfer (the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative manipulated [10]. Thermal insulation is also known as a single material or combination of materials that when properly applied, will retard the rate of heat flow by conduction, convection, and radiation. It retards heat flow into or out of an object or building due to its high thermal resistance [11]. Thermal insulation can be achieved with specially engineered methods or processes, as well as with suitable object shapes and materials. Thermal insulation provides a region of insulation in which thermal conduction is reduced or thermal radiation is reflected rather than absorbed by the lower-temperature body [12].

The insulating capability of a material is measured with thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability (R-value). In thermal engineering, other important properties of insulating materials are product density (r), and specific heat capacity (c) [13].

2. 5. Advantages of thermal insulation:

The primary purpose of insulation is to prevent/minimize thermal energy losses for the conservation of energy. However, insulation helps in several ways as indicated below:

1. Provide more accurate control of process temperatures and protection of the product.
2. Prevent condensation on cold surfaces and the resulting corrosion.
3. Minimize the formation of condensate in steam pipeline and related problems.
4. Provide fire protection and absorbs vibration.
5. Conserve energy by reducing heat loss or gain.
6. Facilitate temperature control of process.
7. Prevent vapor flow and water condensation on cold surfaces.
8. Increase operating efficiency of heating/ventilating/cooling, plumbing, steam, process and power systems found in commercial and industrial installations.
9. Assist mechanical systems in meeting criteria in food and cosmetic plants.
10. Reduce emissions of pollutants to the atmosphere. [14,15].

2.6. Method of thermal Insulation:

There is a basic need for insulation at any surface which is in contact with hot or cold surrounding. To insulate a surface, there are few points that are required to be taken care of like cleaning of surface [16] and application of corrosion repellents like chloride, fluorine and magnesium to have least amount of water gain to prevent corrosion [17].

Thompson [18] reported that, each product has a different temperature for storage, according to this temperature, the optimum operating temperature and the type of insulation material and thickness of insulation is selected. The designing is a very important which involves location of the plant, temperature conditions and service conditions [19]. Thickness of insulation is also very important in designing, there is a thickness below which the insulation is insufficient and the loss of heat is more Higher thickness results into higher cost input with a little thermal savings [20]. Thus, economical thickness has to be calculated for given insulation material. Hart and Yarbrough [21] noticed that, once the insulation system started to absorb significant quantities of greater than 2% volume, the performance might find unsatisfactory. Next step is application of insulation material either in-situ insulation or panel insulation with a glue to the surface in a staggered manner and with a wire mash placed above it for better holding of plaster or tiles [22].

2.7. Temperature Ranges:

The temperature range, within which the term "thermal insulation" will apply, is from -75°C to 815°C. All applications below -75°C are termed "cryogenic", and those above 815°C are termed "refractory". Thermal insulation is further divided into three general application temperature ranges as follows:

A. Low Temperature Thermal Insulation:

1) 5°C through 0°C - i.e. Cold or chilled water.
2) 0°C through -40°C - i.e. Refrigeration or glycol.
3) -40°C through -75°C - i.e. Refrigeration or brine.
4) -75°C through -275°C (absolute zero) - i.e. Cryogenic.

B. Intermediate Temperature Thermal Insulation:

1) 16°C through 100°C - i.e. Hot water and steam condensate.
2) 100°C through 315°C - i.e. Steam, high temperature hot water.

C. High Temperature Thermal Insulation:

1) 315°C through 815°C - i.e. Turbines, breechings, stacks, exhausts, incinerators [10].

2.8. Important properties of insulation materials:

There are many properties of insulating materials which are important to consider for the selection of insulation materials from the market. The final selection not only depends on the properties of the material but on the basis of economics and structural considerations.

An ideal insulating material should fulfil a number of criteria such as low thermal conductivity, non-corrosive, non-toxic, non-flammable and exhibit little or no decomposition at long period of time [23]. The five key properties of an insulating material to be considered have been described; these properties are compressive strength, service temperature range, thermal conductivity, water absorption and thickness tolerance [24,25]. The compressive strength of most insulating materials decreases as temperature increases and therefore it is necessary to consider the compressive strength at the service temperature. The service temperature is the highest temperature at which the insulation material can perform reliably in long-term application. Thermal conductivity (K) is the most important in determining a material's ability to resist the flow of heat. The absorption of water in insulating material increases conductivity of the material and causes swelling of the material. Thickness tolerance is important for achieving alignments and product quality. A low value of thermal expansion at operating temperatures is required for the insulation [26].

2.9. types of insulation materials:

There are three types of insulation materials in general [27]:

1. **Fibrous Insulation:** composed of small diameter fibres which finely divide the air space. The fibres may be perpendicular or parallel to the surface being insulated, and they may or may not be bonded together. Silica, rock wool, slag wool and alumina silica fibres are used. The most widely used insulations of this type are glass fibre and mineral wool. Glass fibre and mineral wool products usually have their fibres bonded together with organic binders that supply the limited structural integrity of the products.

2. **Cellular insulations:** composed of small individual cells separated from each other. The cellular material may be glass or foamed plastic such as cellular glass, phenolic foam or nitrile rubber.
3. **Granular insulations:** composed of small nodules which may contain voids or hollow spaces. It is not considered a true cellular material since gas can be transferred between the individual spaces. This type may be produced as a loose or pourable material or combined with a binder and fibres or undergo a chemical reaction to make a rigid insulation. Examples of these insulations are calcium silicate and vermiculite.

2.10. Insulation Forms

Insulations are produced in a variety of forms suitable for specific functions and applications. The combined form and type of insulation determine its proper method of installation. The forms most widely used are:

- Rigid boards, blocks, sheets, and pre-formed shapes such as pipe insulation, curved segments, lagging etc. Cellular, granular, and fibrous insulations are produced in these forms.
- Flexible sheets and pre-formed shapes. Cellular and fibrous insulations are produced in these forms.
- Flexible blankets. Fibrous insulations are produced in flexible blankets.
- Cements (insulating and finishing). Produced from fibrous and granular insulations and cement, they may be of the hydraulic setting or air-drying type.
- Foams. Poured foam used to fill irregular areas and voids. Spray used for flat surfaces [10].

2.11. Productivity:

In today's increasingly competitive world, it is important to constantly improve, either a manufacturing or service industry. Quality with quantity is a main characteristic which helps a company to stay in the competition. Technology has taken leaps of development lately and this has brought about an increase in the customer demands [28].

At the present stage of economic development, one of the main components of successful industrial organizations is planning productivity. Increased productivity reduces the cost of work on the production unit or an increase in output. Study of the productivity growth is becoming more important against a backdrop of market relations [29].

The term productivity can be used to examine efficiency and effectiveness of any activity conducted in an economy, business, government or by individuals. In the context of the real world, productivity is mostly examined and evaluated with reference to businesses or an economy.

Accordingly, it is essential to study productivity in order to:

- Understand the processes of a business.
- Control the business processes.
- Continuously improve processes.
- Assess performance of a business.
- Determine a business ability to sustain in the long run.

Productivity is also confused with terms like efficiency and effectiveness and these terms are wrongly considered synonymous to productivity. Efficiency and effectiveness are two different terms such that efficiency indicates how well the resources are utilized to accomplish a result. Alternatively, effectiveness refers to the degree of accomplishing the objectives [28].

2.12. Importance of productivity:

Therefore, it is essential to know the importance of higher improved productivity in manufacturing company organization. Thus, importance of productivity can be summarized as follows:

1. **Productivity is a key to prosperity:** Rise in productivity results in higher production which has direct impact on standard of living. It reduces cost per unit and enables reduction in sale price. It increases wages for workers and increased profit for organization. Higher demand creates more employment opportunities.
2. **Higher productivity leads to economic growth and social progress:** Higher productivity helps to reduce cost per piece which make product available at cheaper rate. Thus, it is beneficial for consumers. Low price increases demand of the product which in turn increases profit of the organization. Higher profit enables organization to offer higher dividend for shareholders. It increases export and increases foreign exchange reserves of a country.
3. **Higher productivity requires elimination of waste in all forms:** It is necessary to eliminate wastage in raw material, wastage of time in case of men and machinery, wastage of space etc. to improve productivity. Several techniques like work study, statistical quality control, inventory control, operation research, value analysis etc. are used to minimize wastage of resources.
4. **Minimize level of poverty and unemployment.**

2.13. Productivity improvement:

Productivity improvement is one of the best strategies towards manufacturing excellence and it also is necessary to achieve good financial and operational performance. It enhances customer satisfaction and reduce time and cost to develop, produce and deliver products and service. Improving productivity means increasing or raising productivity with the help of using same amount of materials, machine time, land, labor or technology [30].

Improvement may be realized through improved methods, investment in machinery and technology, improved quality, and improvement techniques and philosophies such as just-in-time, total quality management, lean production, supply chain management principles, and theory of constraints.

A firm or facility may undertake a number of key steps toward improving productivity:

- Develop productivity measures for all operations; measurement is the first step in managing and controlling an organization.
- Look at the system as a whole in deciding which operations are most critical, it is overall productivity that is important.
- Develop methods for achieving productivity improvement, such as soliciting ideas from workers (perhaps organizing teams of workers), studying how other firms have increased productivity, and re-examining the way work is done.
- Establish reasonable goals for improvement.
- Provide management support and encouragement.
- Measure improvements and publicize them [31].

2.14. Factors of Productivity Improvements:

There are varieties of factors which can affect productivity, both positively and negatively. Some factors can be controlled and some cannot be controlled due to natural limitations. Some of these factors are:

1. Capital investments in production.
2. Capital investments in technology.
3. Capital investments in equipment.
4. Capital investments in facilities.
5. Economies of scale.
6. Workforce knowledge and skill resulting from training and experience.
7. Technological changes.
8. Work methods.
9. Procedures.
10. Systems.
11. Quality of products.
12. Quality of processes.
13. Quality of management.
14. Legislative and regulatory environment.

15. General levels of education.
16. Social environment.
17. Geographic factors.

The first 12 factors are highly controllable at the company or project level. Numbers 13 and 14 are marginally controllable, at best. Numbers 15 and 16 are controllable only at the national level, and 17 is uncontrollable [31].

2.15. Productivity measurement:

In industry, the measurement and analysis of productivity serves the following five major functions:

1. **Define productivity and direct behavior:** The measurement system provides an implicit definition of productivity for the operation. It communicates to the worker, the supervisor, and others the common expectation from the task. The productivity measurement provides specific direction and guides the worker toward productive activities.
2. **Monitor performance and provide feedback:** The measurement system provides a means to check progress toward an objective. In addition, it can be a major part of the employee's performance evaluation leading to rewards or disciplinary action.
3. **Diagnose problems:** Productivity analysis, particularly the examination of trends, helps identify problems before they become crises and permits early adjustment and corrective action. Like any other indicator, productivity measurements do not necessarily identify the source of the problem, only that one exists.
4. **Facilitate planning and control:** Productivity measurement provides information on costs, time, output rate, and resource usage to allow decision making with respect to pricing, production scheduling, purchasing, contracting, delivery scheduling, and many other activities in the industrial cycle.
5. **Support innovation:** Productivity analysis, combined with cost data, aids in the evaluation of proposed changes to existing products or processes and the introduction of new ones. It is one of the primary foundations for the continuous improvement efforts that are both popular and necessary for survival in business firms today [32].

The purpose of the measurement system is critically important in determining the specific measures to be used. Every measure of productivity is a ratio between output and input(s).

Simplest and most frequently-encountered measure: labor productivity:

labor productivity (LP) = total output / labor input = Q / L

- Indicates how efficiently labor is used in production.
- Not necessarily an indicator of effort per worker [33].

Table 2.1. productivity measures

Type of output measure:	Type of input measure			
	Labor	Capital	Capital & labor	Capital, labor & intermediate inputs (energy, materials, services)
Gross output	Labor productivity (based on gross output)	Capital productivity (based on gross output)	Capital - labor MFP (based on gross output)	KLEMS multi-factor productivity
Value-added	Labor productivity (based on value-added)	Capital productivity (based on value-added)	Capital – labor MFP (based on value-added)	-
	Single factor productivity measures		Multi-factor productivity (MFP) measures	

KLEMS: capital (K), labor (L), energy (E), material (M), service (S) inputs.

MFP: Multi-factor productivity.

2.16. Methods of increasing productivity:

2.16.1. Quality improvement programs

Six Sigma quality program is a comprehensive and flexible system for achieving, sustaining and maximizing business success. Sex sigma is uniquely driven by close understanding of customer needs, disciplined use of facts, data, statistical analysis, and diligent attention to managing, improving, and reinventing business processes. Six sigma principals strive to cut costs, improve processes and maximize production value. Six Sigma companies learned that quality saves money, because there are fewer throw-outs, fewer warranty payouts and fewer refunds. And doing all that, in turn, increases profits. The Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) methodology can be thought of as a roadmap for problem solving and product/process improvement [34].

A. Define phase:

The Define Phase is the first phase of the Lean Six Sigma improvement process. In this phase, the leaders of the project create a Project Charter, create a high-level view of the process, and begin to understand the needs of the customers of the process. This is a critical phase of Lean Six Sigma in which you define the outline of the project.

Table 2.2. Phases and Tools in Define

DMAIC Phase Steps	Tools Used
D – Define Phase: Define the project goals and customer (internal and external) deliverables.	
Define Customers and Requirements (CTQs) Develop Problem Statement, Goals and Benefits Identify Champion, Process Owner and Team Define Resources Evaluate Key Organizational Support Develop Project Plan and Milestones Develop High Level Process Map	Project Charter Process Flowchart SIPOC Diagram Stakeholder Analysis DMAIC Work Breakdown Structure CTQ Definitions Voice of the Customer Gathering

B. Measure phase:

Measure phase is critical throughout the life of the project and translation of the problem into a measurable form, and measurement of the current situation. As the team focuses on data collection initially, they have two focuses: determining the start point or baseline of the process and looking for clues to understand the root cause of the process.

Table 2.3. Phases and Tools in Measure

DMAIC Phase Steps	Tools Used
M – Measure Phase: Measure the process to determine current performance; quantify the problem.	
Define Defect, Opportunity, Unit and Metrics Detailed Process Map of Appropriate Areas Develop Data Collection Plan Validate the Measurement System Collect the Data Begin Developing Y=f(x) Relationship Determine Process Capability and Sigma Baseline	Process Flowchart Data Collection Plan/Example Benchmarking Measurement System Analysis/Gage R&R Voice of the Customer Gathering Process Sigma Calculation

C. Analyze phase:

This phase is often intertwined with the Measure Phase. As the team reviews the data collected during the Measure Phase, they may decide to adjust the data collection plan to include additional information. This continues as the team analyzes both the data and the process in an effort to narrow down and verify the root causes of waste and defects.

Table 2.4. Phases and Tools in Analyze

DMAIC Phase Steps	Tools Used
A – Analyze Phase: Analyze and determine the root cause(s) of the defects.	
Define Performance Objectives Identify Value/Non-Value-Added Process Steps Identify Sources of Variation Determine Root Cause(s) Determine Vital Few x's, Y=f(x) Relationship	Histogram Pareto Chart Time Series/Run Chart Scatter Plot Regression Analysis Cause and Effect/Fishbone Diagram 5 Whys Process Map Review and Analysis Statistical Analysis Hypothesis Testing (Continuous and Discrete) Non-Normal Data Analysis

D. Improve phase:

once the project teams are satisfied with their data and determined that additional analysis will not add to their understanding of the problem, it's time to move on to solution development, design and implementation of adjustments to the process to improve the performance. The team is most likely collecting improvement ideas throughout the project, but a structured improvement effort can lead to innovative and elegant solutions

Table 2.5. Phases and Tools in Improve

DMAIC Phase Steps	Tools Used
I – Improve Phase: Improve the process by eliminating defects.	
Perform Design of Experiments Develop Potential Solutions Define Operating Tolerances of Potential System Assess Failure Modes of Potential Solutions Validate Potential Improvement by Pilot Studies Correct/Re-Evaluate Potential Solution	Brainstorming Mistake Proofing Design of Experiments Pugh Matrix QFD/House of Quality Failure Modes and Effects Analysis (FMEA) Simulation Software

E. Control phase:

This phase is a mini version of process management. The team has been building a form of infrastructure throughout the life of the project, and during the Control Phase they begin to document exactly how they want to pass that structure on to the employees who work within the process.

Table 2.6. Phases and Tools in Improve

DMAIC Phase Steps	Tools Used
C – Control Phase: Control future process performance.	
Define and Validate Monitoring and Control System Develop Standards and Procedures Implement Statistical Process Control Determine Process Capability Develop Transfer Plan, Handoff to Process Owner Verify Benefits, Cost Savings/Avoidance, Profit Growth, Close Project, Finalize Documentation Communicate to Business, Celebrate	Process Sigma Calculation Control Charts (Variable and Attribute) Cost Savings Calculations Control Plan

DMAIC will produce consistently better results than most other methods. This six-sigma method is the new culture at much organization today. [35]

2.16.2. Lean production methods:

The lean production approach offers a different but complementary way to improve productivity and quality. The emphasis in lean production on elimination of waste and continuous improvement combined with a strategic focus on quality by the company. Lean manufacturing is "A systematic approach for identifying and eliminating waste through continuous improvement by flowing the product at the pull of customer in pursuit of perfection" [36]. The basic definition of Lean Manufacturing can be stated as, a perspective to manufacturing that searches for an opportunity to reduce the operation time of processes, increase maneuverability, and improve the corresponding attributes. The primary concept behind Lean manufacturing is optimizing customer significance while minimizing wastes, thereby achieving manufacturing excellence through the creation of more value with fewer or absolutely no capital investments [37].

Lean tools have not been derived or proposed in one single day. They have been derived from the research of many people throughout the history. As they are very complex & interdependent on each other and one can find similarities in one another Currently in practice, there are approximately 25 Lean Tools, out of which, these three tools are considered to be the most critical Lean Tools of all:

1. Bottleneck Analysis.
2. Wastes (MUDA).
3. Standardized Work (SDW) [38].

A. Bottleneck Analysis:

A point of concourse in a machine or system that arises when work load gathers at a point in the system more hastily than that specific point can hope to maintain them. The intricacies fetched about by the bottleneck often make a queue and a longer overall cycle time. By definition, a bottleneck is a phenomenon where the competency of a complete system or line is restricted or limited by a single or limited number of components or resources & analysis of such event is called as Bottleneck Analysis.

Hence, Bottleneck Analysis is nothing but the identification of which part/machine of the manufacturing process/line limits the overall output and focuses on improvement the performance of that part/machine of the process/line. Bottleneck Analysis is usually done along with the Time Study Method [39].

B. Wastes (MUDA):

Anything in the manufacturing process that does not add value to the product from the customer's perspective is known as Waste. In simple Language, it is nothing but any process for which the customer does not pay the company.

There are 7 most Deadly Wastes in common:

1. **Transportation:** The unnecessary movements of operator, products or components from one place to another result in this waste.
2. **Inventory:** Inventory is the quantity of materials in stores, which are required to manufacture a job. When they are not used, they take up valuable storage space, may become useless.
3. **Motion:** This waste comprises of all unnecessary movements occur when operator is moving around his work area and as a result of this; his time & efforts are wasted.
4. **Waiting:** If operators, machine, system or materials of the production process are delayed by any reason, production time is wasted, the productivity is decreased & the cost of production will be increased.
5. **Over Processing:** It can also mean manufacturing the products of a larger quality than required. This can also be result of not checking what the customers' real requirements are.
6. **Over Production:** It arises when the manufacturer is producing more products than the customer really asks for. This is the worst kind of waste, as it generally creates other kinds of wastes. It increases rework factor, material storage, processing, holding & waiting, as well as transportation & unnecessary motion.
7. **Defects (Rework, Scrap):** Rework is required when products and components are defective or damaged. Defects are caused by bad manufacturing processes (caused by human or machine errors). In worst case scenario the items have to be discarded [38].

C. Standardized Work (SDW):

Standardized work is a collection and implementation of the best practices known to that point. It includes what is mandatory to begin the procedure and the completed state of the same. Standardized work is defined as work in which the sequence of job elements has been efficiently organized and is repeatedly followed by a team member. Because improvements in safety, quality, productivity & profitability will arise from time to time & the standardized work is to be updated via work instructions document, training, and practice.

These are the methodologies that improve quality, safety, productivity & profitability. Basically, standardized work consists of four elements:

- Takt time, which is the rate at which the products must be manufactured in order to meet customer demand on time.
- The accurate work sequence in which the operator performs tasks within takt time.
- The corresponding inventory, including jobs in machines, required to maintain the process operation smoothly.
- The dexterity of the operator & the maneuverability of the machine or system [40].

2.16.3. work study:

Work study 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. Work Study is the generic name of methods study and work measurement. It was the most important basis technique in industrial engineering, which was developed on the basis of action study of Gilberth and time study of Taylor. The most obvious character is using less investment or no investment to increase the production efficiency and benefit, reduce the cost and to strengthen the competition ability through improving the operating process and method, implementing the advanced and reasonable working quota, fully utilizing the human resources, material resources and financial resources inner the enterprise [41].

Method study (sometimes also called Work Method Design) is mostly used to improve the method of doing work When applied to existing products, method study aims to allocate better methods of manufacturing the jobs that are safe, effective, & economical, require mitigated human effort, and need smaller make-ready time. The better method involves the optimum use of best materials and appropriate manpower so that work is performed in well-organized manner leading to increased resource utilization, optimized quality and appeased costs.

Time study is the technique of establishing an allowed time standard to perform a given task, based upon measurement of work content of the prescribed method, with due allowance for fatigue and personal and unavoidable delays. According to Meyers (2002), time standards can be defined as "the time required to produce a product at a work station with the three conditions:

1. A qualified, well-trained operator,
2. Working at a normal pace,
3. Doing a specific task."

Stopwatch time study measures how long it takes an average worker to complete a task at a normal pace. A "normal" operator is defined as a qualified, thoroughly experienced operator who is working under conditions as they customarily prevail at the work station, at a pace that is neither fast nor slow, but representative of an average. The actual time taken by the above-average operation must be increased, and the time taken by the below-average must be reduced to the value representative of normal performance [38].

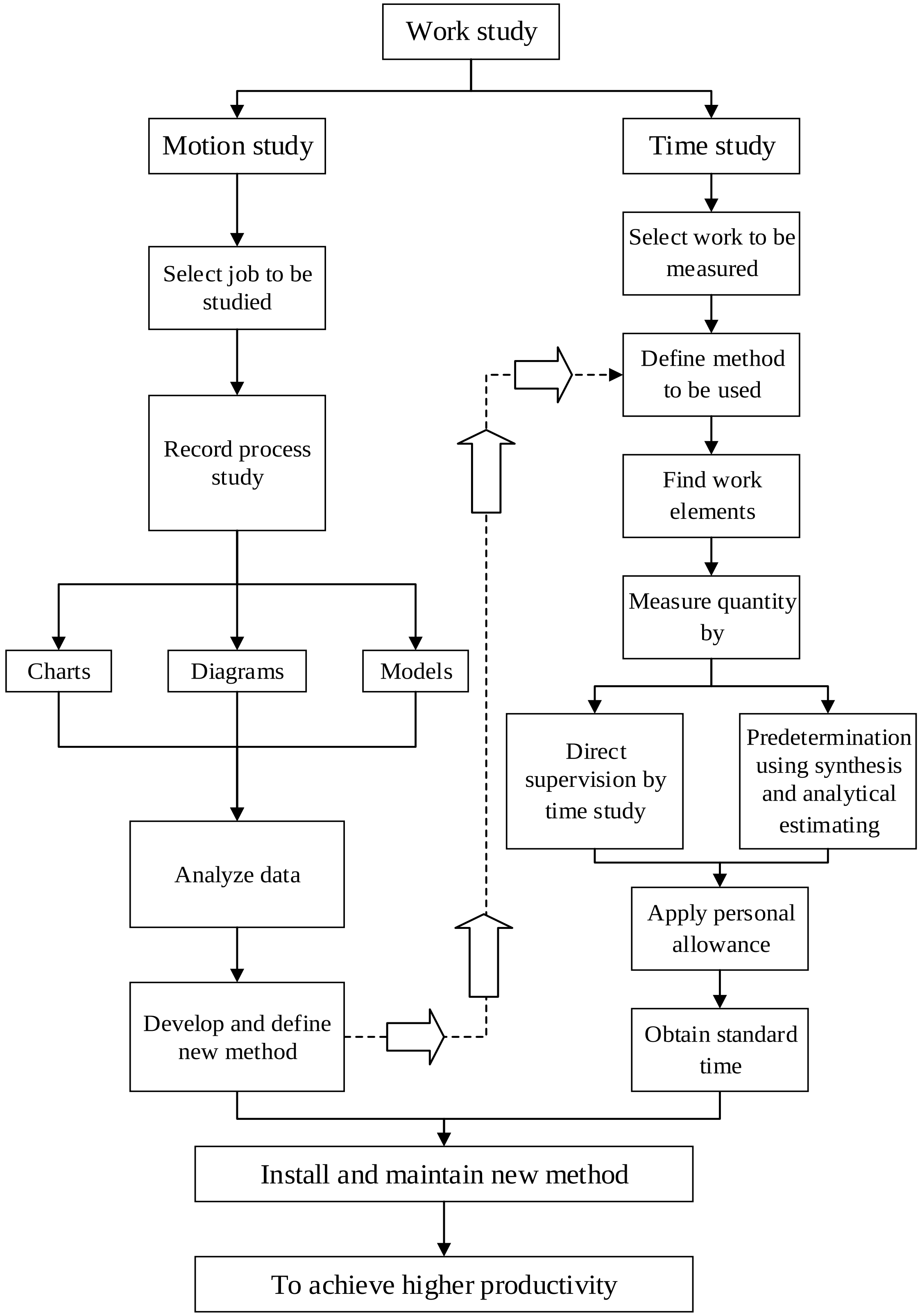


Figure 2.1. Flow chart of work study

2.16.4. Supply chain management

In an increasingly effective supply chain management, globalized economy are a prerequisite to global competitiveness. Most firms have at least some international sourcing or production and sales. These global supply chains must be managed well for the firm to maximize its productivity gains and add to its competitiveness. Many firms do very little actual manufacturing these days having outsourced their production to third-party subcontractors, usually in developing countries. Yet their brand name is on the product, and their brand equity will be largely determined by the performance of their subcontractors. They need to work with these subcontractors as well as logistics providers to assure high quality, low costs, and quick delivery. There are increasing concerns about Corporate Social Responsibility (CSR) that also must be factored in; these involve working conditions in overseas plants and environmental issues. If the CSR concerns are not properly addressed, the firm's brand image and sales may suffer. The key to effective supply chain management is viewing it as an integrated process where, if any partner improves everyone else in the supply chain benefits. Increased sales due to lower costs, better product design, and better quality in the downstream partners feedback in terms of greater sales and profits for the upstream partners. Lower costs and higher productivity in the upstream partners yield increased sales for the downstream creating a virtuous cycle. To achieve this, the supply chain partners need to work together to coordinate their production schedules and shipments. They also need to cooperate on product design to maximize the comparative advantage of each partner. Most importantly, they need to share expertise and assist each other in improving their internal quality and productivity [42].

2.16.5. Automation and information technology

The role of information and automation technology (IT) in productivity improvement was frequently discussed. Conventional wisdom is that the pickup in productivity growth in the U.S. in the 1990s and, continuing to the present is due primarily to the widespread application of computers and information technology. The correlation has been noted, but the linkage between productivity growth and IT appears to be more complex. It has been observed that some of the industries that invested heavily in IT experienced little productivity improvement. One explanation for this paradox is the role of "intangible capital" in the use of IT. If a firm invests in computers and information technology without also changing their internal processes to effectively use it, little productivity improvement is forthcoming. IT plays only a supporting role in this view. Information technology has the potential to improve productivity in a global firm if it is supportive of improvements in business processes. The growth of global supply chains offers one of the most important applications of IT.

The barriers to integrating a global supply chain is difficulty communicating across cultures and time zones. The development of modern communication and information technology has greatly facilitated this effort and made tightly integrated global supply chains feasible, whereas only a few years ago they were not. The Internet has made possible real time linkage of production and logistics in global firms as well as an enhanced ability to scout out potential suppliers and customers. Improved software such as ERP, SCM, and CRM allow companies around the world to integrate their purchasing, production scheduling, inventory, logistics, and product design functions. Technologies including barcode scanning have also contributed to tracking the movement of materials in a supply chain [42].

2.15.6. Professional development of the workforce

Driven by the requirements of lean production and the quality programs, firms have been able to significantly improve productivity by upgrading the skills of their workforce. This may occur due to more selective hiring, but often is created internally by more extensive training, job rotation, multitasking, and empowerment of employees. The model of a worker performing a simple, repetitive task over and over has been replaced by one that has a factory worker rotating jobs in a team and participating in kaizen activities. This is improving employee morale in general and can yield substantive benefits in terms of highest quality and workers suggestions for improvements in the process. As the employee understands a larger portion of the production process, he or she is more able to contribute to improvement efforts which in itself may be motivating. The higher morale and resultant reduced labor turnover create an incentive for firms to continue to invest in training for workers, which makes them more successful (and often better) creating another virtuous cycle that fosters long term productivity increases. In addition, the training and professional development of jobs may make the application of information technology more productive [42].

Chapter Three

Methodology

Chapter three

3. Methodology

3.1. Preface:

A productivity improvement technique used in this research is Six Sigma DMAIC to increase the production of (xy) insulator company.

The Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) methodology can be thought of as a roadmap for problem solving and product/process improvement.

3.2. Define phase:

This phase aims to create a clear project charter that includes the project's problem, goal, and quality characteristic of interest, financial benefit and scope.

Table 3.1. Used Phases and Tools in Define

DMAIC Phase Steps	Tools Used
D – Define Phase: Define the project goals and customer (internal and external) deliverables.	
Develop Problem Statement, Goals and Benefits Define Resources Develop High Level Process Map	Process Flowchart Industry layout

Problem Statement: improve the production processes in order to increase the capability and reduce the production time and the waste of raw materials.

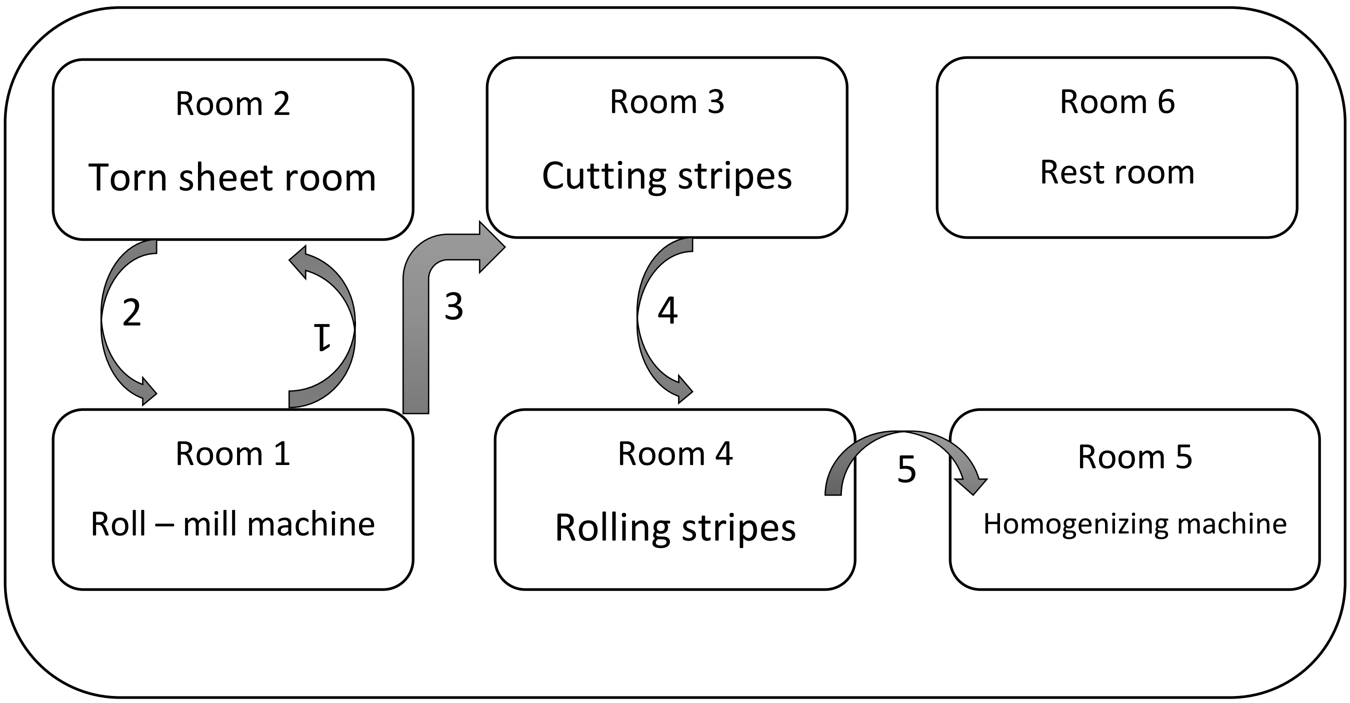


Figure 3.1 Industry layout

3.3. Measure phase:

In this phase, data regarding the quality characteristic of interest is collected in order to:

- Understand the current performance of the process.
- Determine the baseline of the current process performance.

Table 3.2. Used Phases and Tools in Measure

DMAIC Phase Steps	Tools Used
M – Measure Phase: Measure the process to determine current performance; quantify the problem.	
Detailed Process of Appropriate Areas Collect the Data Determine Process Capability	Process Flowchart Time study

3.3.1. Current process:

1. **Weighting:** at this stage, the worker weighs the raw materials (in room one) according to the required proportions by electronic balance and places them in the designated container for use in the next process and two workers work in this process.
2. **Roll-mill:** the worker puts the weighted materials into a mixing machine where the machine mixes the materials and takes them out in a form of a heterogeneous sheet and four workers work in this process.
3. **Torn into small pieces:** the worker tears the heterogeneous sheet into small pieces manually and two workers work in this process.
4. **Roll-mill:** the worker puts the small pieces into a mixing machine where the machine mixes it and takes them out in a form of a homogeneous sheet and four workers work in this process.
5. **Cut into small stripes:** the worker cuts the sheet into strips by cutter manually with the required width and two workers work in this process.
6. **Rolling the stripes:** the worker rolls the small strips on a mandrel with a diameter equal to the outer diameter of the pipe, which represents the inner diameter of the insulator, and the outer diameter of the insulator is determined by Vernia, then it is weighed by an electronic balance and the extra weight is manually cut by a cutter and four workers work in this process.
7. **Homogenizing:** the worker inserts seven rolls from the last step in a mandrel and puts them in an oven that heats and presses them to produce one long coherent cylinder piece, which represents the final product of the factory and four workers work in this process.

The raw materials that make up the thermal insulator are polymer (PVC), filler (sio_2 , sbo_2 , tio_2) , plasticizer (DOP, DOA, TER), thermal stabilizer ($caco_3$,talc powder) and other material.

3.4. Analyze phase:

In this phase, all possible root causes of the problem have been identified, it was decided to focus only on the main issues that would contribute mostly in improving the system.

Table 3.3. Used Phases and Tools in Analyze

DMAIC Phase Steps	Tools Used
A – Analyze Phase: Analyze and determine the root cause(s) of the defects.	
Define Performance Objectives Determine Root Cause(s) Determine improvement areas	Time study Statistical Analysis

3.4.1. data collection:

The timing of the cycles of each process will be done and the average times, normal times and standard times will be determined. After the times are calculated, a table is created with the data, taking into consideration the allowance and the rating factors. In addition to the time measurements, information is also collected on the production demand of every shift, number of breaks per shift and their duration.

The data processing for the standard time calculation follows 3 steps:

1. Sample size calculation.
2. The observed times are multiplied by the rating factor(V), and the value found is called normal time (TN). The rating factor is determined by the observer himself, where:
   $V>100\%$ - Rating above normal; $V=100\%$ - Normal rating; $V<100\%$ - Rating below normal.
   TN = Average * V …………………………………………………………….. (1)

3. The normal times found are multiplied by the allowance factor (FT) of each operation – the allowance factor is a value corresponding to the existence of an allowance for personal needs, fatigue, waiting and break time.
   Production time (TP) = TN * FT ………………………………………… (2)

   $FT = \frac{1}{1-P}$ where P ≡ Permissive time …………………………………… (3)

There are several ways to calculate the rating and the allowance factors of an activity. To make the determination less subjective, the Westinghouse system, as seen on the Tables 1 and 2 below, is utilized.

$\text{Takt time} = \frac{\text{worked time}}{\text{demond}}$ ………………………………………………….. (4)

Table 3.4. Operations timing model.

F/S	**Cycle time analysis**	**Value**	**Cycle 1**		
30	**Video name:**	**VA: 1 NVA: 0**	**First**	**Last**	**Frames**
1	Operation 1	0	X1	Y1	Y1-X1
2	Operation 2	0	X2	Y2	Y2-X2
3	Operation 3	1	X3	Y3	Y3-X3
4	Operation 4	1	X4	y4	Y4-X4
5	Operation 5	1	X5	Y5	Y5-X5
6	Operation 6	0	X6	Y6	Y6-X6
7	Operation 7	0	X7	Y7	Y7-X7
8	Operation 8	1	X8	Y8	Y8-X8
9	Operation 9	0	X9	Y9	Y9-X9
10	Operation 10	1	X10	Y10	Y10-X10
	Total				SUM

VA: value added
NVA: non-value added

Table 3.5. Cycle times per operation.

Cycle time analysis (in seconds)							
#	Video:	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Average
1	weighting	X1	X2	X3	X4	X5	$\frac{x1+x2+x3+x4+x5}{5}$
2	Roll-mill	X1	X2	X3	X4	X5	$\frac{x1+x2+x3+x4+x5}{5}$
3	Torn into small pieces	X1	X2	X3	X4	X5	$\frac{x1+x2+x3+x4+x5}{5}$
4	Roll-mill	X1	X2	X3	X4	X5	$\frac{x1+x2+x3+x4+x5}{5}$
5	Cut into small stripes	X1	X2	X3	X4	X5	$\frac{x1+x2+x3+x4+x5}{5}$
6	Rolling the stripes	X1	X2	X3	X4	X5	$\frac{x1+x2+x3+x4+x5}{5}$
7	homogenizing	X1	X2	X3	X4	X5	$\frac{x1+x2+x3+x4+x5}{5}$

3.5. Improve phase:

The main goal of this phase is to implement the best solutions with controlled risk. The suggested solutions are based on the results of the analyze phase.

Table 3.6. Used Phases and Tools in Improve

DMAIC Phase Steps	Tools Used
I – Improve Phase: Improve the process by eliminating defects.	
Perform Design of Experiments Develop Potential Solutions Validate Potential Improvement	Brainstorming Design of Experiments Simulation Software

3.6. Control phase:

The main goal of this phase is to maintain the new improved state of the system and prevent the problem from arising again.

Table 3.7. Used Phases and Tools in Improve

DMAIC Phase Steps	Tools Used
C – Control Phase: Control future process performance.	
Develop Standards and Procedures Determine Process Capability Verify Benefits, Cost Savings, Finalize Documentation	Standardize work Cost Savings Calculations

Chapter Four
Results and Discussion

Chapter Four

4. Results and Discussion

4.1. Preface:

The (xy) insulator company was studied and time study was done for the company to know the process that takes place in the longest period of time to reduce its time and thus reduce the production time of one unit and thus an increase productivity. After studying the above process that takes long time, a solution was proposed by an amendment of the way it works and the tools used in it to reduce the time spent on it. the proposed tool was drawn by **Solid Work** program. The effect of this proposed amendment was calculated to reduce the production time per unit and increasing industry productivity.

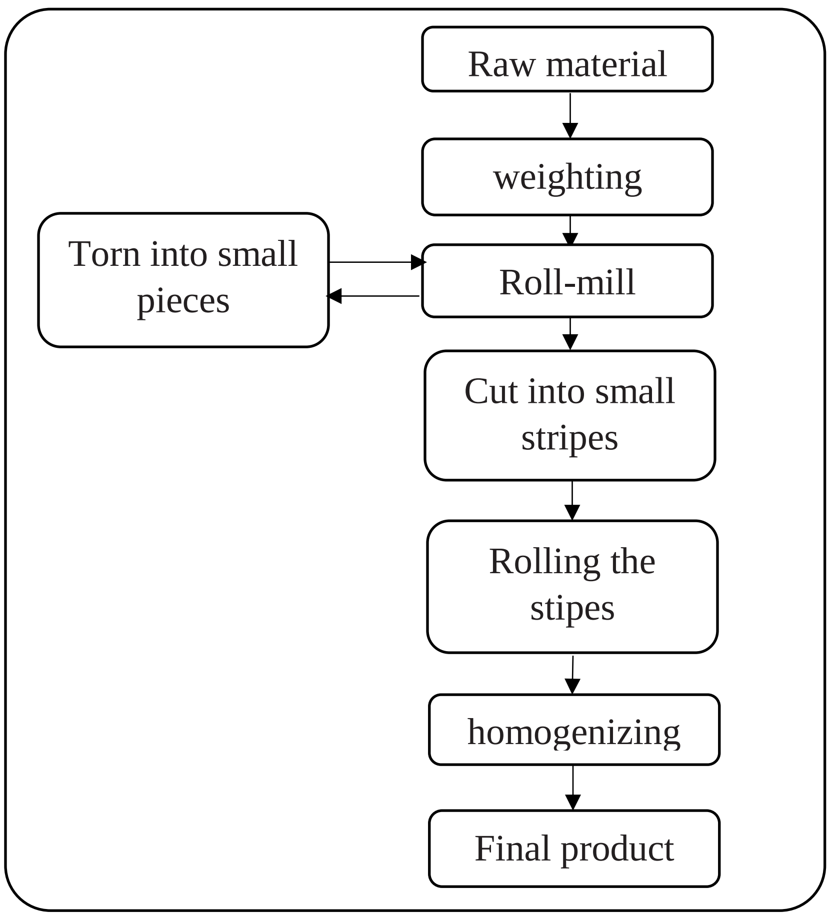


Figure 4.1. Product flow chart

4.2. Previous situation calculations:

The normal time and production time were calculated in table (4.1.) and table (4.2.) With the method and equations shown in the previous section.

TN = Average * V

Production time (TP) = TN * FT, FT = $\frac{1}{1-P}$ where P ≡ Permissive time

Table4.1. Calculation of the normal time of operations.

Cycle time analysis (in minutes)				
#		Average	rating factor (V)	the normal time
1	weighting	0.83	0.03	0.85
2	Roll-mill	5	0.05	5.25
3	Torn into small pieces	0.83	0.02	0.85
4	Roll-mill	5	0.05	5.25
5	Cut into small stripes	3	0.06	3.18
6	Rolling the stripes	8	0.03	8.24
7	homogenizing	4.79	0.02	4.89

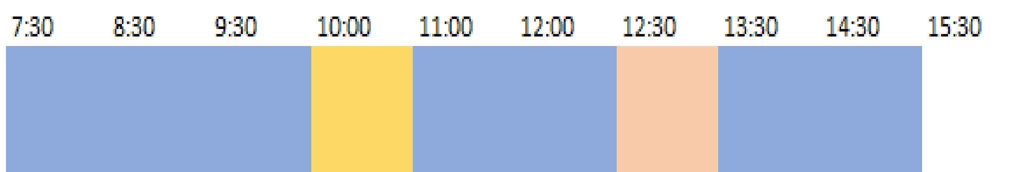
Table 4.2. Calculation of the standard time of operations.

Cycle time analysis (in minutes)				
#		the normal time (TN)	allowance factor (FT)	Time of production
1	weighting	0.85	6%	0.91
2	Roll-mill	5.25	5%	5.53
3	Torn into small pieces	0.85	3%	0.87
4	Roll-mill	5.25	5%	5.53
5	Cut into small stripes	3.18	6%	3.38
6	Rolling the stripes	8.24	7%	8.58
7	homogenizing	4.89	5%	5.14

- From the information on demand and duration of the shift, it was possible to calculate the takt time of the line using the Equation 3.4 and build a diagram with the operators' times, relating the working hours to the break times shown in Figure 4.2.
- The labor works about eight hours per shift, have one hour for breakfast and one hour for pray and personal needs (twenty minutes).

Takt time = 8.58

- With the takt time result, it's possible to build a chart with the standard time of each station and verify the production situation at the time of the study, according to Figure 4.3. below. The chart shows the times for all operations of the studied line, it is noted that all cycles are in accordance with the takt time needed to meet the demand determined by production shifts.
- It means that the production of 38 units per day (10,000 units per year) should be met provided there are no unforeseen events.
- So, if we reduce the time of the process number six (rolling the strips) from 8.58 minutes to the highest time in the other operations (5.53 minutes), it's possible to produce a total of 59 units per day (15,500 units per year), the increase percentage of production is 55% more.



total time	60	60	30	60	60	30	60	60	60	480
worked time	60	60	30		60	30		30	60	330
breakfast				60						60
pray							60			60

Figure 4.2. Production time per minutes

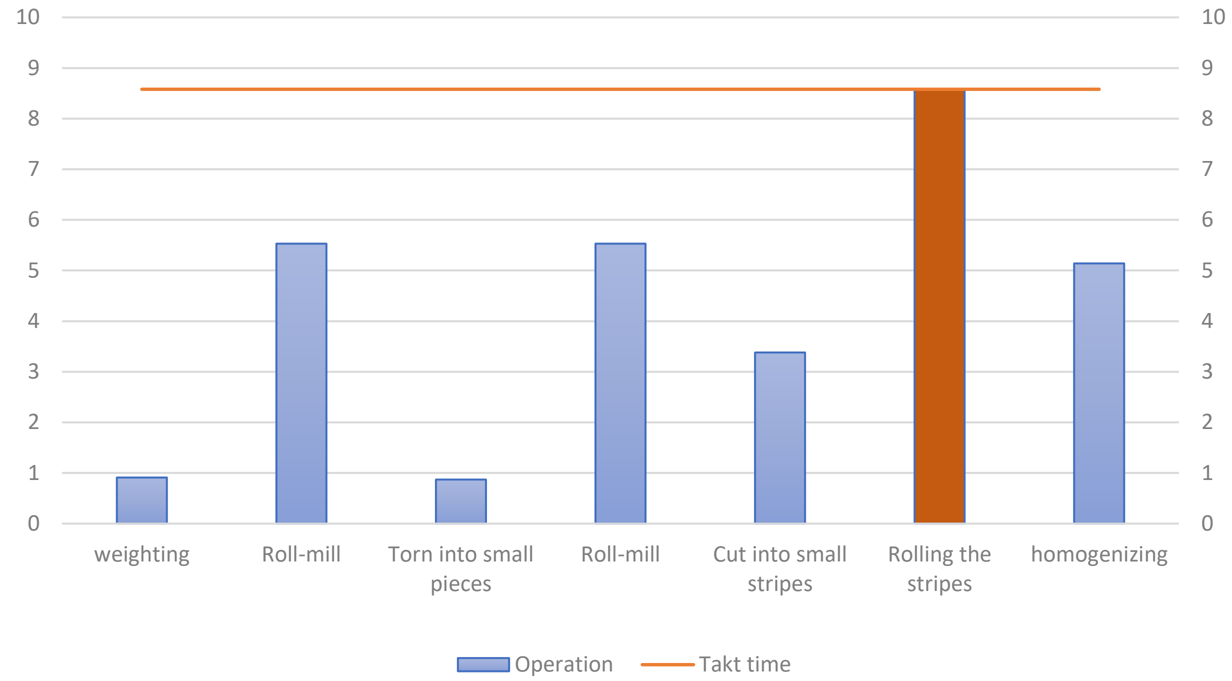


Figure 4.3. Cycle time X Takt time

4.3. Potential Solutions:

In the past, the worker cuts the sheet manually into strips with the required width and rolls the small strips on a mandrel with a diameter equal to the outer diameter of the pipe, and the outer diameter of the insulator is determined by Vernia. Then it is weighed by an electronic balance and the extra weight is manually cut by a cutter. Six workers work in these two processes. A tool was designed to simplify cutting and rolling process. **A designated tool is made up of:**

1. Mandrel: the mandrel is attached by arm to rotate the mandrel manually as shown in figure 4.4.
2. Cutters carrier: it consists of a ruler that contains holes to fix the cutters and to control the required width of the piece as shown in figure 4.5.
3. Cutter: to cut the sheet to the required width as shown in figure 4.6.

4. Diameter identification ruler: it is a moving ruler placed under the mandrel to control the outside diameter of the piece as shown in figure 4.7.
5. Table: is a table that consist of:
    i. Mandrel holder: fix the mandrel and allows it to rotate around its axis.
    ii. Adjustable Cutters carrier holder: it allows two modes in the first cutters carrier be in position so that the cutters are in contact with the mandrel to cut the pieces, the second position so that the cutters are far from the mandrel so that it cannot cut the piece.
    iii. Diameter identification ruler holder: it fixes the diameter identification ruler in several positions so that each position represents one of the required diameters.
    iv. Sheet holder: prevents the sheet from falling off the table.

    As shown figure 4.9.

6. Lockers: fix the parts in the space provided for them, As shown figure 4.8.

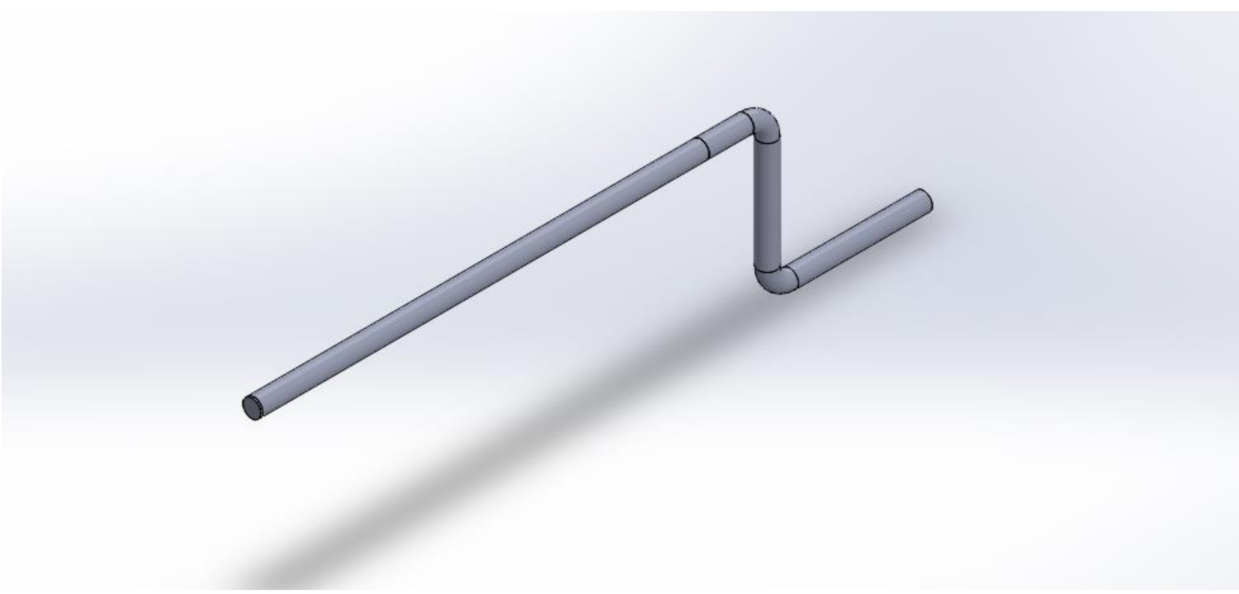


Figure 4.4. Mandrel

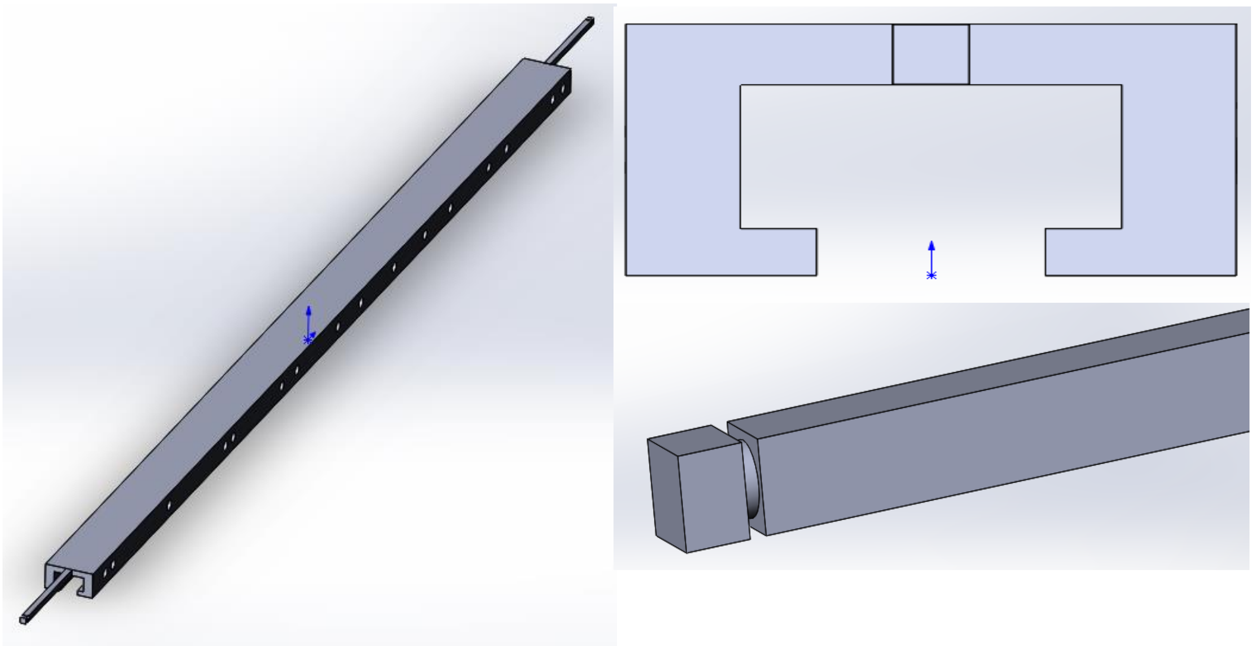


Figure 4.5. Cutters carrier

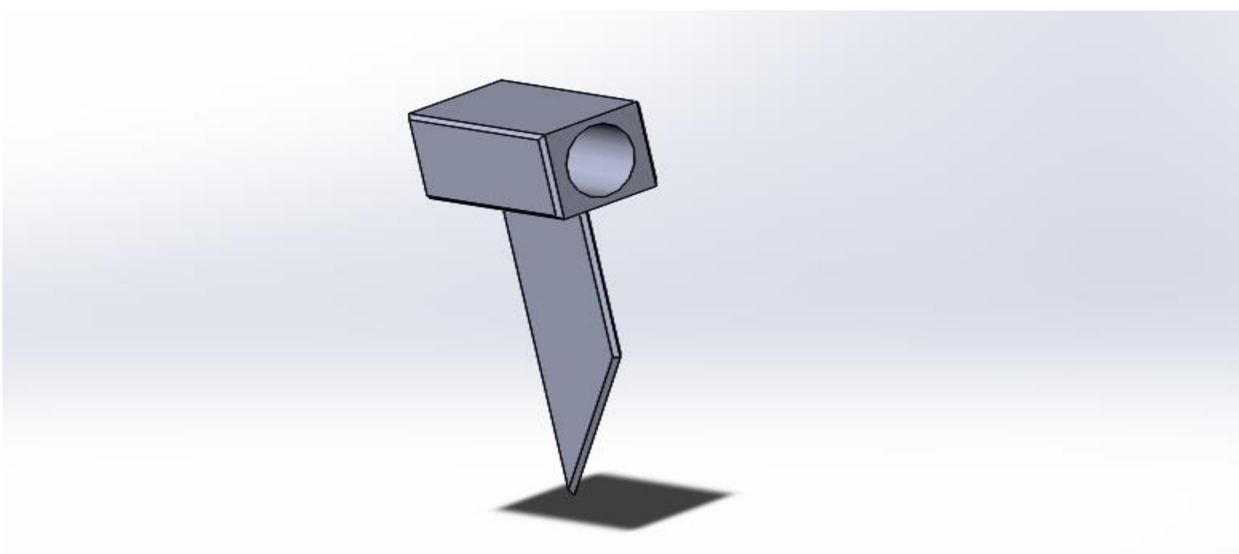


Figure 4.6. Cutter

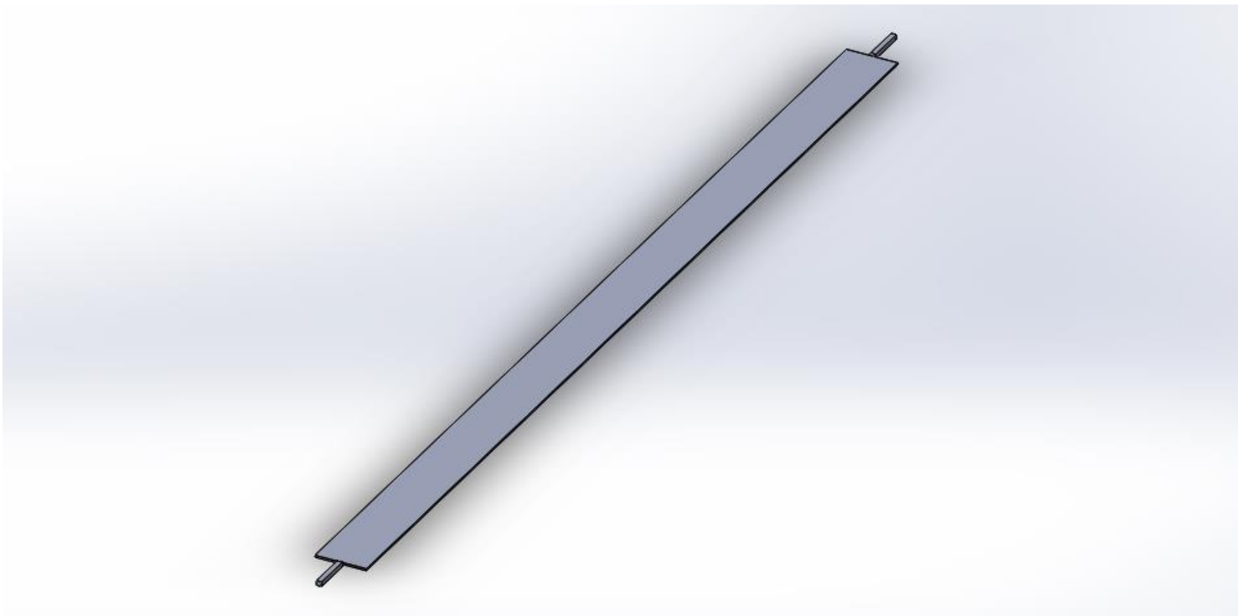


Figure 4.7. Diameter identification ruler

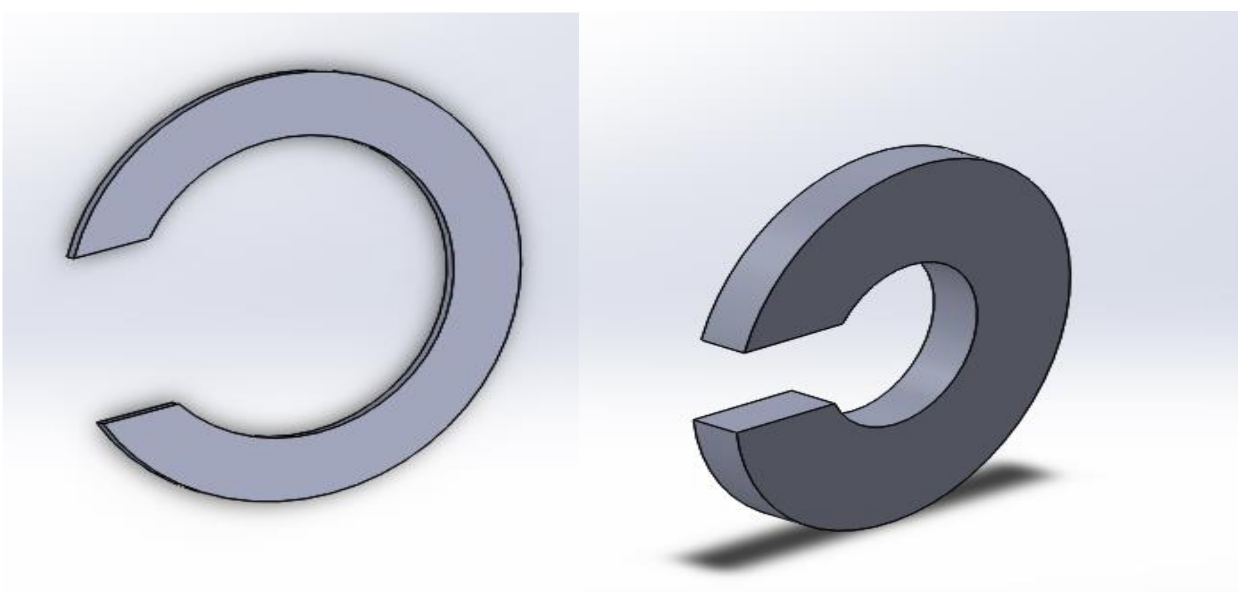


Figure 4.8. Lockers

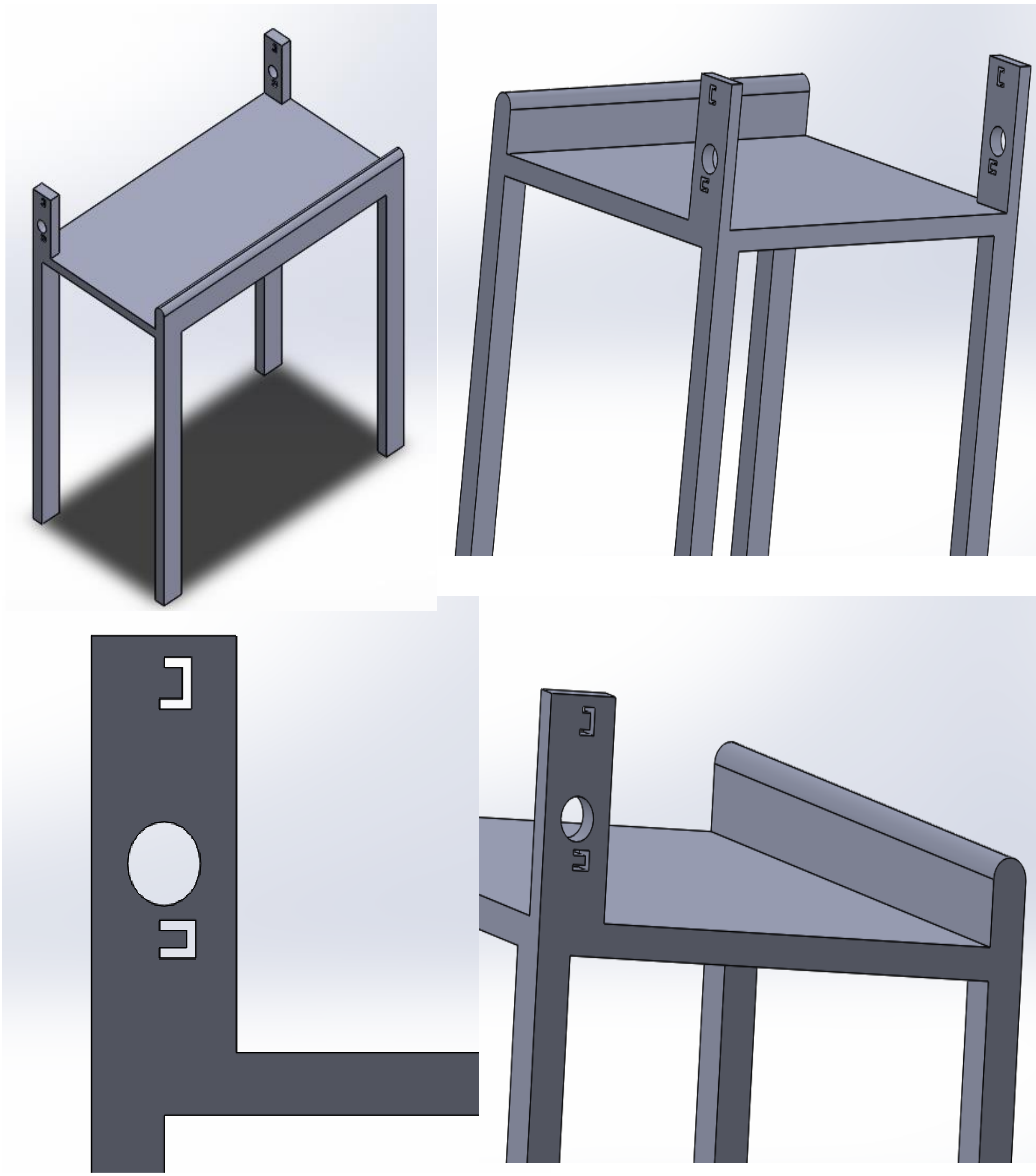


Figure 4.9. Table

4.4. Procedures of the designated tool:

1. Place the sheet on the table.
2. Ensure that the Cutters carrier is in the non-cut position.
3. Ensure that the diameter identification ruler is in the required position.
4. Place the tip of the sheet on the mandrel and wrap it in a full roll manually.
5. Glue the first roll of the sheet.
6. Place the Cutters carrier in the cutting position.
7. Roll the mandrel by its hand until it reaches the diameter that controlled by the diameter identification ruler.
8. Cut the stripes from the main sheet longitudinally.
9. Disassemble the mandrel to remove the small rolled stripes.
10. Weigh each rolled stripe by an electronic balance and remove the extra weight with a cutter manually.

4.5. Results discussion:

Two processes are combined into one process. Therefore, a room was dispensed and the number of workers was reduced by two workers (11.1% of the total number of workers). Some tools have been dispensed such as Vernia. The time used to produce one piece was estimated to be 3 minutes.

So, the normal time = 3.15 minutes

And the time of production = 3.32 minutes

Table 4.3. new calculation of the standard time of operations.

Cycle time analysis (in minutes)		
#		Time of production
1	Weighting	0.91
2	Roll-mill	5.53
3	Torn into small pieces	0.87
4	Roll-mill	5.53
5	Cut into small stripes And Rolling them	3.32
6	Homogenizing	5.14

The new takt time will be 5.53 minutes as shown in figure 4.10

The new production rate will be 59 units per day (15,500 units per year), the increase percentage of production is 55% more.

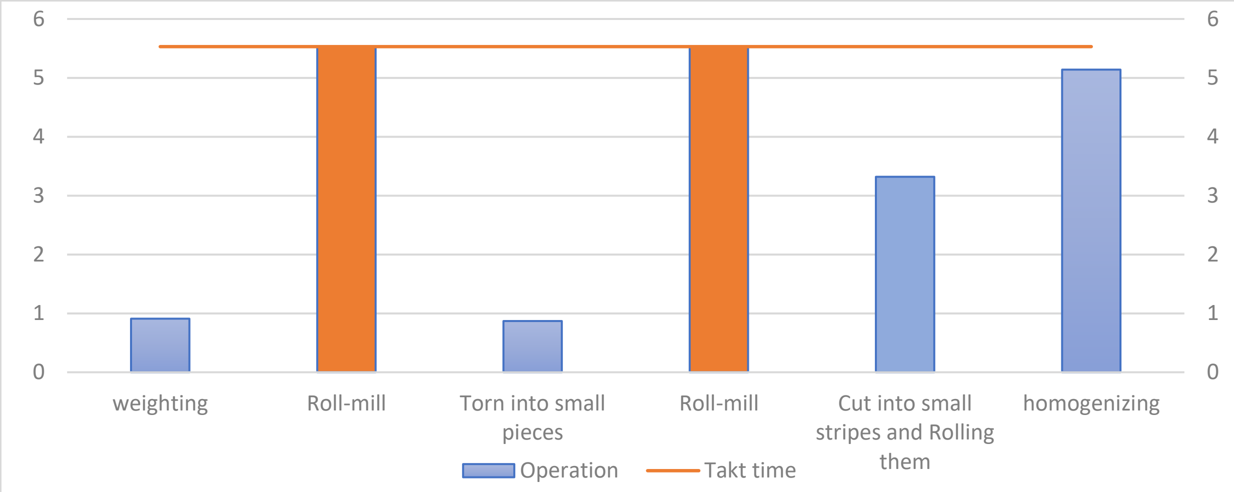


Figure 4.10. New Cycle time X Takt time

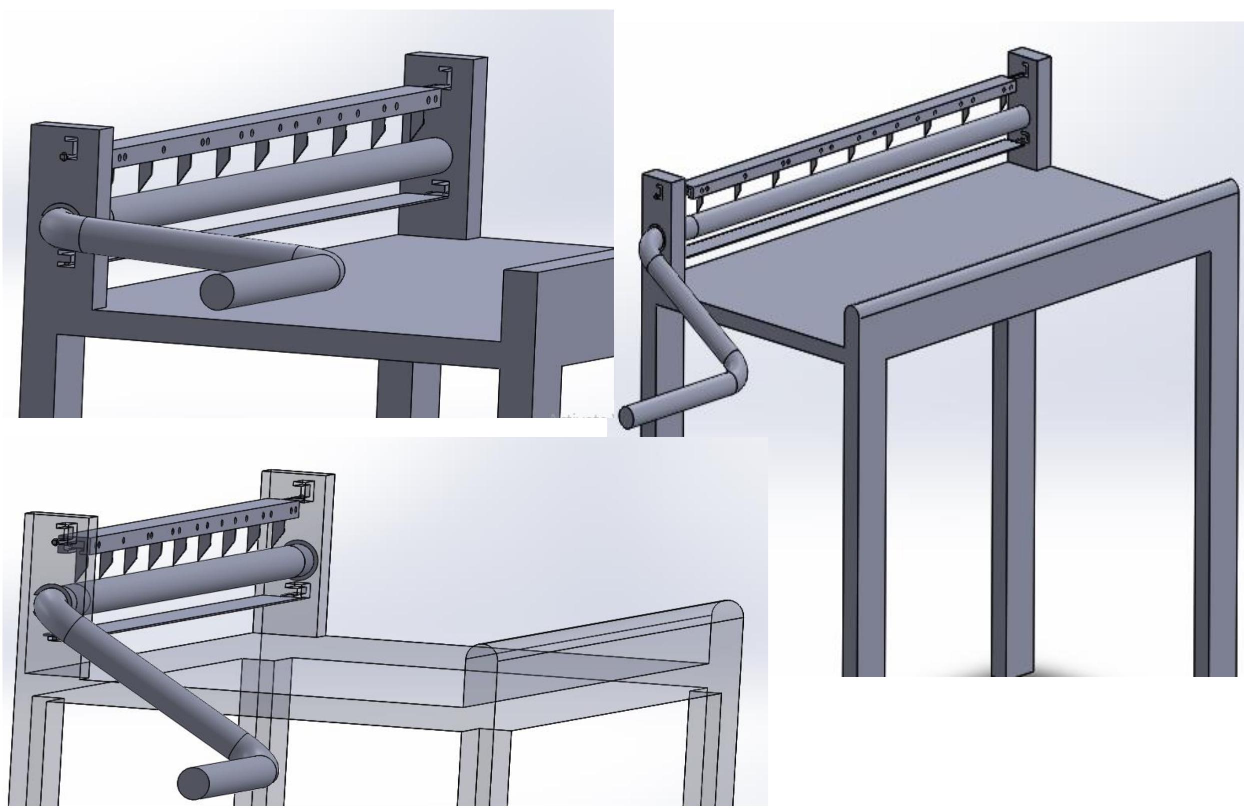


Figure 4.11. the designated tool

4.6. The cost of manufacturing the proposed tool on march 2020:

This tool consists of number of pieces as following:

1. Square pipe 4*8 cm with a length 6 m = 1,000 SDG
2. Plate 1*0.5 m with thickness 2mm = 1,000 SDG
3. Strip plate 5*100 cm with thickness 5 mm = 500 SDG
4. Cutter Carrier consisting of 2 plate in angle shape and one strip plate with thickness 5 mm = 800 SDG
5. Cutters: 8 pieces of cutters 400SDG*8 pieces = 3,200 SDG
6. Mandrel with arm = 2,000 SDG
7. The piece that hold Cutters carrier, Diameter identification ruler and mandrel sold plate with dimension 4*8*25 cm = 1,100 SDG
8. Rod with dimension 5*5*200 mm = 20 SDG
9. Lockers 4 pieces = 200 SDG
10. Bearing 2 pieces = 400 SDG

- Welding, turning and workmanship =5,000 SDG
- Total cost of machine = 15,220 SDG.

Previously to produce 100 elements of insulator
for cutting the stripes **two** workers are needed for 338 minutes = 5.63 hours;
thus:
11.26 manpower-hour.
then to roll stripes **four** workers are needed for 858 minutes = 14.3 hours;
thus:
57.2 manpower-hour.
So, to cut and roll the stripes for 100 element it takes:
11.26 +57.2 = 68.46 manpower-hour.

In the proposed solution to produce 100 elements of insulator:
for cutting and rolling the stripes four workers are needed for 332 minutes = 5.53 hours;
thus:
it takes 22.12 manpower-hour.

So, the reduction is 46.34 manpower-hour.
The manpower-hour cost 75 SDG
The reduction is 46.34 * 75 = 3,475.5 SDG

Chapter Five
Conclusion & Recommendations

Chapter Five

5. Conclusion & Recommendations

5.1. Conclusion:

- In this research, the DMAIC methodology was used.
- A tool was designed to simplify cutting and rolling process. These two processes are combined into one process.
- The cutting room was dispensed and the number of workers was reduced by two workers which was 11.1% of the total number of workers. Some tools have been dispensed such as Vernia.
- The time used to produce one piece - in the proposed process - was estimated to be 3 minutes instead of 8 minutes. The new takt time will be 5.53 minutes (the highest time in the new set of operations) instead of 8.58 minutes.
- The previous production rate was 38 units per day (10,000 units per year), The new production rate is increased to 59 units per day (15,500 units per year), the increase percentage of production is 55% more.

5.2. Recommendations:

- The solution proposed in this research is manual, and a motor can be added to it in order to increase production and accuracy.

- There are a number of processes that are still manual and can be explore, such as a weight control process.

- the highest time in the new set of operations is roll-mill and this process can only be done by a machine, so the time of this process can only be reduced by increasing the number of machines used in it.

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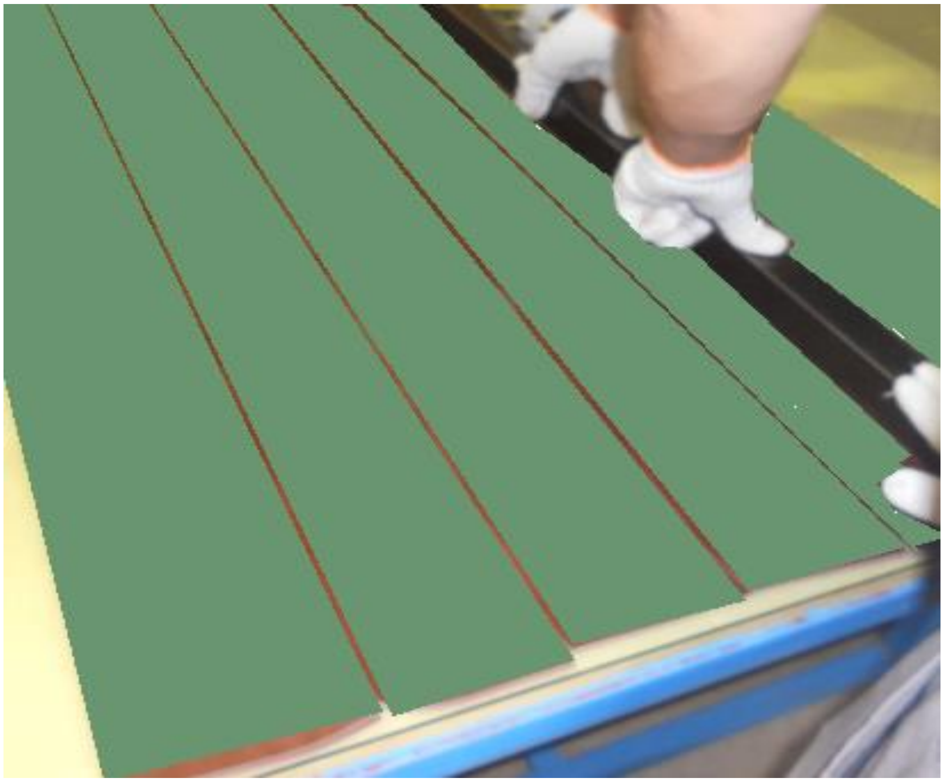
Appendix

Appendix

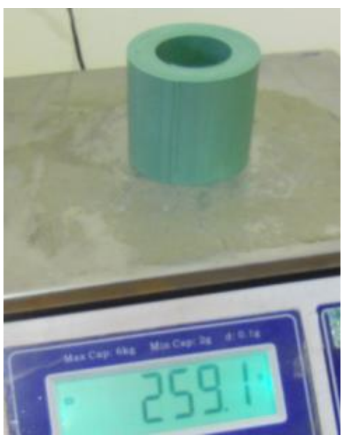
roll-mill machine



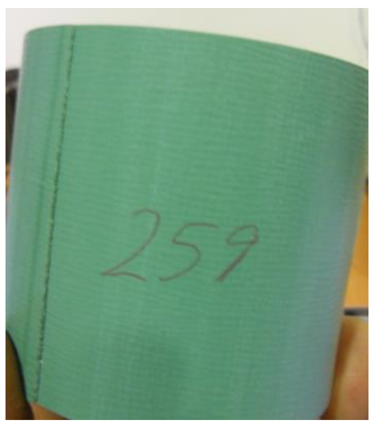
Cut into small stripes

Rolling the stripes

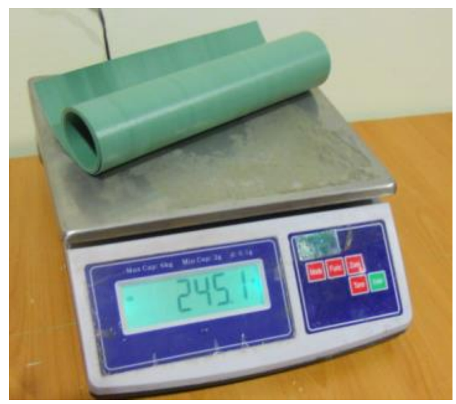
Measure the outer diameter



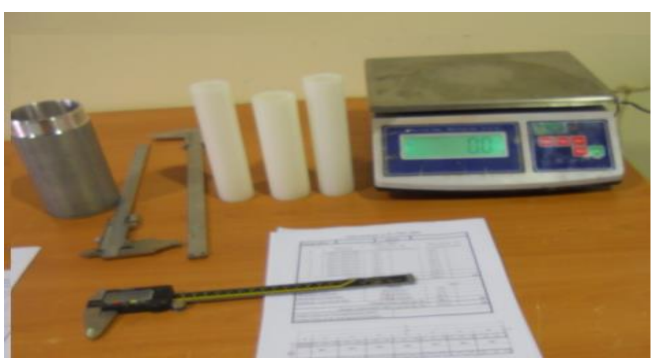
Weighting the piece



writing the weigh on the piece



Weighting the piece



Rolling stripes tools

Put the pieces in cupper mandrel

Put the mandrel in homogenizing machine

numbering the pieces

After the homogenizing process