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Optimization of CNC machining Workshop

Master Thesis

Liberec 2020

Ravivarman Thirugnanam

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Study programme:	N2301 Mechanical Engineering
Study branch:	Manufacturing Systems and Processes
Author:	**Ravivarman Thirugnanam**
Thesis Supervisors:	Ing. František Koblasa, Ph.D.
	Department of Manufacturing Systems and Automation

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Master Thesis Assignment Form

Optimization of CNC machining workshop

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Study branch: Manufacturing Systems and Processes
Assigning department: Department of Manufacturing Systems and Automation
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The aim of this thesis is to optimize CNC machining workshop at Research Center CXI implementing Lean and ergonomic tools.
Thesis will include:
1/ Literature review of Lean principles, economic and design of manufacturing principles.
2/ Current state analysis of manufacturing system focusing on Lean principles and ergonomic using selected manufacturing tasks.
3/ Design improvements in current layout.
4/ Schedule budget and improvement process.

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[1] Handbook of design, manufacturing, and automation. New York: Wiley, 1994. ISBN 9780470172452.
[2] IRANI, S. A. Handbook of cellular manufacturing systems. New York: Wiley, 1999. ISBN 978-0471121398.
[3] PYZDEK, T. a P. KELLER. The six sigma handbook. Fourth edition. New York: Mcgraw-Hill, 2014. ISBN 9780071840538.
[4] IMAI, M. Gemba Kaizen. A Commonsense Approach to a Continuous Improvement Strategy. Second Edition. New York: McGraw Hill, 2012. ISBN 978-0071790352.
[5] TOMPKINS, J.A. et al. Facilities planning. 4th ed. Hoboken, NJ: John Wiley, 2010. ISBN 9780470444047

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ABSTRACT

The context presented in this thesis is optimization of CNC machining workshop at Research Centre CXI. The main goal of this thesis is to optimize the CNC Machining workshop by using Lean tools which include current state analysis of the manufacturing system focusing on the Lean principles using selected manufacturing tasks, implementation of 5S, design improvements in the current layout and addition of assembly workplace in the laboratory. The content starts with the literature review of basic Lean principles, Manufacturing system analysis, 5S and Ergonomic rules for assembly followed by the analysis of current system, 5S implementation, design and selection of variants and finally economic evaluation. Assembly work place is designed and new layout for the workshop is suggested for optimization by using the multi criteria analysis.

KEYWORDS

Lean Manufacturing, 5S, Layout, Process, Assembly.

ABSTRAKT

Tématem této práce je optimalizace CNC dílny ve výzkumném centru CXI na TUL. Hlavním cílem této práce je optimalizovat dílnu pomocí nástrojů Lean, Práce obsahuje analýzu současného stavu výrobního systému se zaměřením na ergonomické principy a Lean s využitím vybraných výrobních úkolů. Práce postupně presentuje literární rešerši základních principů Lean, nástroje analýzy výrobního systému, metodu 5S a ergonomická pravidla návrhu pracovišť. Následně provádí analýzu současného stavu, implementuje 5S, navrhuje montážní pracoviště, navrhuje a pomocí multikriteriální analýzy vybírá variantu rozložení pracoviště. V závěru práce presentuje ekonomické zhodnocení implementace navržených zlepšení.

KLÍČOVÁ SLOVA

Štíhlá výroba, 5S, Rozvržení pracovišť, Proces, Montáž.

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1 INTRODUCTION

At present, the competition within the global market is high and companies have to constantly enhance and evolve. In any segment of the manufacturing sector, the two foremost expensive and commonest kinds of problem are with the efficiency and the wastage. In order to overcome the problems,–implementation of the Lean manufacturing and the Lean Tools are a proven method to enhance the business and beat the competition. Lean is set of tools and techniques that mainly focus on the minimization of wasteful activities and adding value to the final product to meet the customer demands by engaging the staffs to improve the quality, productivity, customer services and staff morale. The basic lean thinking is removal of MUDA – which means waste in Japanese. Here waste defines anything which doesn't have any value or activity which doesn't add value to the final product. Lean manufacturing has emerged as a successful way for the manufactures who focuses on the actual needs of the customer by preventing waste from being built into the system.

Many manufacturing industries have chosen to follow the way towards 5S which is one of the Lean method for implementing order in the work place. The main purpose of 5S is to increase the efficiency by eliminating the waste of motion. It is a work place management where the workplace and the work area is organized thus minimizing the loss of time and motion. It is the first step towards eliminating the waste in manufacturing processes which leads to improving the bottom line results.

Another way to reduce the waste and cost of the production is by employing the Design for Manufacturing. Design for Manufacturing is one of the critical part of the product development cycle which involves in the optimization of the design of the product for its manufacturing and the assembly process which merges the design requirements of the product with the production method. It gives a fact that nearly 70 % of the manufacturing cost of a product are determined by the 30 % of the design decisions such as process planning, machine tool selection which makes to focus on the design optimization to reduce the waste and cost of the manufacturing.

The aim of the thesis is to optimize the CNC machining workshop at Research Centre CXI by implementing Lean and ergonomic tools.

The work includes the following steps

- Current state analysis of Manufacturing system focusing on the Lean and Ergonomic principles using selected manufacturing tasks
- Design improvements in the current layout
- Schedule budget and improvement process

Laboratories have no development plans or lean methodology in their use. The problem with the laboratories is the lack of systematic usage of the tools and equipment which leads to the lack of visualization and motivation. Implementation of the above described Lean methodology helps to overcome the above mentioned problems.

2 LITERATURE REVIEW

The main goal of the Lean is to remove or eliminate the waste which comes as any non-value added component in the manufacturing process.

The five basic lean manufacturing principles are

Identify the Value

The first step of Lean principle is identification of the value. This step needs the business to outline what the customers value and the way their product or services meet those values.

The value requires

- Designing Products to satisfy the requirements of the customers
- Removing options that is not required for meeting those requirements

By designing the products to fulfil specific requirements, businesses can eliminate wasteful steps that are needed for unwanted features. Hence the Value is defined by the customer and created by the producer

Map the Value Steam

The second step includes the Mapping of Value stream. A Value Stream is that the complete life cycle of a product which incorporates the Product's design to Customers use of the product and disposing of the product. Lean implementation includes the map value stream to analyse delays, production limitations, inefficiencies as well as the value creating steps.

Any steps which is not creating any value ought to be eliminated. Once the Value stream has mapped then it will be easier to find and eliminate the steps which do not add value.

Create Flow

The Third step in Lean Principle is creating flow. The efficient product flow needs things to move from the production to shipping without any interruption in a sequence. All the factors from Workers and equipment to materials and shipment has to be taken into account for ensuring the products to move in the production process without any interruption. This step ensures the product to flow smoothly to the customers. The goal in the step is having continuous and synchronized production.

Establish Pull

This step relates with the creating flow and requires the business to use a Pull Production system. This system Pulls the customer order from the shipping department that then prompts the new product to be manufactured and signals the additional materials to be purchased.

Lean Manufacturing tools like Kanban will facilitate the business to establish a pull system to manage the flow of materials during production.

Strive for Perfection

The final step includes the companies to improve the perfection. The lean implementation has to take every opportunity in improving in each part of the value stream. To target the perfection identification and removal of root causes of the issues from the production process is followed. This principle is achieved by group effort and involvement from Production floor to the higher management is required.

TYPES OF WASTE

Considering the elimination of waste in manufacturing which is the Primary Objective of the Lean, the waste cane be classified into major 8 types as follows.

Over Production

Over Production comes when a product or an element of a product is produced before it is required and more than the customer has ordered. This creates the most serious of all other wastes in the Lean Manufacturing which leads in getting to other wastes. By the concept of Lean Manufacturing (Just in Time) products are manufactured only when they are required by the customers by pulling what is exactly ordered by the customers through workflow. The most common causes of this type of waste includes

- Large batch sizes
- Unreliable process
- Inaccurate forecasts and demand information
- Unclear customer demands
- Unstable schedules
- Long and delayed setup times

This type of waste can be eliminated by implementation of the better planning and work coordination procedures. Process mapped and measured working process can result in reducing the setup time and thus allowing the small batch sizes. Pull system such as KANBAN system are used to control of the Over Production

Over Processing

Over processing generally means to doing more than what is needed or necessary. General over processing includes generation of more information than actually required, over designing, Over analysis, More test points, extra fine tuning beyond the requirements. Putting more into the products than the value required by the customers. Over Processing costs with the money regarding with the time of the workers, materials and with the machines or equipment. The most common cause of this waste are

- Unclear standards and specifications which leads to the workers to spend more time on finishing or polishing to the products or materials which is not required.
- Non standardized working practices which gives differences in the products with change of different people.
- Too many approvals and tests required for an action

These type of waste can be eliminated or reduced by understanding the work requirements from the customer point of view. Process mapping can be employed often to optimize the workflow and eliminates the over processing.

Defects

Defects in manufacturing are any imperfections which will have an effect on the performance, operations or appearance in the final product. This occurs when the final product is not fit for use which leads in either reworking of the product or scrapping the product. This wastes are included with the time, money and resources given to correcting these defects. Defects are mainly caused by

- Lack of training
- Lack of skills
- Poor quality control at the production area
- Lack of maintaining the standards
- Not understanding the customer requirements

These wastes can be eliminated by reviewing the product design for defects and checking the work plans and implementation of the standard operations procedures, maintaining the proper quality control and proper training of the employees.

Waiting

Waiting refers to time wasted due to some interruption in the production process which causes the whole process to slow down or stop. This includes the people material and the machines or equipment which costs the company in terms of money in various aspects. Waiting waste includes waiting for the materials to arrive for the process, waiting for taking the action for manufacturing and insufficient machine capacity and idealness of the machines these leads to excess material in the inventory and over production. Waiting may also lead to additional waste such as defects in which if the waiting leads to taking up a lot of activities to get done results in not following up of the standard work procedure by shortcuts taking to rush the work.

Waste in waiting mainly caused by

- Unplanned downtime
- Delayed setup time
- Lack of Process control
- Idealness of machines
- Poor Man-Machine coordination

Waiting can be eliminated or reduced by balancing the production process to ensure the continuous flow, improving the machine reliability and minimizing the movement between and inside the cells, training of workers to be multi skilled so that they can be adjusted to multiple work demands, methods of planning combined with the daily meetings to ensure what is required for process on that day, maintaining standard basic preventive maintenance schedule to reduce machine downtime

Inventory

Inventory is a form of waste because of the related holding costs. Raw materials, work in process and finished goods comes account in the inventory. This happens because of poor process link between the manufacturing and purchasing or scheduling. Excess inventories also prevents in the production related problems like defect identification which are accumulated before identified.

Inventory waste is mainly caused by

- Over Purchasing, over producing of Work in process and over production than the customer requirement
- Large batch sizes
- Lack of balances in the work flow

Excess inventory can be prevented by several management techniques by implementing the Just in time, using FIFO (First In First Out) for inventory consumption. Purchasing of the raw materials only when needed and what quantity is needed, reducing the buffer between the production processes and creation of queue system to prevent the over production, reducing the definition of safety stock to achieve the less inventory cost. Improved techniques in warehousing and using of the ERP systems will helps in reducing the production and scheduling of unwanted items.

Motion

The waste in motion refers to unnecessary movement of people, materials, equipment or the machinery. This includes lifting, walking, reaching for materials, searching of the files, sifting of the inventory, walking to get a tool or material, readjustment once the action is completed and other actions which do not add any value to the product or the customer.

This type of waste is mainly caused by

- Poor layout of the workstation
- Poor designing of the methods – Transferring of the parts
- Poor Organization of the workplace
- Shared machines and equipment

Transportation

Transportation waste occurs when materials, tools, machines, equipment, finished and semi-finished goods are moved or relocated for different stages of the processes. This is considered as waste since the time, energy and efforts have been put for transporting which does not add any value to the final product. Excessive movement of the materials can also lead to product damage and defect, movement of machines and tools can lead to greater wear and tear and damages.

Transportation waste can be caused by

- Poor Layouts
- Multiple storage places
- Large and complex material handling systems
- Shared tools and machines
- Poor Production system design

While transportation is important and necessary since the process itself adds no worth to the end product minimization of cost and time related to this activity is important. Reorganization of Physical layouts and minimizing the distances covered between the process can reduce the waste in transportation inside the manufacturing environment. Building plants closer and utilizing the transportation means can reduce the wastes in transportation.

Non Utilized Talent

The waste of human potential is also considered as one of the major type of waste. This waste occurs when the role of management is separated from the employees. Without engaging the front line worker's knowledge and expertise improvement in the process will be a difficult one. This is because only people who are doing the particular work can easily and capable of identifying the problems and can help in developing the solutions for them. Non Utilization of the talents and employee abilities can impact directly on employee motivation and engagement to the work which affects the overall productivity.

Some causes of this type of wastes are

- Lack of recognition
- Poor Management
- Lack of Team training
- Inappropriate policies
- Limiting the employees
- Failure on involving employees in workplace design and development

By engaging all employees and incorporating the ideas given by them, providing proper training and growth opportunities and involving them within the creation of the improvements in the process designing will reflects their experience and skills can lead to the overall effectiveness in the organization. Encouraging people to take leadership in their areas will promote a sense of pride and involvement within them.[1]

2.1 MANUFACTURING SYSTEM ANALYSIS

Some of typical questions while designing or optimizing a manufacturing system like what machines do we need to choose? How many machines we need to use? What configuration of workstations we need to use? What products we need to focus? Do we need buffers if so what size? All these questions are based on the analysis of the Manufacturing system and here we will see about some of analysis used in the manufacturing systems.

2.1.1 PARETO ANALYSIS

Pareto Analysis is a statistical method or technique used for decision making for the selection of limited number of tasks that produces significant overall effect. It uses the Pareto principle 80/20 rule which has been derived from the famous observation by Vilfredo Pareto that 20% of the population owned the 80 % of the property in Italy.

This Principle has been applied in many forms like 80% of the problems are produced by the 20% of the causes, 20 % of the work consume the 80 % of the time and resources, 20 % of the stock consumes 80% of the space in the warehouse etc.

The reason that this principle is valuable because we tend to expect that each one cause can have roughly the same significance but which is not in the actual case. Using this principle gives clear relationship between the two comparison. Typically, this principle states that input, causes or effort divide into two categories

- A small minority thing which have a major dominant impact
- The majority things which have a little impact

Steps for using Pareto Analysis

Pareto analysis starts with the analysis of subject definition - selection of process or activity or area or problem where we need to focus likely to increase the efficiency or earnings and prioritise.

- Identify a set of criteria what we want to measure against that
- Collect the relevant data which are all needed to make the accurate analysis
- Sort the data by its appearance, frequency, weightage etc. in descending order
- Create a vertical bar chart with x axis for the causes and no of occurrences (count) on the Y axis by arranging the chart in descending order
- Calculate the cumulative count for each cause and cumulative count percentage in descending order and create a second y axis with percentage descending from 100% to 10%.
- Plot the cumulative count percentage of each cause on the X-axis and join the points to form a curve.
- Draw a line at 80% on the y axis running parallel to x axis. Then drops the line at the point of intersection with the curve on the x axis. This point on x axis separates the major causes on the left. [2]

The following picture (Figure 1) shows an example of Pareto diagram

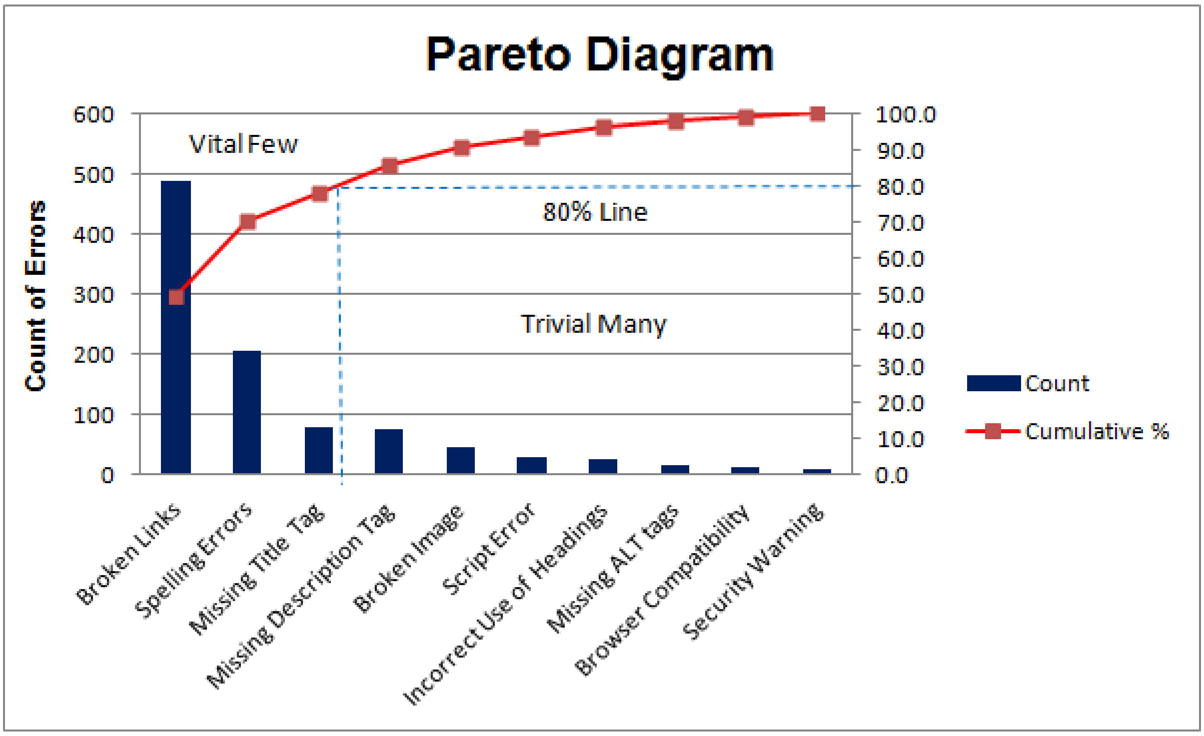


Figure 1: Pareto Diagram [3]

In this example X axis denotes the type of errors in a webpage description and Y axis in the left side denotes the error counts and by Pareto principle 80% of the problems are caused due to the 20% of the cases.

2.1.2 ABC ANALYSIS

ABC analysis is an inventory management technique which is used to classify the inventory items based on its consumption value. It helps the team to identify the most important products and ensuring them to give more priority than the less valuable items. This approach is based on the Pareto Principle which helps in identify what matters in taking account in which 80 % of the value of inventory would be held in 20 % of the items.

By using the ABC approach the inventory items are rated from A to C with the following rules

A-items are those which annual consumption value is the highest. The top of 70-80% of the annual consumption value typically accounts on this 10-20 % of those total inventory items. These comprises a very small number of items but have a relatively high consumption value.

B-items are interclassing items with a medium consumption value with values lower than the A items and higher than the C items. 15-25% of annual consumption value is typically accounts on this these 30% of the inventory items.

C-items have the lowest consumption value and typically largest category which contributes least value. This class have a high proportion of total number with relatively low consumption values which accounts 50% of total inventory items.

A-items should have an extremely controlled inventory control, additional secured storage areas and higher sales forecasts. Reordering should be frequent with weekly or maybe daily reorder. For C-items reordering is made less frequently. Generally, inventory policy for the C-items consists of just one unit to be had and reordering is done when actual purchasing is made. For C-items the question isn’t so much what percentage of units do we store? But rather can we even keep this item in the store? B-items generally benefit intermediate between A and C. A vital aspect of class B is the monitoring of potential evolution towards class A or towards the class C. Scope of this class is determined by the estimation of cost benefit of class reduction. The following picture (Figure 2) shows an example of a warehouse layout before and after ABC analysis

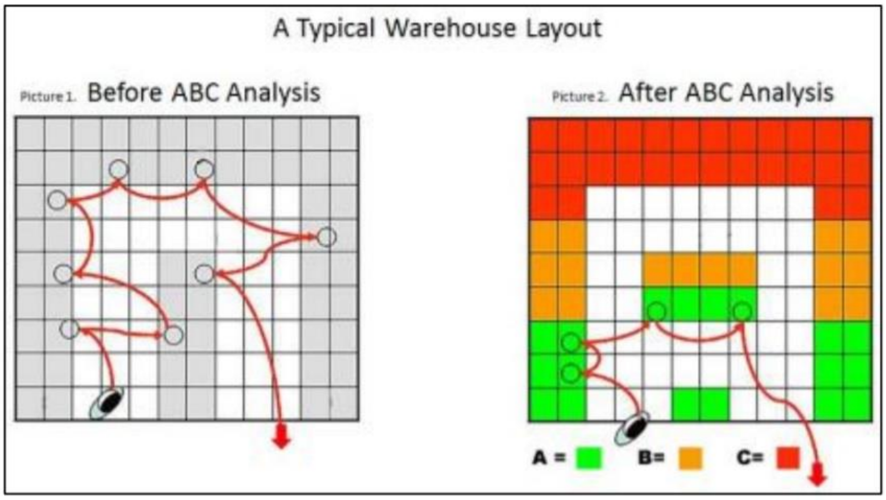


Figure 2: ABC Analysis [4]

2.1.3 SANKEY DIAGRAM

Sankey diagrams is a visualization technique used to show the flow of resources. The key to making, reading and interpreting Sankey Diagrams is width is proportional to the quantity represented. It has directed arrows which have a width proportional to the flow quantity visualized. The directed flow is always drawn between two nodes (processes). The things which are being connected are called nodes and the connections are called as links.

These diagrams are used to show the weighted networks. It can be done with several data structures

Evolution – The nodes area unit duplicated in a pair of or a lot of groups that represents stages. Connections show the evolution between the states.

From source to end – Each node is unique. Considering a total amount, the diagram show where it comes from and where it ends up with possible intermediate steps. The following picture (Figure 3) shows an example for Sankey diagram.

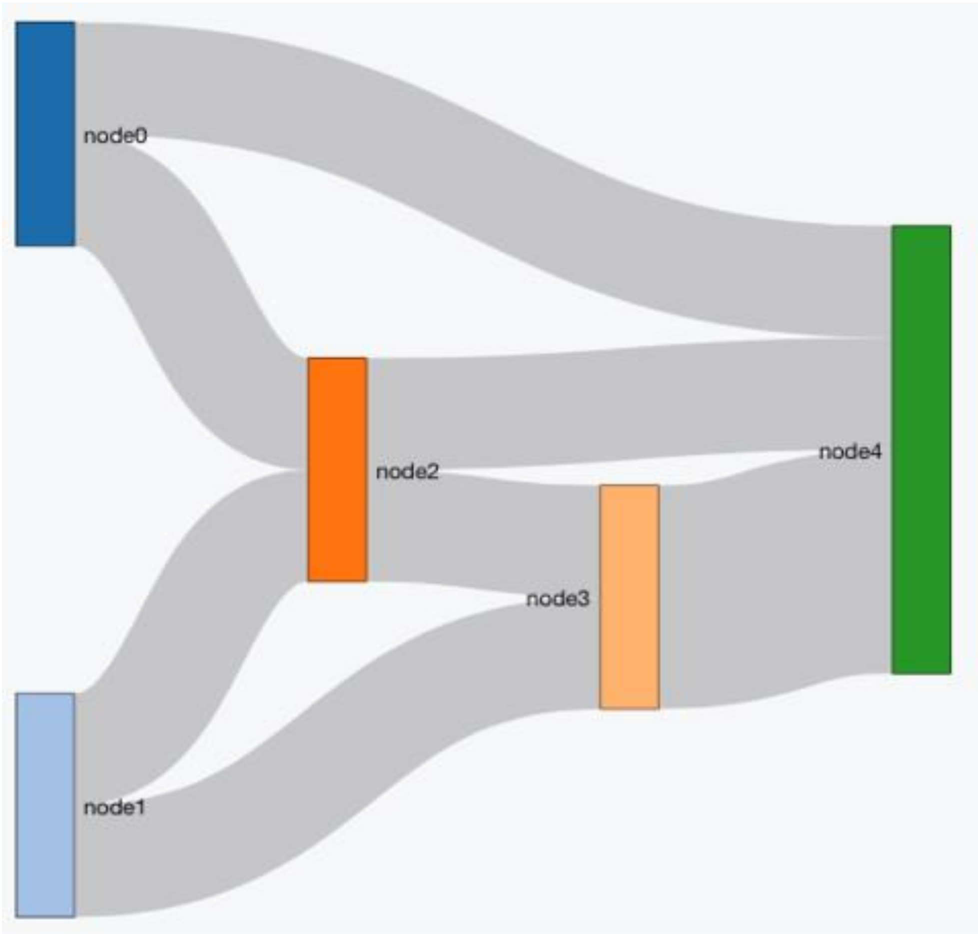


Figure 3: Sankey Diagram [5]

2.1.4 SPAGHETTI DIAGRAM

Spaghetti diagram is a visual representation of physical flow using a continuous flow line tracing the path of an item or activity or people through the process. It works on the physical layout of a process for achieving the goal. It is one of the tool in the LEAN that helps in reduce the waste on motion, transportation and the waiting time. It details about the distance, flow and waiting time of the transportation of items in a process. In additional it also traces the walking pattern of individuals, shuttling back and forth of the materials between tasks and work stations.

Procedures to draw a Spaghetti diagram

- Outline the sketch of current work area in detail
- Describe or draw the movement of each unit or person by drawing a line from a point to another.
- The lines should be redrawn for every trip or every movement. When the movement is more corresponding lines for each movement are drawn.
- The lines should be represented as naturally as possible since straight lines are practically non-existent

To improve the efficiency at the workplace or in processes Spaghetti diagram can be used for analysis to design the strategies by minimizing the distances and stops. Most connected tasks should be placed near as close as possible to reduce the movement or distance as they are frequently used. Simplification of the process has been done. Arrange the things or machines in a better sequence to which helps in a continuous flow. It identifies the inefficiencies in the work place and helps in reducing the non-value added time spent during the processes. It clearly shows where most of the time is lost. It also helps in work place area occupational safety and reduces the fatigue of employees due to unnecessary movements. The following picture (Figure4) shows an example of spaghetti diagram.

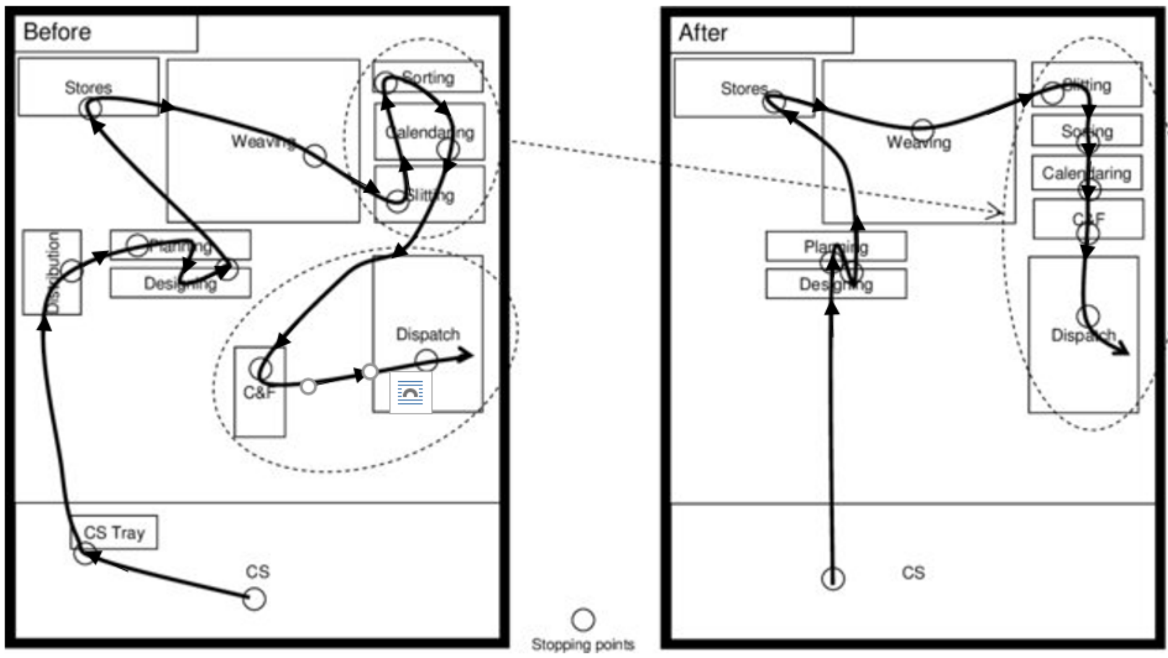


Figure 4: **Spaghetti Diagram** [6]

2.1.5 PROCESS DIAGRAM

A Process diagram or Process flow diagram is a graphical way used to indicate the general flow of the Processes or equipment or machines in the plant. It displays the relationship between the major equipment. This is an initial step in the engineering process or in the continuous improvement. Flow charts are used to define or analyse an existing process, when we need to standardize or redesign a process, when you need to find areas for improvement in the process.

Procedure for making process diagram

- Identify the goal or process which needs to be diagrammed
- Outline the proc3ess steps by the help of people who knows the process well
- Define the first and last step in the process. Brainstorming of the activities has done. And the activities are arranged in a proper sequence using some notes
- Define the process as it exits and while documenting the process steps may occur parallel
- The diagram has symbols which is used to represent the different items in a process

The following picture (Figure 5) shows the symbols used in the process diagram.

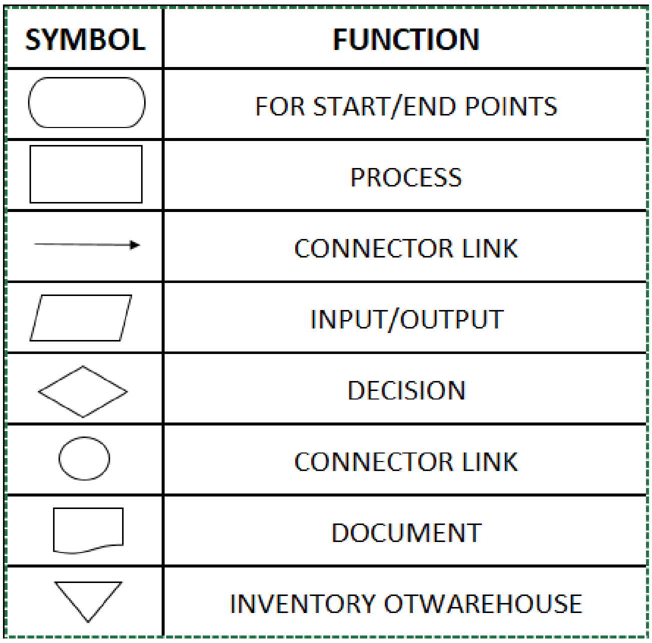


Figure 5: Process Diagram [Source: Own]

Work through the entire process and show the actions and decisions appropriately in the same order as they occur.

Unfamiliar steps can be noted in the middle if we have some doubts and can proceeded after the last step is completed.

2.2 5S

5S is 5S is a lean manufacturing tool. A basic fundamental step to pursue a successful Lean Manufacturing process is implementing the 5S.

5S methodology is used for setting up and maintaining the quality of working environment in an organisation. Such organisations can manage and organise in efficient way which require less human efforts, space, time, and capital to make products with less error and make a well ordered and a clean workplace.

5S system is used to decrease the waste and ɵ optimize the productivity as well as quality by monitoring an organised environment and using the visual evidences to get more firm results. Using this 5S technique gives an effective way to improve safety standards, health, housekeeping and environmental performance.

5S USES

- Disciplined approach for an organized workplace
- Safety
- Employee Involvement
- Efficiency
- Cleanliness
- Space - Saving
- Timely deliveries of products
- Faster Training of new employees

The 5S's are

- SEIRI – SORT OR ORGANIZE
- SEITON – SET IN ORDER OR SYSTEMIZE
- SEISO – SHINE OR CLEAN
- SEIKETSU – STANDARDIZING
- SHITSUKE – SUSTAINING AND SELF - DISCIPLINE TO MAINTAIN IT

2.2.1 SEIRI – SORT OR ORGANIZE

SEIRI means the sorting of the unnecessary items from the other items in the work place area which are actually needed. This stage needs the team to get rid of all the things that clearly don't belong in the working space and solely leave things only those which are needed for the processes. The necessary and unnecessary things offered within the workplace should be classified and sorted. By sorting these everyone can identify the tools, materials, equipment and necessary things for this. The most often used items are placed very near to reach while the other not frequently used are placed subsequently. However, this step is not just a cleaning process, this makes an opportunity to re-evaluate the tool at their disposal and by making sure that they will use the most effective tools for their processes. This processes involves in going through the target area and marking with the red tags to those items that appears the out of place or unnecessary. And same time a designated area has to be identified and allotted on the Production area where all of these unnecessary things can be shifted and stored. This area has been identified as Red tag area and hit has to be clearly marked so that everyone can understand and identify that. Questionable and doubted items can be left in the holding area for a period of time and the most unwanted items can be disposed in the appropriate manner. Thus it helps to maintaining the clean workplace and efficiency of searching things can be improved.

Sorting Methodology

- Any unnecessary things which is inflicting the mixture of other things should be filtered
- Any unnecessary part of the item placed other side has to be taken back to its original place
- All the tools of materials on the production area has to be in the tool floor
- All the tools are classified properly with the rules
- After all these above steps we will sort the unnecessary things and by Red label or Red tag technique these items identified and tagged with the information containing why those were tagged and what has to be done and moved to the Red tag area

The following picture (Figure 6) shows an example of 5S Red Tag model and picture (Figure7) shows an example of Red tagged objects.

Figure 6: 5S Red Tag (Left) [7] **and Red Tagged Objects (Right)** [8]

The following picture (Figure 7) shows an example of 5S Red Tag holding area

Figure 7: **Red tag holding area**[9]

5S Flow Chart

The following table (Table 1) shows the flow chart of 5S methodology

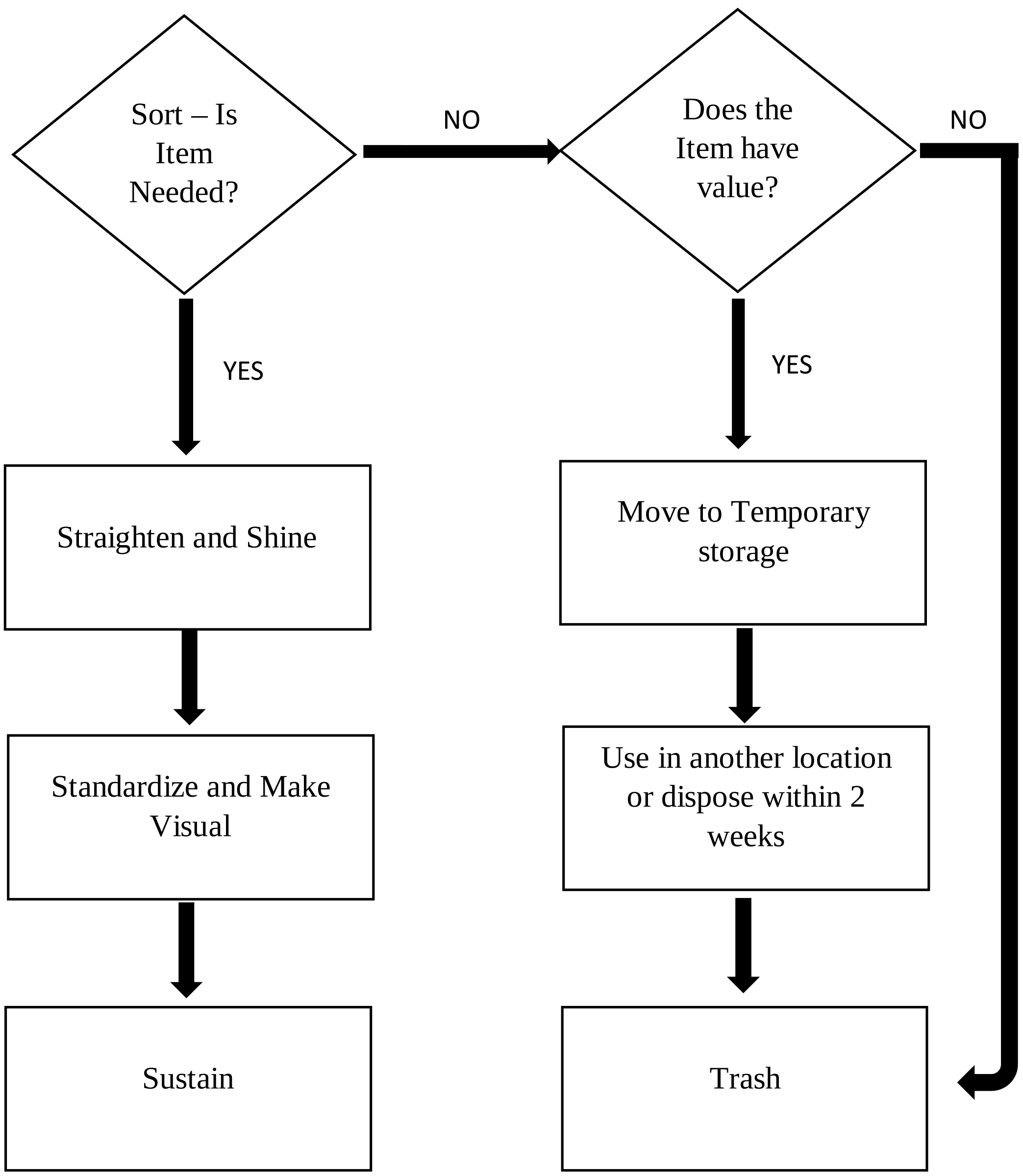


Table 1: 5S Flow Chart [Source: Own]

2.2.2 SEITON – STRAIGHTEN OR SET IN ORDER

This is the second step in the 5s methodology after sorting out. This process takes the required items which are remaining after the removal of unnecessary things and arranging them in an efficient manner by using the ergonomic principles and therefore ensuring every item has a place to keep and everything is in its place. This step goes with cleaning and organizing the items neatly and systematically so all the items can be easily taken for use and returned to their original position after using.

The aim of this step is to minimize the number of work which a worker has to perform during the operations. This step includes the visualization of the work place which is very important. For example, painting of the floor helps to identify easily the transport ways or storage of each material, drawing of the shape of the tools makes way to putting aside them on constant places where it is kept before, colouring the labels helps in the identification of the spare parts, materials or the documents. Tools, equipment materials must be systematically arranged for the easiest and most efficient way of access.

Straighten Methodology

- The position of every place where the items supposed to be place should be decided earlier
- All the tools should be segregated on the basis of the regular usage
- All the important items have to be put in an accessible position where it can be brought easily
- Small tools should be placed in an organised specific place
- Safety items should be placed in a right positon for in case of emergency demand

The below picture (Figure 8) shows an example of orderly set assembly work place.

Figure 8: Set in Order Assembly [10]

The following picture (Figure 9) shows an example of orderly set warehouse

Figure 9: Set in Order Warehouse [11]

The following picture (Figure 10) shows an example of orderly placed tools.

Figure 10: Set in order Tool Area [12]

2.2.3 SEISO – SHINE

This process starts with the thorough cleaning of the area, tools, machines and other equipment. And this will make sure that any non-conformity stands out such as leaking of oil from a machine onto a bright and newly painted clean floor.

For aesthetic point of view its essential to make a clean, regular working and living environment in workplace because dirt, wastes and dusts will reduce the efficiency of the workplace. Cleaning has to become a daily activity, workplace has to be cleaned at a regular interval of time for better production. Regular cleaning permits in the identification and elimination of the disorders. During cleaning each and every item cleanness on the workplace is checked.

A sheet of checklist for cleaning can also be created by the operator to ensure the cleanness in the workplace.

This step involves not only the cleaning up of work place but also eliminate the root cause of the problem and helps to fix the safety hazards

Shine Methodology

- Clean all the machines present in the work shop on a daily routine
- Check all the equipment, tools on regular period of time and provide the necessary cleaning.
- Clean the work floor and shop floor

The below picture (Figure 11) shows an example of before and after the shine methodology

Figure 11: Shine machine [13]

2.2.4 SEIKETSU – STANDARDIZE

This is the method of making certain that what we have done among the primary three stages of the 5S has become standardized. That's we tend sure that we've common standards and ways that of working. Standardising the work is one of the most important principles of Lean Manufacturing. This maintains the habit or standard of cleanness all time in the industry.

Standards has to be very clear and easy to understand. And the standards should not be implemented not only in the processes such as maintenance, production, storing but also in the administrative processes also.

Standardize Methodology

- Giving strict instructions about cleanness to the whole staff
- Maintaining habit of checking the progress of the cleanness
- Make an audit sheet for ensuring the cleanness

Figure 12: Standardize [14]

2.2.5 SHITSUKE - SUSTAIN

It is not enough to implement solely the first four steps of 5S as a result of entire 5S effort would be futile if they can't be sustained. Practicing of 5S is more difficult and important than implementing it.

5S has to become a part of the culture of the organization and everyone's responsibility.

This step makes the habit for the staffs in the industry to Learn all above 4S. Trained and skilled persons have to teach the staff about the all 4S and these tasks has to be undertaken by the Leader. And the leaders should explain about the importance of the 5S through various training programs to the other personnel

The knowledge of the personnel regarding the 5S should be kept updated through the 5S boards which has to be formed at the workplaces. To maintain the standards and technique in a safe and efficient order. Its conjointly necessary to understand the requirement of executing the 5S rule on a fixed interval and learning of 5S has to be executed once a month by a trained team.

Sustain Methodology

- Manager of the organization ought to take the responsibility to command a program on 5S rule
- Staffs should also have eagerness on learning the technique[15], [16]

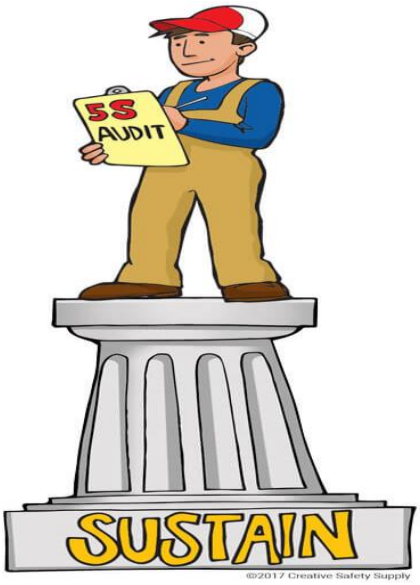


Figure 13: Sustain [17]

2.3 LAYOUT COMPOSITION RULES

The basic rules while designing a Production area layout are

1. While designing the layout the machines has to be placed in such a way that the flow of products should be shortest and fastest
2. The layout has to be designed without any crossings which means without the crossing of Labours or products.
3. The flow of labour or product has to be in One direction
4. The path should be wide enough to do necessary activities
5. Each and every path of the Labour or the part or the product has to be well defined
6. And the layout has to be designed in such a way the flow has to be in Continuous

The following picture (Figure 14) shows an example of a layout design without the consideration of above mentioned basic rules. And the circled number in the figure depicts the problems in the layout without taking the above layout composition rule points into consideration

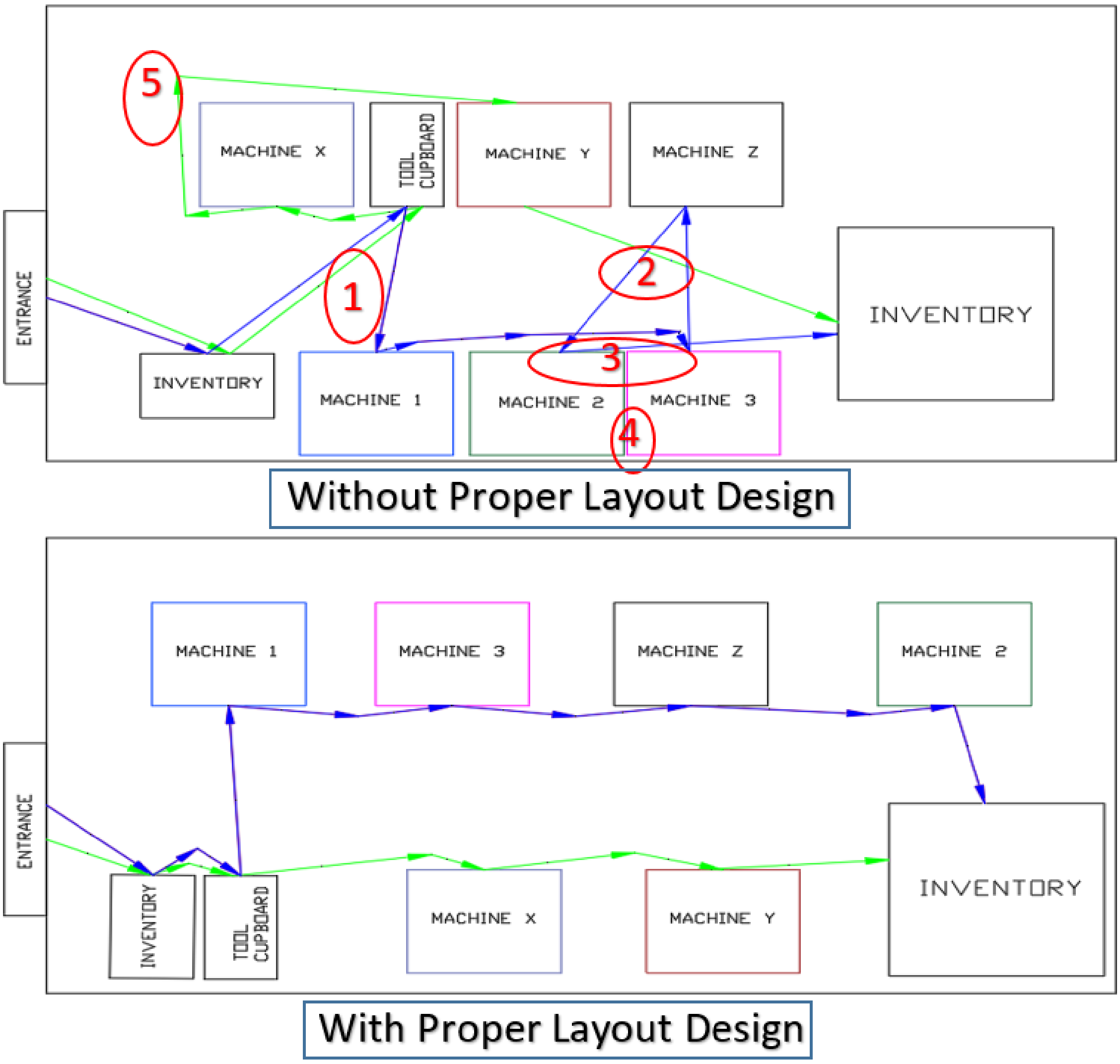


Figure 14: Layout Composition rules [Source: Own]

2.4 ERGONOMIC RULES – GENERAL + ASSEMBLY

The following description elaborates the ergonomic rules for the general and assembly work place

LIGHTING

Technical standards cover lighting requirements for plant use and maintenance including

- the direction and intensity of lighting
- the contrast between background and local illumination
- the colour of the light source, and
- reflection, glare and shadows. [18]
- Rough and average machine and assembly tasks REQUIRES MINIMUM LIGHTING OF 300 – 500 LUX [19]

TABLE HEIGHT

- Average Optimum working height for general and assembly workplace has been found as 1125 ±100 mm.
- The Work table height follows from the optimum working height minus the height of the work piece. So minimum of 1000 mm is the recommended height for the table.
- The following picture shows an example of 5S Red Tag holding area
- The following picture shows an example of 5S Red Tag holding area

The following picture (Figure:15) shows the table and working height for a worker

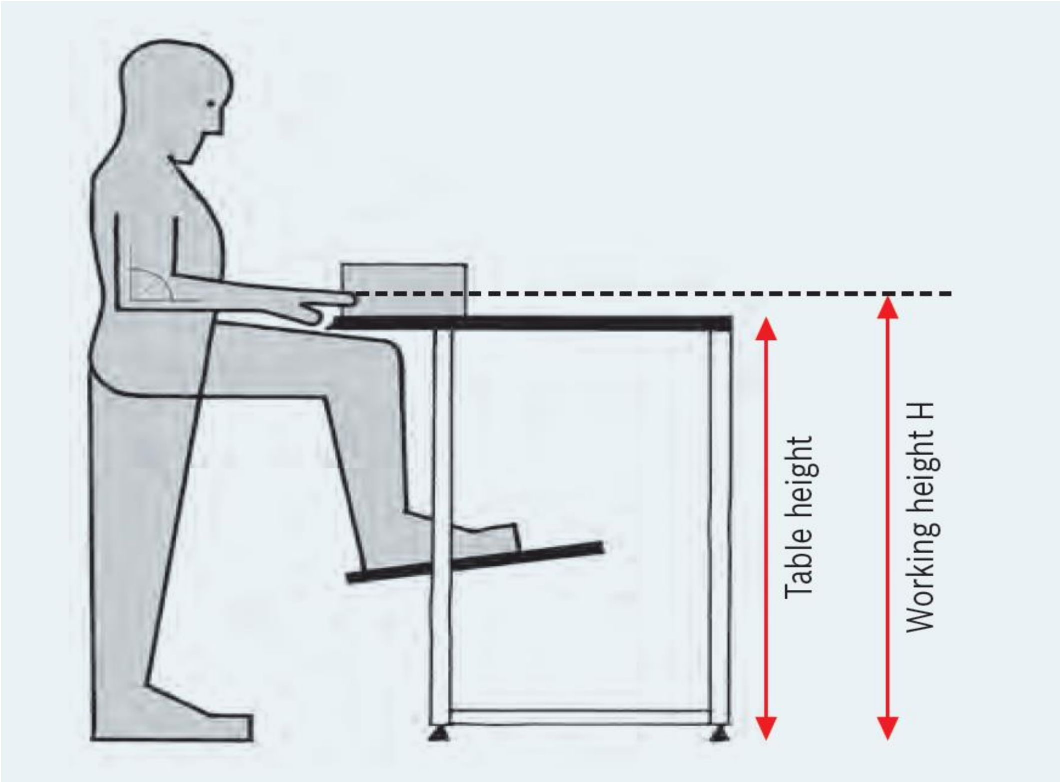


Figure 15: Table Height [19]

The distance to the working area influences the following

- Position of the arms
- Viewing distance
- Inclination of the head

Avoid work above the heart (over 1500 mm)

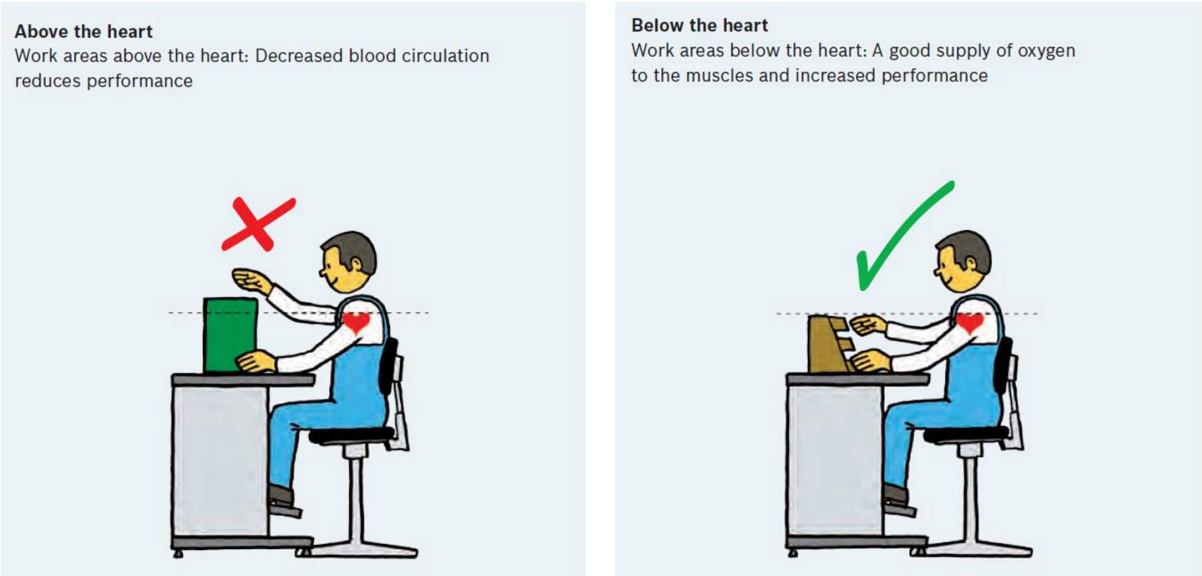


Figure 16: Working height [19]

The following rules apply for an ergonomic reach zone design: all containers, equipment, and operating elements must be easily accessible and arranged in the anatomic/physiological range of movement for the employee

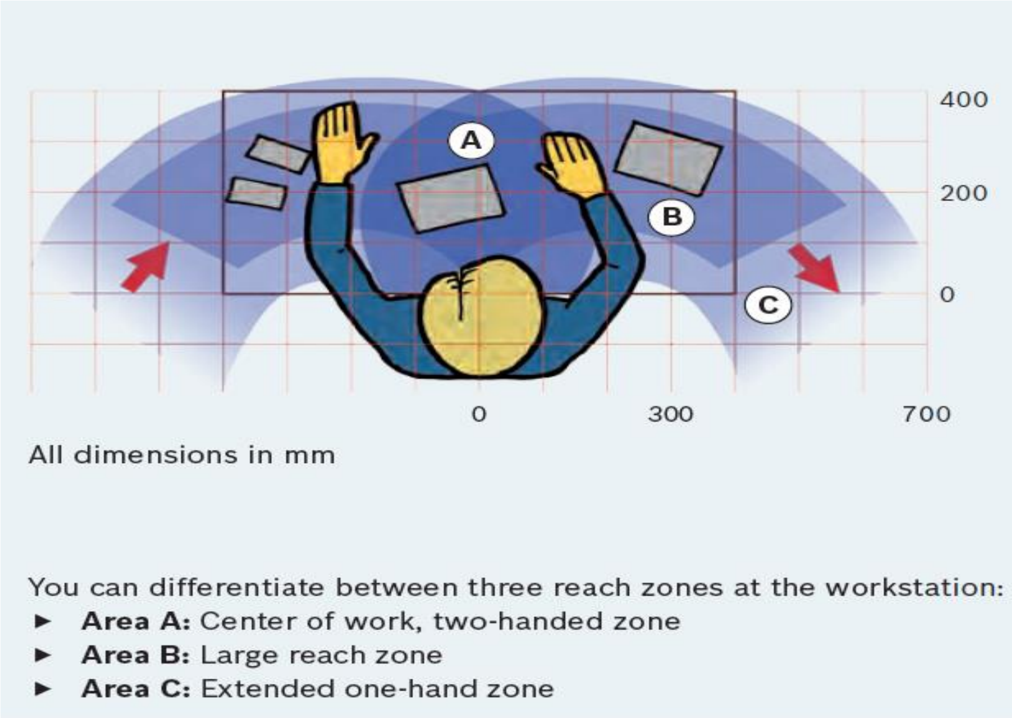


Figure 17: Working Zone [19]

Characterization of the three reach zones

Area A

- This area is optimum for working with the both hands, as both hands can reach this zone easily and are in the employee's field of view Possible to handle lighter weights and also enables improved assembly, inspection and coordination activities
- Pure lower arm movements
- Smaller muscle groups are in use
- Area for work piece support, work piece pallet, or equipment

Area B

- Area for tools and parts that are often grabbed with one hand
- Upper and lower arm movements without use of the shoulders and rotation of the torso

Area C

- For occasional handling, e.g. of empty containers or transferring parts to the range of movement for the next employee
- With shoulder and torso movement

Range of Vision

During Planning of Workstation for better range of vision the following aspects has to be taken in account

- Avoid the unnecessary movement of eye and head
- Implementation of Vision distances that are identical as much as possible eliminates refocusing
- Avoid the fastening locations which are not visible to the worker

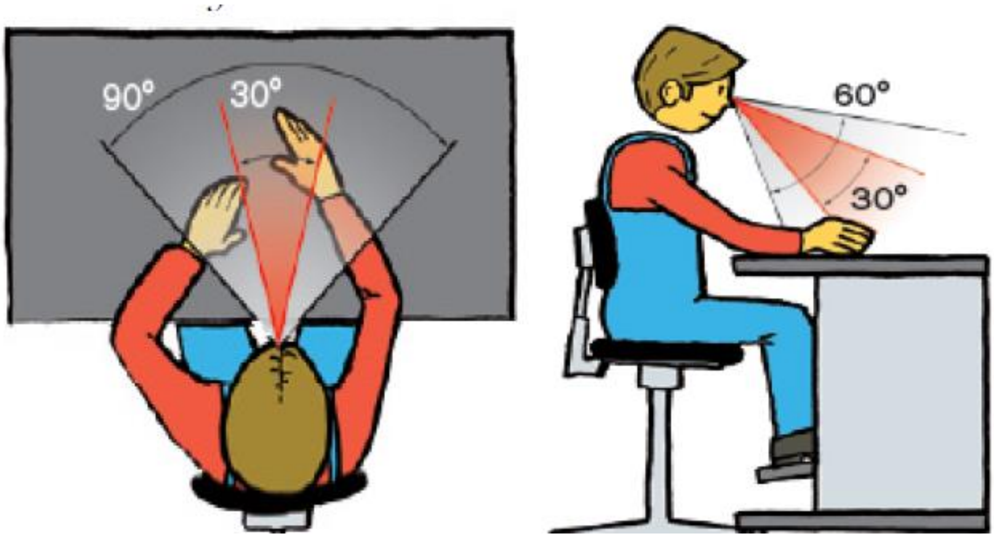


Figure 18: Range of vision [19]

Proper Ergonomics for range of vision has been shown by differentiating two work vision areas in the above image (Figure 18).

- In the Range of view Red vision area many objects can be focused simultaneously without moving head or eye
- In the Range of view grey vision area objects can be focused by moving the eyes but not the head
- Every time when we turn our eyes or head of changing the direction of vision and refocusing results in loss of time and Money [19]

3 ANALYSIS OF CURRENT SYSTEM

The main goal of this work is to optimize the CNC LABORATORY at Research Centre CXI. The principal goals and activities at this laboratory are Manufacturing of machinery components using the CNC machines including the complex shapes and prototypes in a single clamping of stock, manufacturing of components using Laser cutting machine and training for students in CNC programming and working of CNC machines for educational purposes.

3.1 MACHINE TOOLS

The laboratory is equipped with three major CNC machines and a Laser cutting machine which includes a modern 5 axis milling and turning machine and EMCO machines which is mainly used for the education purpose. The machines description as follows

MAZAK

- Products from Turning and Milling operations
- Cylindrical products only
- Maximum diameter for the products is 120 mm and Maximum diameter through spindle is 40 mm and maximum length will be 700 mm
- Aluminium, Brass, Steel and Plastics materials can be machined

Figure 19: MAZAK [Source: Own]

HERMLE

- Products from milling operations only
- Maximum work piece dimension can be 200*200*300 in X, Y, Z axis respectively

Figure 20: HERMLE [20]

EMCO

- Turning operations
- Product materials can be machined Aluminium, Plastic and Brass
- Maximum diameter of product is 40 mm and maximum length is 100 mm

Figure 21: EMCO [Source: Own]

LASER CUTTING

- Sheet metal cutting
- Maximum thickness of material for processing- Steel can be 3 mm and for stainless steel is 2 mm and for Aluminium is 2 mm

Figure 22: Laser Cutting Machine [Source: Own]

3.2 CURRENT LAYOUT

The following layout (Figure 23) shows the current layout of the laboratory

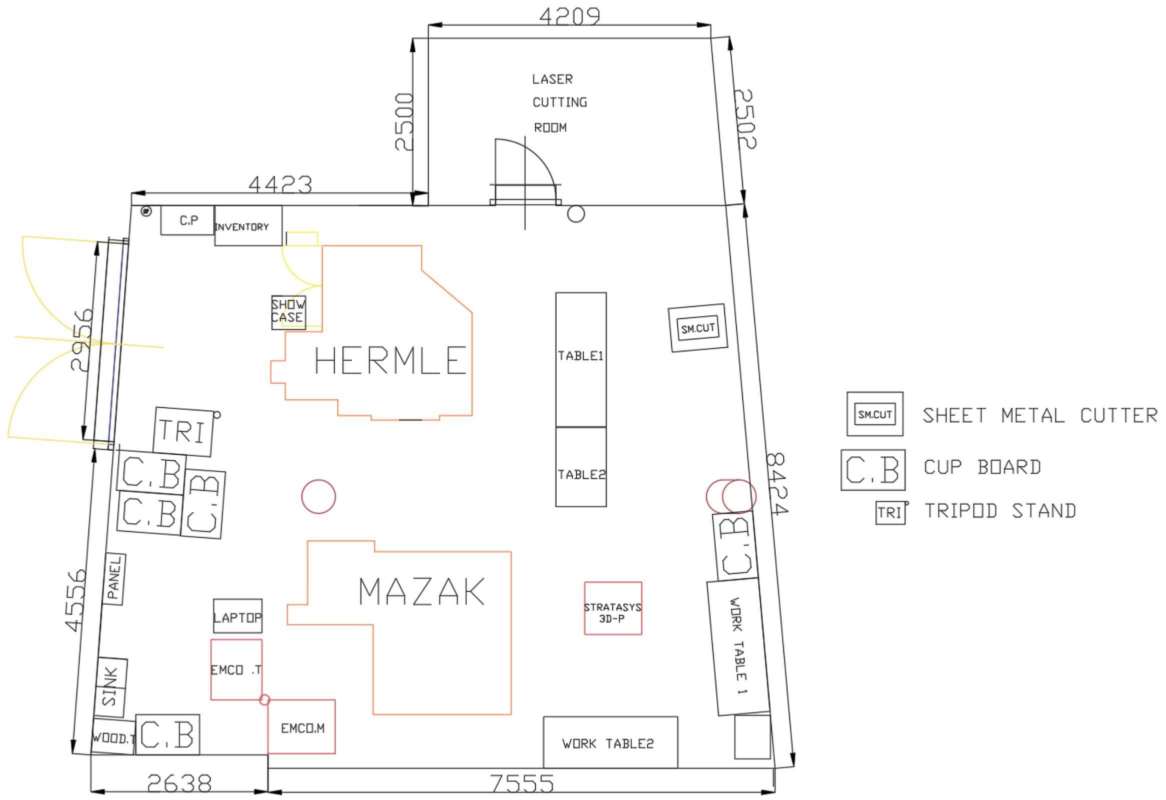


Figure 23: Current Layout of Lab [Source: Own]

Note: All dimensions are in mm

3.3 PRODUCT PORTFOLIO

The laboratory is equipped with mainly three CNC machines and a Laser cutting machine which has about 20 customer orders annually for CNC Machines and 70 jobs in overall for Laser cutting machine.

EMCO machines are 2 axis CNC lathe which are mainly used for the educational purpose and training of the CNC machining programming. Products from customer order gets done in this machine very rarely which has an annual customer order of only one order

A 5 axis multi operational turning-milling centre MAZAK Integrex 100-IV which is used production of complex shape parts, prototypes and short productions. This machine gets customer order about nine orders annually.

HERMLE C 250 machines are entry level 5 axis milling capability machines. This machine gets annual customer about 10 orders.

Generally, in this case Pareto analysis has to be done to find the overall typical part or product which are made in this laboratory for the optimization. But in our case since there is no proper maintenance of job records and there is no ERP system we have chosen two major products Drill Assistant and Adjustable spanner for the analysis purpose.

3.4 PARETO ANALYSIS

Drill Assistant has total of 13 parts and here Pareto Analysis is done to find the typical parts on the manufacturing of Drill Assistant based on the Part Count.

PART NAME	PART COUNT	PERCENTAGE	CUMMULATIVE
COLLAR PIN	4	30.77%	30.77%
PIN	4	30.77%	61.54%
CROSS CUBE	2	15.38%	76.92%
YOKE A	1	7.69%	84.62%
YOKE B	1	7.69%	92.31%
CONNECTING YOKE	1	7.69%	100.00%
TOTAL	13	100.00%	

Table 2: Pareto Analysis on Part Count [Source: Own]

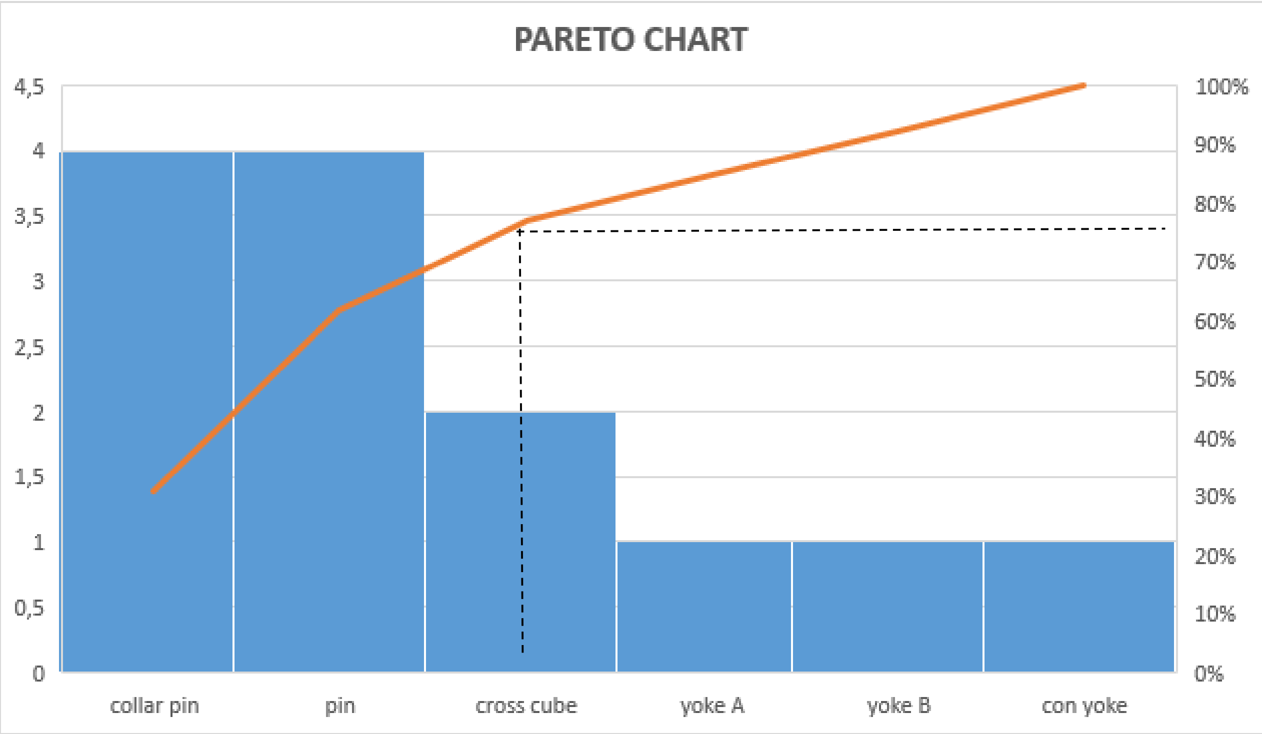


Figure 24: Pareto Chart on Part Count [Source: Own]

From the Pareto chart it is concluded that three parts Collar Pin, Pin and Cross cube holds almost 77% of the total part count and remaining 3 parts hold the rest 23 %. So that the three parts Collar Pin, Pin and Cross cube are the typical parts on the Drill Assistant.

Here another Pareto Analysis is done on Drill Assistant to find the typical part based on the Manufacturing time for its parts for a batch and from these we have concluded the 3 typical parts which are same from the Pareto Analysis done with Part Count.

PART NAME	MANUFACTURING TIME (MIN)	PERCENTAGE	CUMULATIVE
PIN	1074	25%	25%
COLLAR PIN	1034	24%	50%
CROSS CUBE	718	17%	66%
BASE	481	11%	78%
YOKE A	476	11%	89%
CON YOKE	468	11%	100%
TOTAL	4251	100%	

Table 3: Pareto Analysis on Manufacturing time [Source: Own]

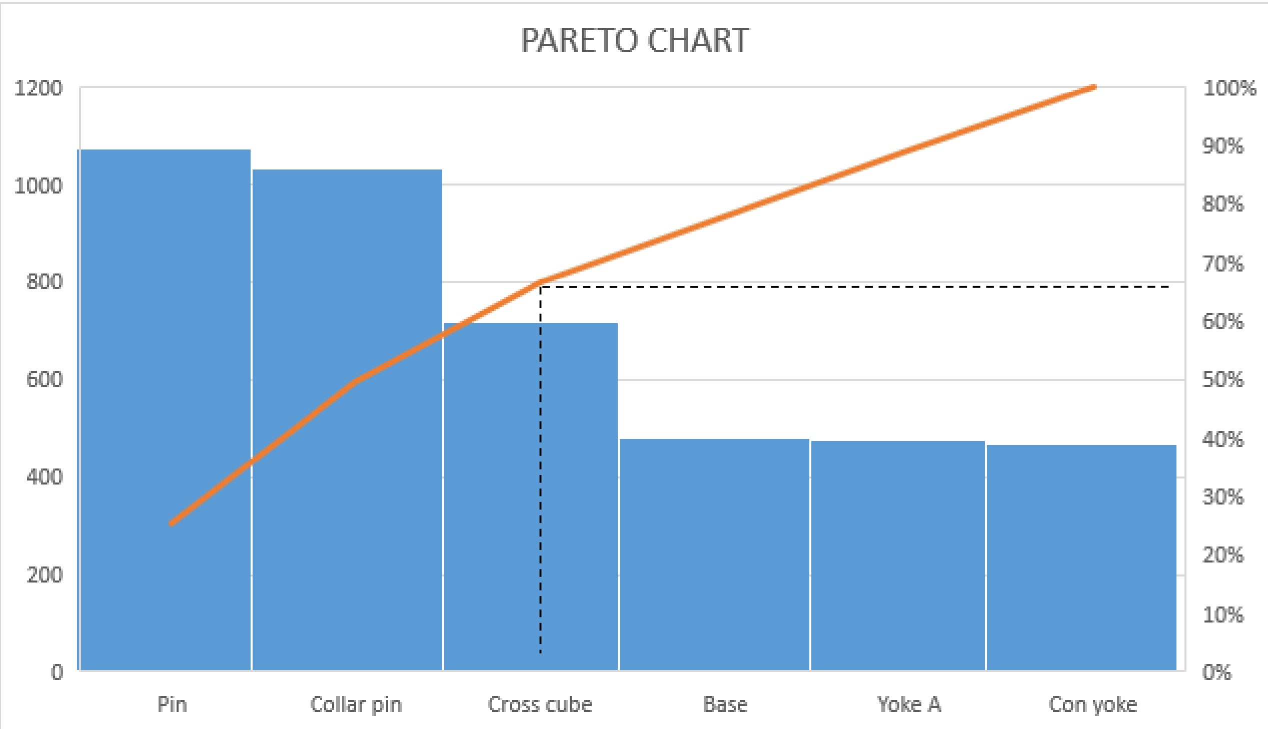


Figure 25: Pareto Chart on Manufacturing Time [Source: Own]

From the Pareto chart it is concluded that three parts Collar Pin, Pin and Cross cube holds almost 77% of the total part count and remaining 3 parts hold the rest 23 %.

So by the both Pareto Analysis it is concluded that the three parts Collar Pin, Pin and Cross cube are the typical parts on the Drill Assistant.

3.4.1 DRILL ASSISTANT

- Drill Assistant is a tool that can be mounted on Drilling Machine for various operations like screwing, drilling, etc.
- The operation of this Tool ranges from -90° to +90° so that this tool can be used to perform its operation by covering a total of 180 degrees
- The important application of this tool is that it enables the user to operate at any complex or awkward positions

Figure 26: Drill Assistant [Source: Own]

3.4.2 ADJUSTABLE SPANNER

- Adjustable spanner is a device used to fasten or remove various sizes of bolts in a single tool.
- This tool can be used to handle the bolt sizes from M4 to M16.
- This tool is designed in such a way it fits perfectly on the bolt heads and overall very compact in size

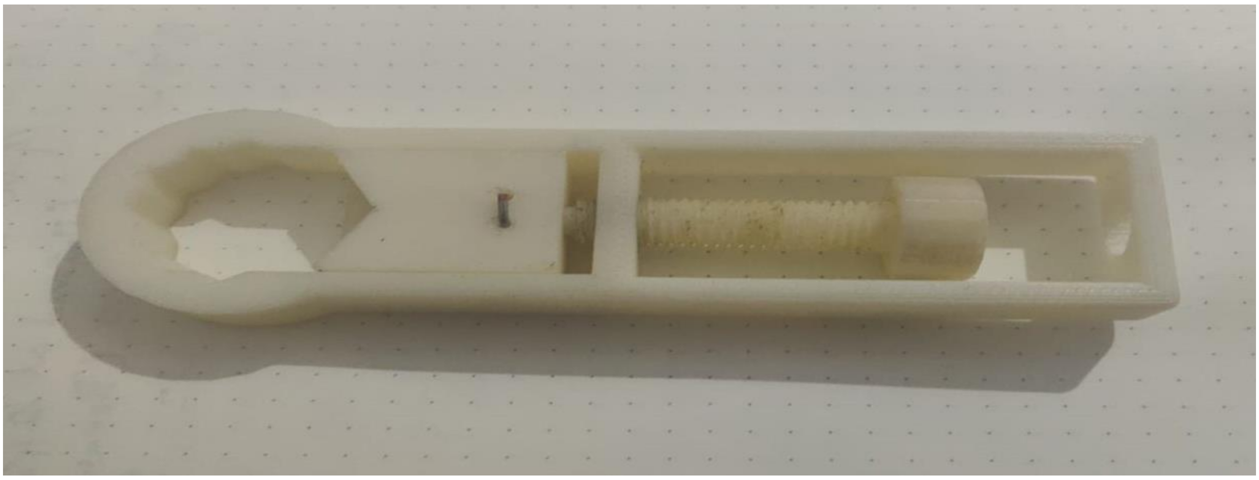


Figure 27: Adjustable Spanner [Source: Own]

3.5 PRODUCT AND PROCESS ANALYSIS

The following tables (Table 4) shows the Product analysis and (Table 5) Process Analysis of Drill Assistant and Adjustable Spanner

Product	Description
AS1	Raw Material - Hermle Milling - Mazak Drilling - Emco Turning - Table 2 - Table 1 - Base
AS2	Raw Material - Mazak Milling - Emco Turning - Table 1 - Table 2 - Tong
AS3	Raw Material - Emco Turning, Parting - Hermle Grooving, Parting - Mazak Milling, Parting - Table 2 - Table 1 - Bolt
AS4	Raw Material - C.B.2 - Hermle Milling - Mazak Drilling - C.B.1 -Laptop - Emco Turning - Table 2 - Table 1 - Base
AS5	Raw Material - C.B.2 - Mazak Milling - C.B.1 -Laptop - Emco Turning - Table 2 - Table 1 - Tong
AS6	Raw Material - C.B.1-Laptop - Emco Turning, Parting - C.B.2 - Hermle Grooving, Parting - Mazak Milling, Parting -Table 2 - Table 1 - Bolt
DA1	Raw Material - Emco Turning - Hermle Facing - Mazak Drilling - Table 2 - Table 1 - Yoke A
DA2	Raw Material - Emco Turning - Hermle Facing - Table 2 - Table 1 - Yoke B
DA3	Raw Material - Emco Turning - Hermle Facing - Mazak Drilling - Table 2 - Table 1 - Connecting Yoke
DA4	Raw Material - Emco Turning - Hermle Facing - Mazak Drilling, Parting - Table 2 - Table 1- Pins
DA5	Raw Material - Hermle Milling - Mazak Turning, Drilling - Table 2 - Table 1 - Collar pins
DA6	Raw Material - Hermle Milling - Mazak Drilling - Table 2 - Table 1 - Cross Cube
DA7	Raw Material - Emco Turning - Hermle Facing - Mazak Drilling - Table 2 - Table 1 - Yoke A1
DA8	Raw Material - C.B.1 -Laptop - Emco Turning - C.B.2 - Hermle Facing - Mazak Drilling - Table 2 - Table 1 - Yoke A
DA9	Raw Material - C.B.1 -Laptop - Emco Turning - C.B.2 - Hermle Facing - Table 2 - Table 1 - Yoke B
DA10	Raw Material - C.B.1 -Laptop - Emco Turning - C.B.2 - Hermle Facing - Mazak Drilling - Table 2 - Table 1 - Connecting Yoke
DA11	Raw Material - C.B.1 -Laptop - Emco Turning - C.B.2 - Hermle Facing - Mazak Drilling, Parting - Table 2 - Table 1 - Pins
DA12	Raw Material - C.B.2 - Hermle Milling - Mazak Turning, Drilling - Table 2 - Table 1 - Collar pins
DA13	Raw Material - C.B.2 - Hermle Milling - Mazak Drilling - Table 2 - Table 1 - Cross Cube
DA14	Raw Material - C.B.1 -Laptop - Emco Turning - Hermle Facing - Mazak Drilling - Table 2 - Table 1 - Yoke A1

Table 4: Product Analysis [Source: Own]

Process Analysis

	Door	Inventory	Laser Cutting	Cupboard 1	Laptop	Emco Machine	Mazak	Hermle	Table1	Table2	Cupboard 2	Sheet Metal Storage
	1	2	3	4	5	6	7	8	9	10	11	12
AS1	1	2				5	4	3	7	6		
AS2	1	2				4	3		6	5		
AS3	1	2				3	5	4	7	6		
AS4	1	2		5	6	7		4	9	8	3	
AS5	1	2		5	6	7	4		9	8	3	
AS6	1	2		3	4	5	8	7	10	9	6	
DA1	1	2				3	5	4	7	6		
DA2	1	2				3		4	6	5		
DA3	1	2				3	5	4	7	6		
DA4	1	2				3	5	4	7	6		
DA5	1	2					4	3	6	5		
DA6	1	2					4	3	6	5		
DA7	1	2				3	5	4	7	6		
DA8	1	2		3	4	5	8	7	10	9	6	
DA9	1	2		3	4	5		7	9	8	6	
DA10	1	2		3	4	5	8	7	10	9	6	
DA11	1	2		3	4	5	8	7	10	9	6	
DA12	1	2					5	4	7	6	3	
DA13	1	2					5	4	7	6	3	
DA14	1	2		3	4	5	7	6	9	8		
LMS	1	2	3									4

Table 5: Process Analysis [Source: Own]

3.6 SPAGHETTI DIAGRAM

Spaghetti diagram for Adjustable spanner (Figure 28) and Drill assistant (Figure 29) parts are shown below

For Adjustable spanner

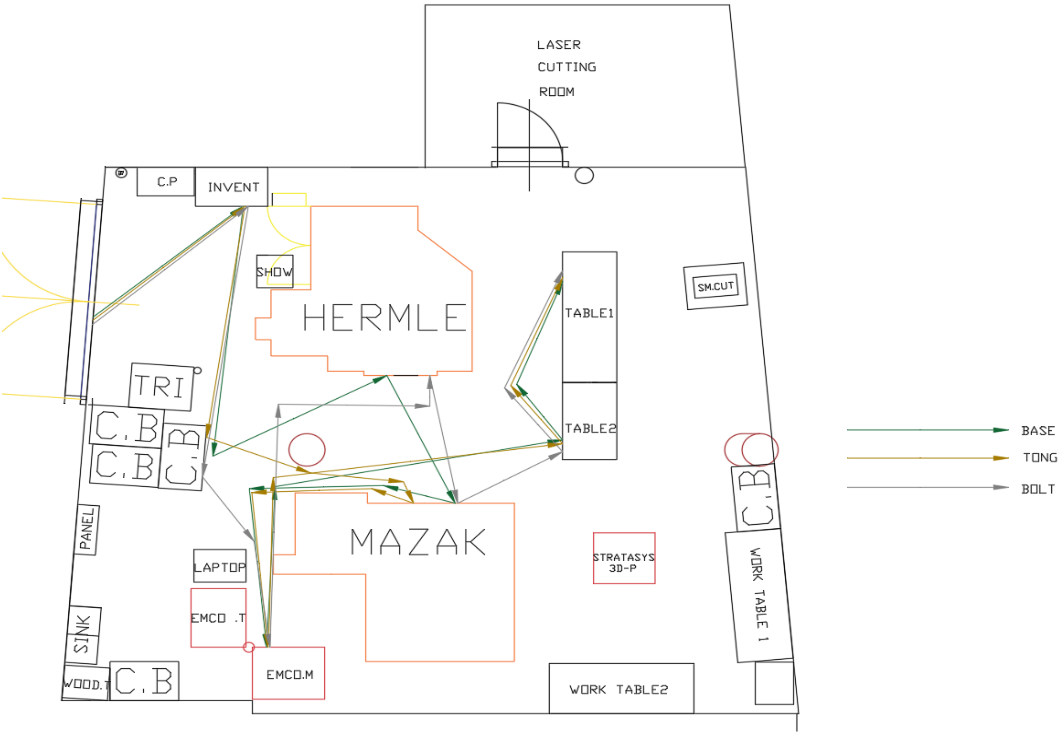


Figure 28: Spaghetti Diagram for Adjustable Spanner [Source: Own]

For Drill Assistant

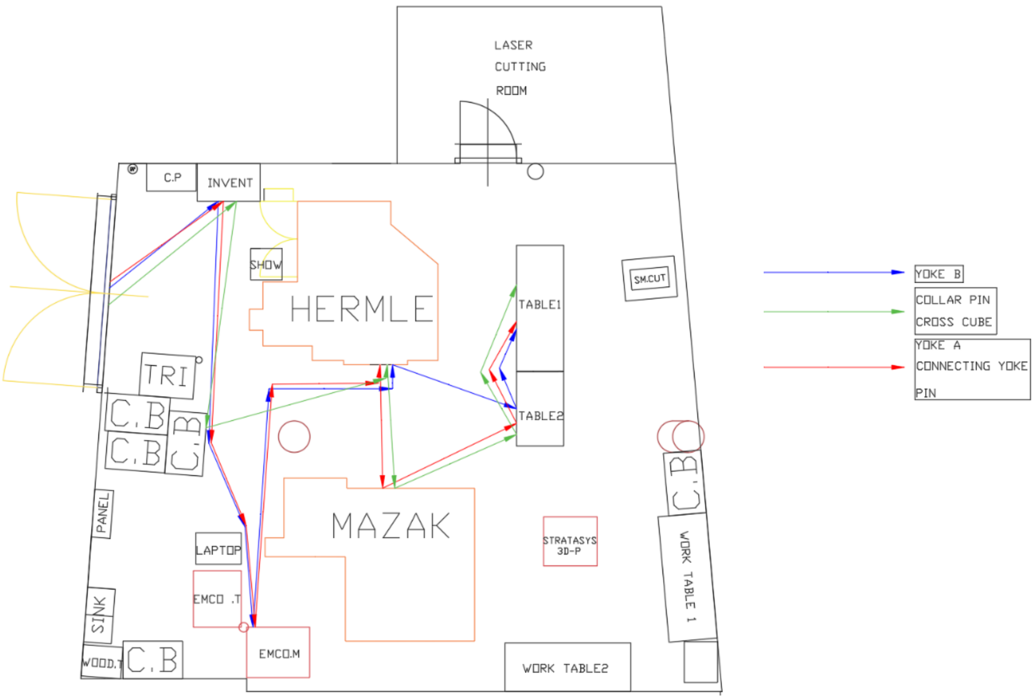


Figure 29: Spaghetti Diagram for Drill Assistant [Source: Own]

For Typical Parts Current Layout

In this Spaghetti diagram for 3 typical parts of Drill Assistant and all 3 parts of Adjustable Spanner has shown in the layout (Figure 30) below

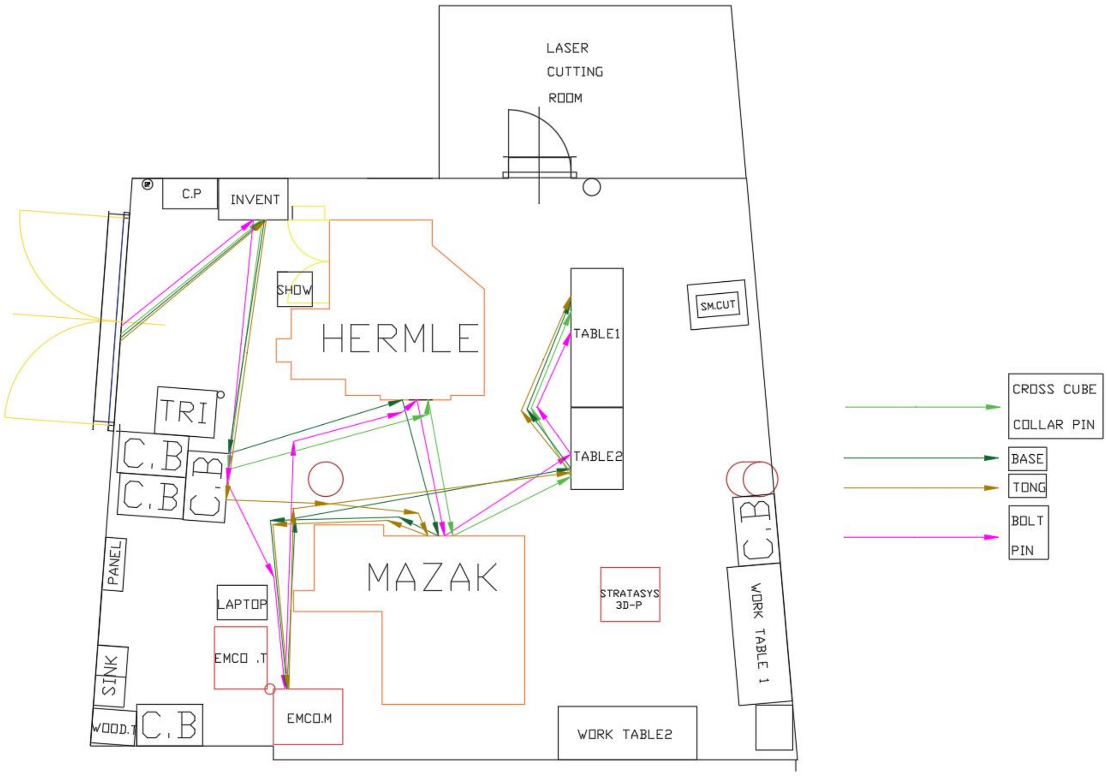


Figure 30: Spaghetti Diagram for Typical Parts [Source: Own]

3.6.1 ANALYSIS OF FLOW

The following picture (Figure 31) shows the analysis of flow using spaghetti diagram in the laboratory

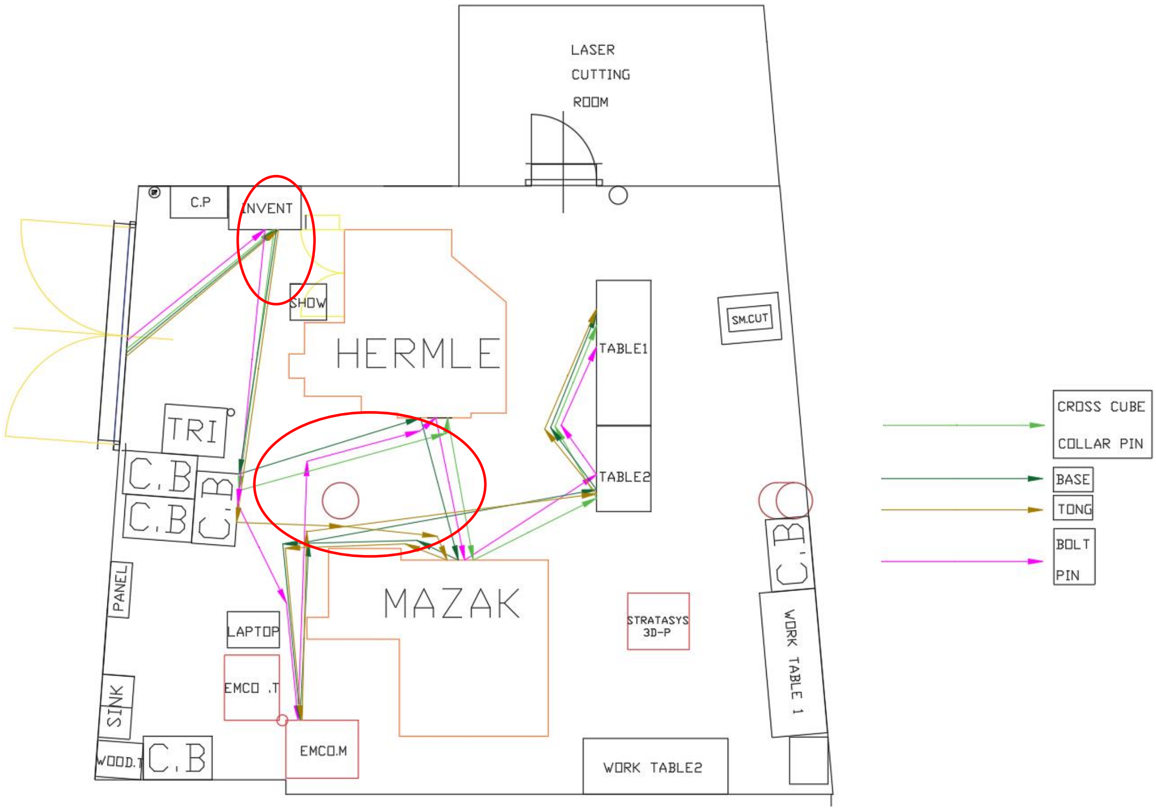


Figure 31: Spaghetti Analysis [Source: Own]

From the Spaghetti diagram for the typical parts the followings problems have been found

- There are many crossings in between the product flow which makes the Labour movement hard and thereby it will make unnecessary movements of the labour and increases the time of product flow
- As the Raw material inventory opening is facing the HERMLE machine and labour will find difficulty to reach and access the inventory since there is very less space to reach

3.7 ANALYSIS OF ASSEMBLY

Design for Assembly (DFA) generally concerned with the reduction of Product Assembly cost by minimizing number and complexity of assembly operations.

With the key principles of DFA, Drill assistant is compared

- Using symmetrical parts – Drill Assistant has 2 major parts Cross cube and connecting yoke which are symmetrical
- Using self-locating parts– The drill assistant does not have self-locating parts
- Using self-fastening parts - The drill assistant does not have self-fastening parts
- Modular Designing – In drill assistant Yoke B can be attached with drill bit or screwing tool which used as multipurpose
- Using Standardize parts – The drill assistant does not have any standardized parts
- Emphasizing top down assemblies – The concept of top down assembly cannot applicable with the drill assistant

The Drill assistant tool does not satisfy majority of the key principles of the DFA which in turn makes the assembly process to put additional efforts and time.

3.7.1 ASSEMBLY DIAGRAM AND R/L ASSEMBLY RULE

The purpose of Assembly diagram is to help the assembly workers for assembling a Product by providing the visual representation about the way in which the parts of the product is fit together.

The purpose of R/L diagram is to instruct the assembly workers regarding how to assemble a product's parts in the best of the motions in right and left hand in a possible sequence. This diagram shows the activities of hands in their relationship with one another. It is a specialized form of assembly process chart. The following picture (Figure 32) shows the assembly diagram and picture (Figure 33 and Figure 34) shows R/L diagram of the Drill assistant tool.

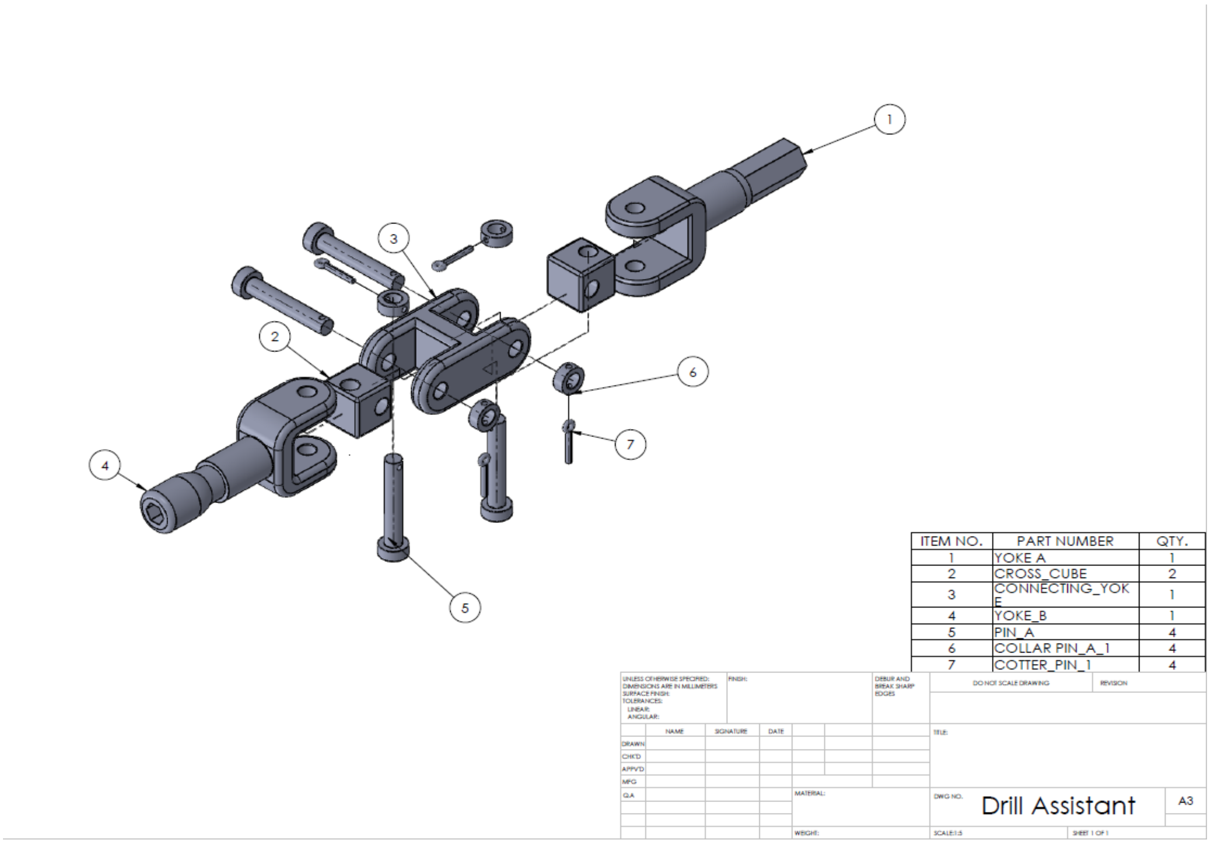


Figure 32: DA Assembly Diagram [Source: Own]

		BILL OF MATERIALS						
STRUCTURE ID	PART ID	NAME	POSITION IN DRAWING	MANUFACTURING /PURCHASING	MANUFACTURING		PURCHASING	
					Quantity	Units	Quantity	Units
1	412019_00	Whole Assembly		M	1			
1.1	412019_04	Yoke A	1	M	1	PCE		
1.2	412019_05	Cross Cube	2	M	2	PCE		
1.3	412019_06	Pins	5	M	4	PCE		
1.4	412019_07	Collar pins	6	M	4	PCE		
1.5	412019_08	Cottor pins	7	P			4	PCE
1.6	412019_09	Yoke B	4	M	1	PCE		
1.7	412019_10	Connecting yoke	3	M	1	PCE		

Table 6: Bill of Materials for Drill Assistant [Source: Own]

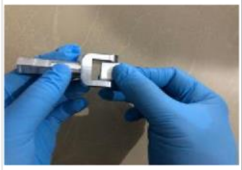
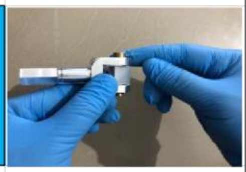
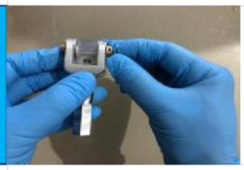
FOR DRILL ASSISTANT				
STEP NO	LEFT HAND	TABLE 1	RIGHT HAND	PICTURE
1	PICK YOKE A FROM TABLE 1		PICK CROSSCUBE FROM TABLE 1	
2		ASSEMBLE CROSSCUBE INTO YOKE A		
3	HOLDING THE ASSEMBLY 1		PICK PIN FROM TABLE 1 AND ASSEMBLE IN TO ASSEMBLY 1	
4	HOLDING THE ASSEMBLY 2		PICK COLLAR PIN FROM TABLE 1 AND ASSEMBLE INTO ASSEMBLY 2	
5	HOLDING THE ASSEMBLY 3		PICK COTTER PIN FROM TABLE 1 AND ASSEMBLE INTO ASSEMBLY 3	
6	HOLDING THE ASSEMBLY 4		PICK CONNECTING YOKE FROM TABLE 1 AND ASSEMBLE INTO ASSEMBLY 4	
7	HOLDING THE ASSEMBLY 5		PICK PIN FROM TABLE 1 AND ASSEMBLE INTO ASSEMBLY 5	
8	HOLDING THE ASSEMBLY 6		PICK COLLARPIN FROM TABLE 1 AND ASSEMBLE INTO ASSEMBLY 6	
9	HOLDING THE ASSEMBLY 7		PICK COTTER PIN FROM TABLE 1 AND ASSEMBLE INTO ASSEMBLY 7	

Figure 33: Drill Assistant R/L Diagram 1/2 [Source: Own]

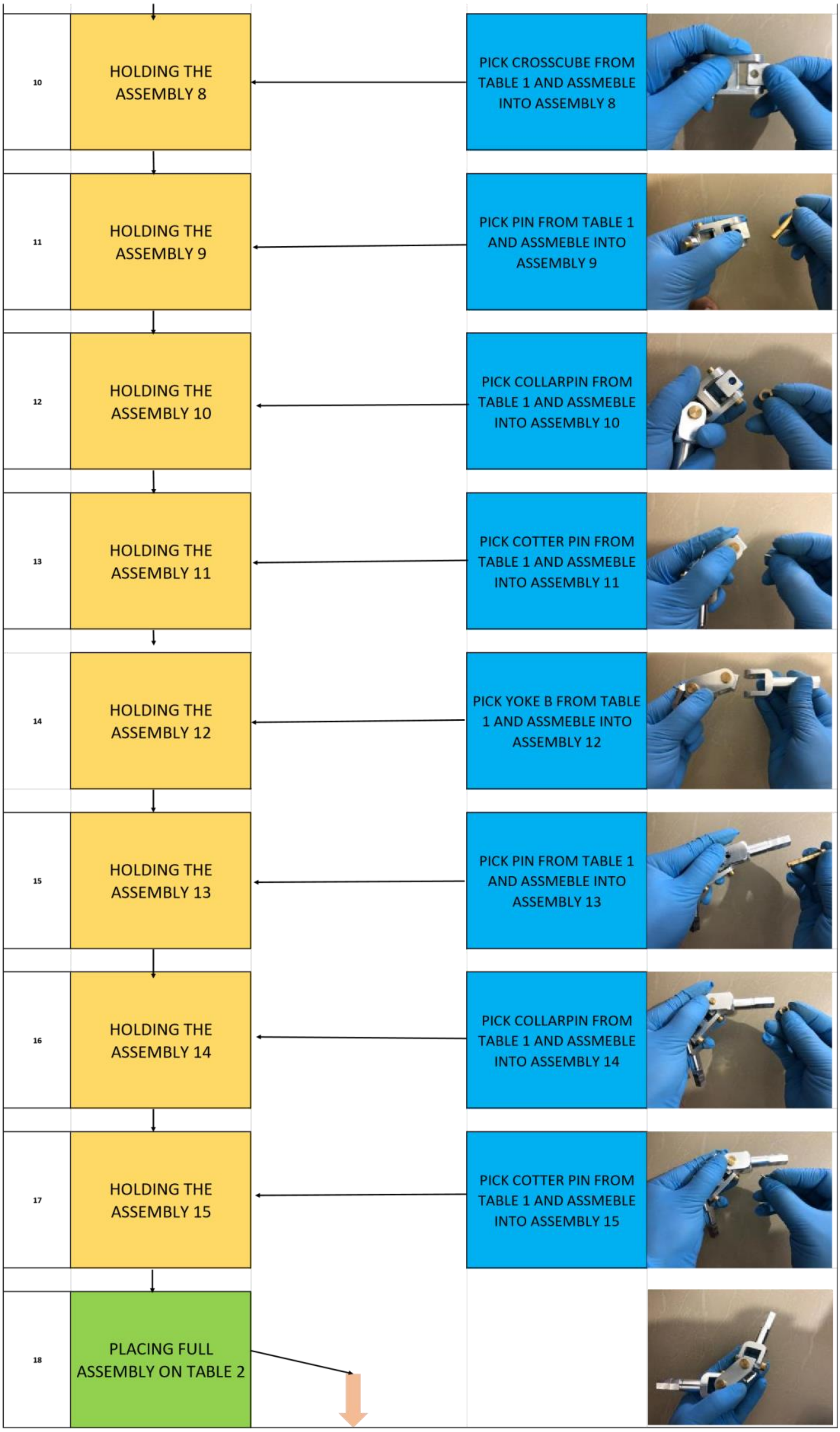


Figure 34: Drill Assistant R/L Diagram 2/2 [Source: Own]

3.8 CONCLUSION OF ANALYSIS

From the Analysis of the flow the following steps has to be taken for the improvement

- The Product flow should be without the crossings and hence changing the position of the machines has to be done to avoid those crossings which helps in smooth flow of the process
- Position of the Raw Material Inventory have to be changed so that it will be easily accessible for use
- Implementation of 5S will improve the Overall structure which helps in better and easy access of tools and equipment, cleanliness of the work place and improves safety and morale by improving the work environment
- More space for the Inventory of Finished product is needed to keep the finished goods and assembly work place is needed for assembly works

4 IMPROVEMENT

Implementation of 5S is typically the first step towards the elimination of waste from the manufacturing process and it will help in the improvement from the bottom line results.

4.1 5S IMPLEMENTATION

5S has been implemented through the following steps

SORTING

In this step we have sorted the unnecessary items from the workplace area. This Stage starts with the preparation of Red tag and followed by identification of things that are clearly not belongs to the particular area and tagging a Red tag to those things. Then all the necessary items are taken back to its original place. All the tools on the production area has been moved to the tool cub boards. And all the tools have been classified properly. After these all the other unknown items has been moved to the Red tag holding area.

The following picture (Figure 35) shows the red tag made for the sorting step in the laboratory

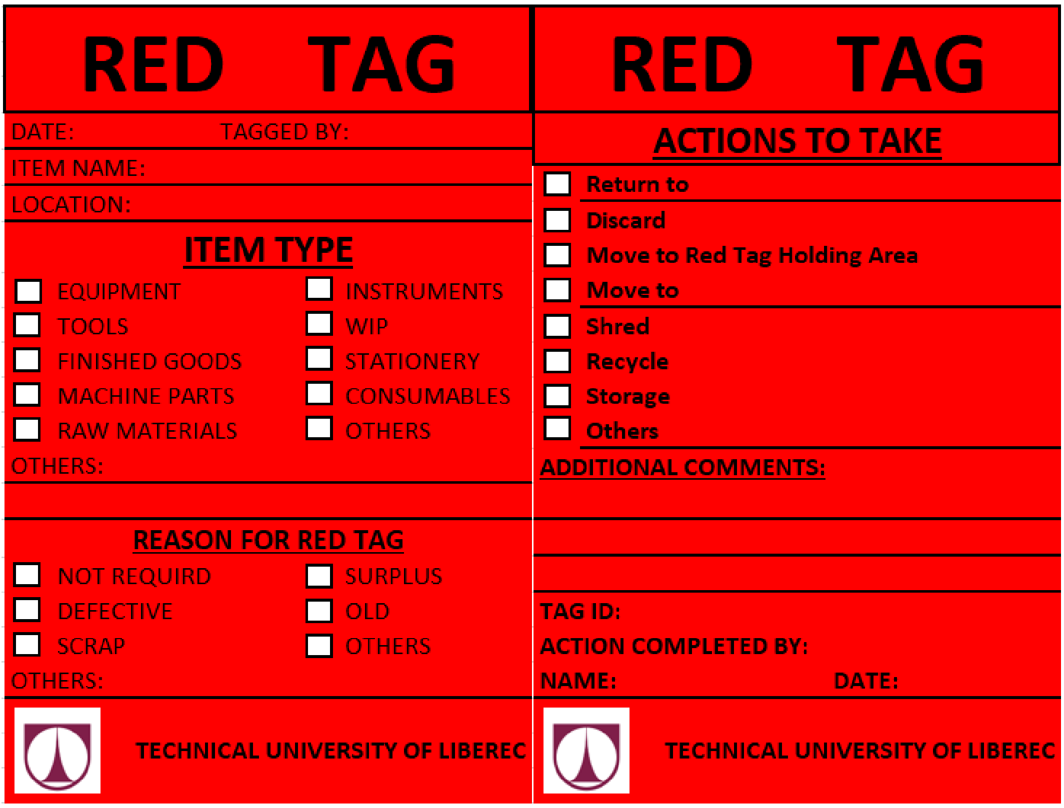


Figure 35: Red Tag Own [Source: Own]

The following picture (Figure 36) shows the Red tagged object in the laboratory

Figure 36: Red Tagged cable [Source: Own]

The following picture (Figure 37) shows the Red tagged scrap area in tha laboratory

Figure 37: Red Tagged Scrap Area [Source: Own]

The following picture (Figure 38) shows th Red tagged holding area in tha laboratory

Figure 38: Red Tag Holding Area [Source: Own]

After these Red tag analysis has been done

TAG ID	ITEM NAME	LOCATION	ITEM TYPE	REASON FOR RED TAG	ACTIONS TO TAKE	ADDITIONAL COMMENT
1	ELECTRO INSTALL ITEMS	C.P	ROPE	NOT REQUIRED	DISCARD	
2	EXHIBIT SHOW CASE	FRONT ENTRANCE	PROPOGATION	NOT REQUIRED	MOVE TO	DIFFERENT LOCATION
3	FRAME	ABOVE TRI STAND	PROPOFATION FRAME	NOT REQUIRED	DISCARD	
4	BOX FILES	ABOVE CB	STATIONERY	NOT IN ITS POSITION	MOVE TO	CB
5	TRIPOD STAND	NEAR HERMLE	MACHINE PARTS	NOT REQUIRED	DISCARD	
6	PROPOGATION STAND	NEAR HERMLE	PROPOGATION	NOT IN ITS POSITION	MOVE TO	DIFFERENT LOCATION
7	CARDBOARD BOX	ABOVE CB	PACKING ITEMS	NOT REQUIRED	DISCARD	
8	TOOLS	CB	TOOLS	NOT IN ITS POSITION	MOVE TO	TOOLS AREA
9	BUBBLE WRAPS	CB	PACKING ITEMS	NOT REQUIRED	DISCARD	
10	BOOKS	CB	STATIONERY	NOT REQUIRED	DISCARD	
11	TOOLS	CB	TOOLS	NOT IN ITS POSITION	SORT	
12	PLASTIC COVERS	CB	PACKING ITEMS	NOT REQUIRED	DISCARD	
13	FIRST AID KITS	ABOVE FIRST AID BOX	FIRST AID BOX	OLD	SHRED	
14	CUTTING TOOLS	BELOW PANEL	TOOLS	NOT REQUIRED	RETURN TO	KOM (SERVINSKY)
15	FIRST AID KITS	FIRST AID BOX	FIRST AID ITEMS	OLD	SHRED	
16	PALLETS	NEAR SINK	PACKING ITEMS	NOT REQUIRED	OTHERS	USE FOR MOVING COOLANT LIQUID BARREL
17	RAW MATERIAL	NEAR PANEL	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
18	CLEANING ITEMS	NEAR SINK	CLEANING THINGS	NOT REQUIRED	DISCARD	
19	LASER BOX HEAD	NEAR SINK	PCKING	WRONG LOCATION	MOVE TO	LASER LAB
20	POWER CHORD	WOODEN BOX	MACHINE PARTS	SCRAP	DISCARD	
21	ELECTRONICS	CB	MACHINE PARTS	NOT REQUIRED	DISCARD	
22	TOOLS	CB	TOOLS	NOT IN ITS POSITION	SORT	
23	RAW MATERIAL	CB	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
24	PENS	LAPTOP	STATIONERY	WRONG LOCATION	MOVE TO	TOOL BOX
25	SCREWS	LAPTOP	CONSUMABLES	WRONG LOCATION	MOVE TO	WAREHOUSE
26	RAW MATERIAL	LAPTOP	WORK IN PROCESS	WRONG LOCATION	MOVE TO	WAREHOUSE

TAG ID	ITEM NAME	LOCATION	ITEM TYPE	REASON FOR RED TAG	ACTIONS TO TAKE	ADDITIONAL COMMENT
27	TOOL KEY	EMCO	TOOLS	WRONG LOCATION	MOVE TO	TOOL BOX
28	RAW MATERIAL	EMCO	WORK IN PROCESS	WRONG LOCATION	MOVE TO	WAREHOUSE
29	COOLING LIQUID TANK	EMCO	MACHINE PARTS	NOT REQUIRED	DISCARD	
30	SPANNERS	EMCO	TOOLS	WRONG LOCATION	MOVE TO	TOOL BOX
31	WOOD BLOCKS	MAZAK	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
32	FINISHED GOODS	MAZAK	FINISHED GOODS	WRONG LOCATION	MOVE TO	WAREHOUSE
33	CLEANING ITEMS	MAZAK	CLEANING THINGS	WRONG LOCATION	MOVE TO	TOOL AREA
34	HAZARDOUS LIQUIDS	CB	CONSUMABL ES	NOT IN ITS POSITION	SORT AND LABEL	THINGS CATEGORIZED BASED ON ITS WEIGHT
35	SILICON MOULDS	CB	TOOLS	WRONG LOCATION	MOVE TO	SILICON MOULDING LAB
36	SPANNERS	HERMLE	TOOLS	WRONG LOCATION	MOVE TO	TOOL BOX
37	MACHINE TOOLS	HERMLE	MACHINE PARTS	WRONG LOCATION	MOVE TO	TOOL BOX
38	SCRAPS	MAZAK	SCRAP AREA	HIGH VOLUME	OTHERS	STANDARDIZE COLLECTING OF SCRAPS
39	PENS	LAPTOP RACKS	STATIONERY	NOT IN ITS POSITION	SORT	
40	RAW MATERIAL	LAPTOP RACKS	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
41	SCREWS	LAPTOP RACKS	CONSUMABL ES	WRONG LOCATION	MOVE TO	TOOL BOX
42	RUBBISH	LAPTOP RACKS	RUBBISH ITEMS	SCRAP	DISCARD	
43	TOOLS	LAPTOP RACKS	TOOLS	WRONG LOCATION	MOVE TO	TOOL BOX
44	EQUIPMENT S	LAPTOP RACKS	EQUIPMENTS	WRONG LOCATION	MOVE TO	TOOL BOX
45	RAW MATERIAL	LAPTOP RACKS	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
46	STEAM ENGINES	LAPTOP RACKS	FINISHED GOODS	WRONG LOCATION	MOVE TO	
47	RAW MATERIAL	LAPTOP RACKS	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
48	ELECTRONI C ITEMS	LAPTOP RACKS	MACHINE PARTS	NOT REQUIRED	MOVE TO	Prof. Keller Office
49	RACKS	CB	EXTRA RACKS FOR CB	SURPLUS	MOVE TO	CB
50	WOODS	BEHIND MAZAK	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
51	LADDER	BEHIND MAZAK	INSTRUMENT S	DEFECTIVE	DISCARD	REPLACE WITH NEW ONE
52	TROLLEY	BEHIND MAZAK	INSTRUMENT S	WRONG LOCATION	MOVE TO	MANIPULATIN AREA
53	STRATASYS 3DP CASE	BEHIND MAZAK	MACHINE PARTS	WRONG LOCATION	MOVE TO	T LAB
54	BOTTOM TOOL FOR MAZAK	BEHIND MAZAK	TOOLS	WRONG LOCATION	MOVE TO	TOOL BOX

TAG ID	ITEM NAME	LOCATION	ITEM TYPE	REASON FOR RED TAG	ACTIONS TO TAKE	ADDITIONAL COMMENT
55	BROOM	BEHIND MAZAK	TOOLS	WRONG LOCATION	MOVE TO	CLEANING TOOLS AREA
56	WOODEN RAW MATERIAL	WORK TABLE 2	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
57	GLOVES	WORK TABLE 2	TOOLS	WRONG LOCATION	MOVE TO	TOOL BOX
58	CLAMPING TOOLS	WORK TABLE 2	TOOLS	WRONG LOCATION	MOVE TO	TOOL BOX
59	GRINDING MACHINE	WORK TABLE 2	EQUIPMENTS	NOT FIXED	OTHERS	TAKE ACTION TO FIX AND MAKE READY
60	3DP MACHINE PARTS	WORK TABLE 2	MACHINE PARTS	WRONG LOCATION	MOVE TO	T LAB
61	TOOLS	WORK TABLE 2	TOOLS	WRONG LOCATION	MOVE TO	TOOL BOX
62	SCRAPS	WORK TABLE 3	SCRAP AREA	SCRAP	DISCARD	TOOL BOX
63	SCREWS	WORK TABLE 1	CONSUMABLES	WRONG LOCATION	MOVE TO	T LAB
64	TOOL BOX	WORK TABLE 2	TOOLS	WRONG LOCATION	MOVE TO	T BUILDING
65	HAND DRILLING MACHINE	WORK TABLE 3	EQUIPMENTS	WRONG LOCATION	MOVE TO	TOOL AREA
66	TOOLS	WORK TABLE 4	TOOLS	WRONG LOCATION	MOVE TO	TOOL AREA
67	EQUIPMENTS	WORK TABLE 2	EQUIPMENTS	SORTING NEEDED	SORT	SORTING NEEDED
68	EQUIPMENTS	WORK TABLE 3	EQUIPMENTS	SORTING NEEDED	SORT	SORTING NEEDED
69	VACCUM CLEANER	WORK TABLE 1	EQUIPMENTS	WRONG LOCATION	MOVE TO	CLEANING TOOLS AREA
70	TOOL ORGANISING SET	WORK TABLE 1	EQUIPMENTS	NOT FIXED	OTHERS	FIX IN SUITABLE AREA
71	TOOLS	CB	TOOLS	SURPLUS AND NOT IN POSITION	MOVE TO	T Lab (SURPLUS items) and SORT REMAINING ITEMS
72	EQUIPMENTS	CB	EQUIPMENTS	SURPLUS AND NOT IN POSITION	MOVE TO	T Lab (SURPLUS items) and SORT REMAINING ITEMS
73	JIGS	CB	MACHINE PARTS	SORTING NEEDED	SORT AND LABEL	
74	ELECTRICAL ITEMS	NEAR PILLAR 2	SCRAP	SCRAP	DISCARD	
75	ELECTRONIC BOARDS	NEAR PILLAR 2	SCRAP	SCRAP	DISCARD	
76	RAW MATERIAL	NEAR SM CUTTER	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
77	MACHINE PARTS	NEAR SM CUTTER	MACHINE PARTS	WRONG LOCATION	MOVE TO	TOOL AREA
78	PROPOGATION FRAMES	NEAR PILLAR 2	PROPOGATION FRAMES	WRONG LOCATION	DISCARD	
79	STRATASYS 3DP		MACHINE PARTS	WRONG LOCATION	MOVE TO	T LAB
80	FINISHED EXHIBIT PARTS	NEAR WINDOW	FINISHED GOODS	WRONG LOCATION	MOVE TO	PROPER LOCATION

TAG ID	ITEM NAME	LOCATION	ITEM TYPE	REASON FOR RED TAG	ACTIONS TO TAKE	ADDITIONAL COMMENT
81	RAW MATERIAL	TABLE 1	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
82	MACHINE PARTS	TABLE 1	MACHINE PARTS	SCRAP	DISCARD	
83	TOOLS	TABLE 1	TOOLS	WRONG LOCATION	MOVE TO	LASER CUTTING TOOLS AREA
84	CARDBOARD BOX	NEAR TABLE 2	RUBBISH ITEMS	SCRAP	DISCARD	
85	CARDBOARD BOX	BEHIND HERMLE	WASTES	SCRAP	DISCARD	
86	RAW MATERIAL	BEHIND HERMLE	RAW MATERIALS	SURPLUS AND SORTING	DISCARD	SORTING NEEDED AND DISCARD SURPLUS
87	SCRAPS	LASER CUTTING ROOM	RUBBISH ITEMS	SCRAP	DISCARD	
88	TOOL CUPBOARD	LASER CUTTING ROOM	TOOLS	SORTING NEEDED	SORT THE TOOLS	
89	RAW MATERIAL	LASER CUTTING ROOM	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
90	RAW MATERIAL	LASER CUTTING ROOM	RAW MATERIALS	WRONG LOCATION	MOVE TO	WAREHOUSE
91	TOOLS AND THINGS	TABLE 2 RACKS	TOOLS	SORTING NEEDED	SORTING NEEDED	

REASON FOR RED TAG	
WRONG LOCATION	46
NOT REQUIRED	14
NOT IN ITS POSITION	7
SCRAP	9
OLD	2
SORTING NEEDED	5
SURPLUS	4
NOT FIXED	2
DEFECTIVE	1
HIGH VOLUME	1
TOTAL	91

ACTIONS TO TAKE	
MOVE TO	53
DISCARD	22
SORT	9
SHRED	2
RETURN TO	1
OTHERS	4
TOTAL	91

Table 7: Red Tag Analysis [Source: Own]

From the Red Tag Analysis, it is found that the major cause for Red tagging and from the analysis we found that there are most of the things, tools and equipment are misplaced in wrong location and main action to take is to sort and move the things to its actual location.

SEITON – STRAIGHTEN OR SET IN ORDER

In this step all the equipment and tools position which has been decided earlier moved to that the corresponding place. Tools are segregated based on its regular usage and most used tools has been placed at a position to access easily and quickly.

EMCO Machine and Tool Cupboard has been already moved to another location for better spacing in the laboratory layout and easy access. Some of tools in the cupboard has to be sorted still. Raw Material Inventory position has been changed for easy access of the raw material.

Figure 39: EMCO Machine New Position [Source: Own]

The following picture (Figure 40) shows the sorted tools in the laboratory

Figure 40: Tools Sorted [Source: Own]

The following picture (Figure 41) shows the sorted tools and things in the laboratory

Figure 41: Sorted things [Source: Own]

The following picture (Figure 42) shows the new placement of Tools cupboard for easy access in the laboratory

Figure 42: Tool Cupboard [Source: Own]

The following picture (Figure 43) shows the new placement of Raw materail Inventory in the laboratory

Figure 43: Raw material Inventory [Source: Own]

SEISO – SHINE

This step started with the cleaning of Workshop Overall from dusts, wastes, scraps, sink. A Checklist has been made to check the cleanliness of the workshop place by place. And the cleaning work has been advised to make regular.

Figure 44: Sink [Source: Own]

Figure 45: Mat [Source: Own]

Figure 46: Scrap Collection Box [Source: Own]

By following the Shine checklist helps to organize and verify easily what are the main things or places needs to be cleaned and maintained.

SHINE CHECKLIST				
S.No	CHECK ITEM	DESCRIPTION	RESULTS	COMMENTS
			YES / NO	
1	FLOORS	ARE THE FLOOR ARE KEPT CLEAN AND DRY WITHOUT DUST OR OIL OR METAL SCRAPS?		
2	MAZAK	ARE THE MACHINES ARE CLEANED PERIODICALLY AND SCRAPS ARE TAKEN OUT WITH REGULAR INTERVALS ?		
3	HERMLE	ARE THE MACHINES ARE CLEANED PERIODICALLY AND SCRAPS ARE TAKEN OUT WITH REGULAR INTERVALS ?		
4	EMCO	ARE THE MACHINES ARE CLEANED PERIODICALLY AND SCRAPS ARE TAKEN OUT WITH REGULAR INTERVALS ?		
5	TOOL CUPBOARDS	ARE THE TOOLS ARE CLEANED PROPERLY AFTER USE AND CUPBOARDS ARE DUST OR OIL FREE ?		
6	WORK TABLES	ARE THE TABLES ARE CLEANED PROPERLY WITH REGULAR INTERVAL ?		
7	ASSEMBLY TABLES	ARE THE TABLES ARE CLEANED PROPERLY WITH REGULAR INTERVAL ?		
8	SINK	IS THE SINK IS CLEAN AND IN PROPER USABLE CONDITION ?		
9	SCRAP COLLECTION AREA	ARE THE SCRAPS ARE COLLECTED REGULARLY WITHOUT FAIL PERIODICALLY ?		
10	CLEANING RESPONSIBLITIE	IS IT CLEAR WITH WHO ARE RESPONSIBLE FOR CLEANING AND THEY ARE PROPERLY COMMUNICATED ?		

Table 8: Shine Check list [Source: Own]

Some changes occurred by 5S implementation in the laboratory is discussed below.

The following picture (Figure 47) shows the state of worktable with unfixed Grinding machine and unnecessary items on it before the start of 5S implementation

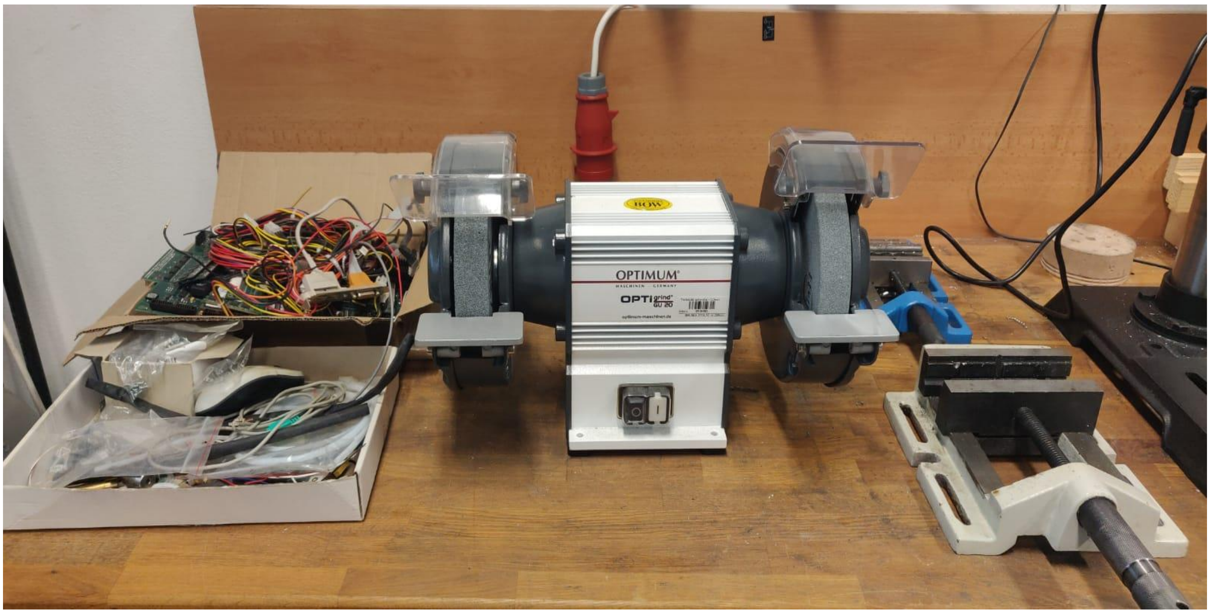


Figure 47: Work table before 5S [Source: Own]

The picture (Figure 48) shows the state of worktable after the 5S implementation with the fixed grinding machine and sorted out unnecessary items.

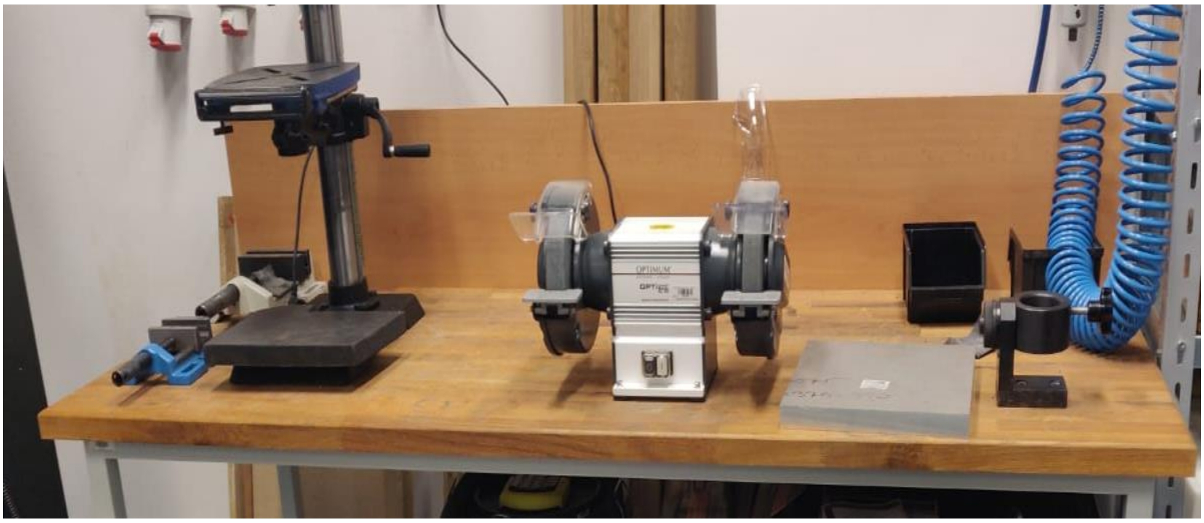


Figure 48: Work table after 5S [Source: Own]

The following pictures (Figure 49) shows the Raw Material Inventory which was in a position with difficult to access before the start of 5S implementation

Figure 49: Raw material Inventory before 5S [Source: Own]

The Picture (Figure 50) shows the position of raw material inventory which is easy to access after the 5S implementation

Figure 50: Raw material Inventory after 5S [Source: Own]

The following picture (Figure 51) shows the Sink area without proper cleaning and maintenance before the 5S implementation

Figure 51: Sink before 5S [Source: Own]

The picture (Figure 52) shows the Sink area after the 5S implementation

Figure 52: Sink after 5S [Source: Own]

The following picture shows the scrap storage area with excess scraps which is caused due to collection of scraps without a regular frequency of time period before the start of 5S implementation

Figure 53: Scrap Area before 5S [Source: Own]

The Picture shows the scrap collection area after the scraps disposed during the 5S implementation

Figure 54: Scrap Area after 5S [Source: Own]

ACTIONS TO BE TAKEN

- Space for the finished goods inventory and assembly workplace have to be added
- All necessary actions which found from the sorting analysis have to be implemented
- Shine Checklist has to be followed to ensure the cleanliness of the Laboratory which helps for the better safety of work place
- Disposal of all kinds of wastes and scraps should be done on regular Interval of time which is not regular now
- By giving strict instructions on cleanness and habit of checking the progress of cleanness and using the audit sheet (Shine Check List) for ensuring the cleanness the Fourth step of the 5S **STANDARDIZE** which is making everything to Standardize can be implemented
- Overall head of the Laboratory ought to take the responsibility to command a Program on the 5S rule to all the staffs in the Laboratory. And teaching the standards and technique of 5S to the staffs of Laboratory helps in implementation of 5S on a regular basis. By doing this 5th step of the 5S which is **SUSTAIN** can be achieved
- Sheet Metal Inventory can be optimized for more space by using Inventory racks like the image below (Figure 55)

Figure 55: Sheet Metal Inventory [21]

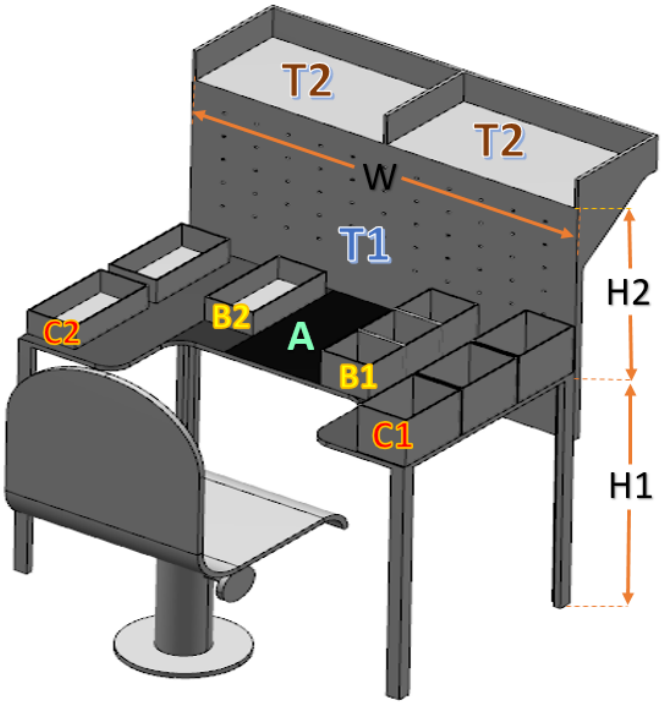
Tables used in the laboratory can be optimized by adding an extra rack below for more space

Figure 56: Worktable with Racks [22]

4.2 DESIGN OF NEW ASSEMBLY WORK SPACE

A new assembly place should be added according to the following ergonomic rules

- The assembly Work place is designed as a Work Table and the height of the table is 1000 mm which is the recommended working height for the assembly work table.
- Since all our product parts weigh less, assembly process can be done by the workers at the desk by sitting. To sit and assemble the products, height adjustable chairs needed to be installed. This facilitates the workers to adjust the height based on them to do work below their heart level, which makes a good supply of oxygen to the muscles and increases the performances.
- The Table total length 1200 mm in C shaped in which the main working area with both hands is 300 mm from centre shown as area A in the table figure below is the optimum for assembly work to take place, then secondary area is B1 and B2 where the parts to be assembled is kept at B1 and assembled products are kept at the B2. These area is usually handled with one hand and it is 150 mm after the Main working area on both sides and remaining length of 300 mm on front and both sides are used to keep Incoming parts after manufactured at C1 and the fully assembled products in boxes at C2.
- Since the maximum reach to the width of the table is 400 mm by the worker the width of the table should be kept as 450 mm.
- The Colour of the Assembly work table should be Black as black absorbs the light and there will not be any backscattering or reflection which will avoid any visual hindrances for the workers.
- The Assembly working area should be lighted up with minimum lighting of 500 LUX for clear visibility during assembly



H1	TABLE WORKING HEIGHT **1000 mm**
W	TABLE WIDTH **1200 mm**
C1	INCOMMING PARTS STORAGE AREA **700 mm * 300 mm**
B1	AREA FOR PARTS TO ASSEMBLE **150 mm * 450 mm**
A	ASSEMBLY AREA **300 mm * 450 mm**
B2	ASSEMBLED PARTS AREA **150 mm * 450 mm**
C2	ASSEMBLED PRODUCT STORAGE **700 mm * 300 mm**
T1	TOOLS HANGING AREA – FREQUENTLY USED
T2	OCCASIONALY USED TOOLS AREA
H2	TOOL HANGING AREA **HEIGHT- 700 mm**

Figure 57: New Assembly work Table [Source: Own]

The following picture (Figure 58) shows the top view of the assembly table with major dimensions

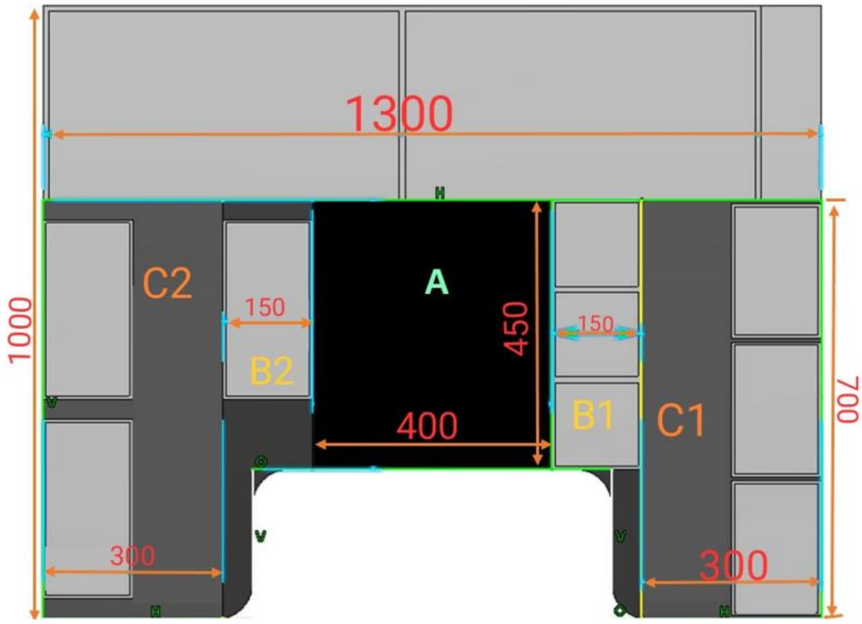


Figure 58: Assembly Table Top view [Source: Own]

5 SELECTION OF VARIANT

From the Analysis of the current layout the following criteria are taken into consideration for the optimization of the Layout.

- More Inventory space for finished products
  There is no space for storage of the finished goods so Inventory space is required for the finished goods.
- Convenient accessing of tool and raw material
  The position of Raw Material Inventory and Tools Cup boards has to be in such way it will be more convenient to access and distance for accessing both should be reduced from the current distance of 6.5 metre
- More Spacious working environment
  All the items, equipment, work tables and especially machines needs to be arranged in a proper manner to get better spacious work place. The distance between EMCO and MAZAK machine which is 400 mm needs to be increased more for spacious work space.
- Change of Machine placement to avoid the crossings
  The position of machines should be changed to avoid the crossings of the product flow and for better spacing
- Optimization of sheet metal Inventory
  Sheet metal inventory has to be optimized to increase the storage capacity.
- Assembly work Place
  New assembly work place has to be added for assembly works

5.1 LAYOUT VARIANTS

Four Layout Variants has been made based on the selected criteria

VARIANT 1

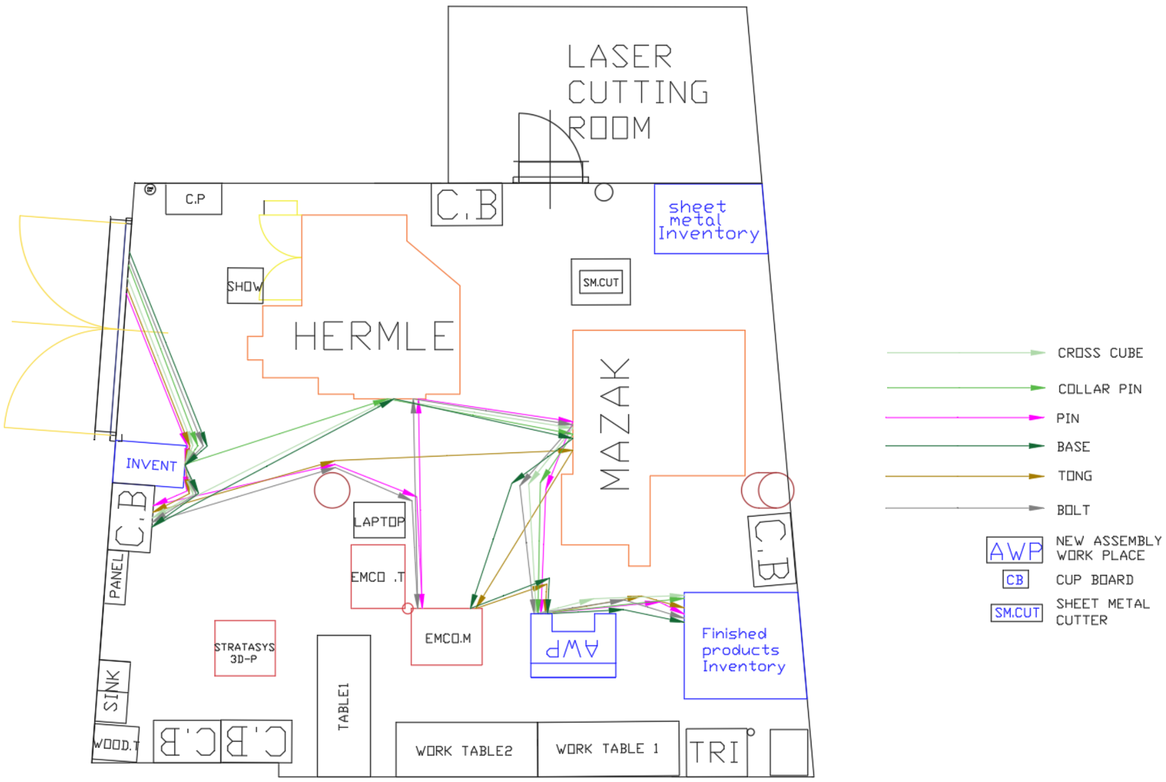


Figure 59: Variant 1 [Source: Own]

- New Finished goods Inventory of area 2.6 m^2 is added in the layout
- Position of the Raw material Inventory and Tool Cup boards are changed. This will make easy access of raw material and tool and reduces the distance covered to access them to nearly 3 metre
- This layout has more space between the machines as it has minimum of 1.5m clear distance between the machines
- The positions of MAZAK and EMCO machines are changed to reduce the product flow crossings
- New Assembly work place is designed and added in the Layout
- Sheet Metal Invetntory can be optimized by using horizontal Inventory Racks and has more space.

VARIANT 2

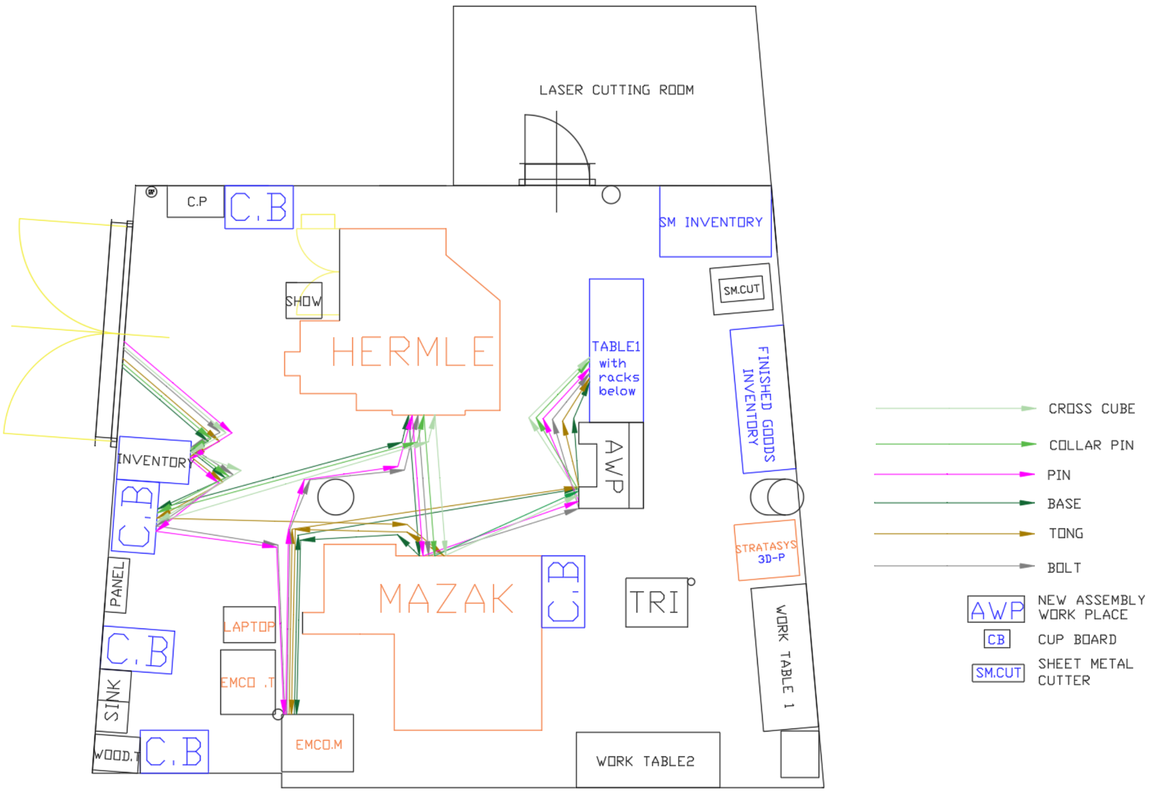


Figure 60: Variant 2 [Source: Own]

- New Finished goods Inventory of area 1.5 m^2 is added in the layout
- Position of the Raw material Inventory and Tool Cup boards are changed. This will make easy access of raw material and reduces the distance covered to access the raw material and tool to nearly 3 metre
- New Assembly work place is designed and placed
- However the problem of more crossings of product flow and space between the machines is still there since the machines positions are not changed.
- Sheet Metal Invetntory can be optimized by using horizontal Inventory Racks and has more space.

VARIANT 3

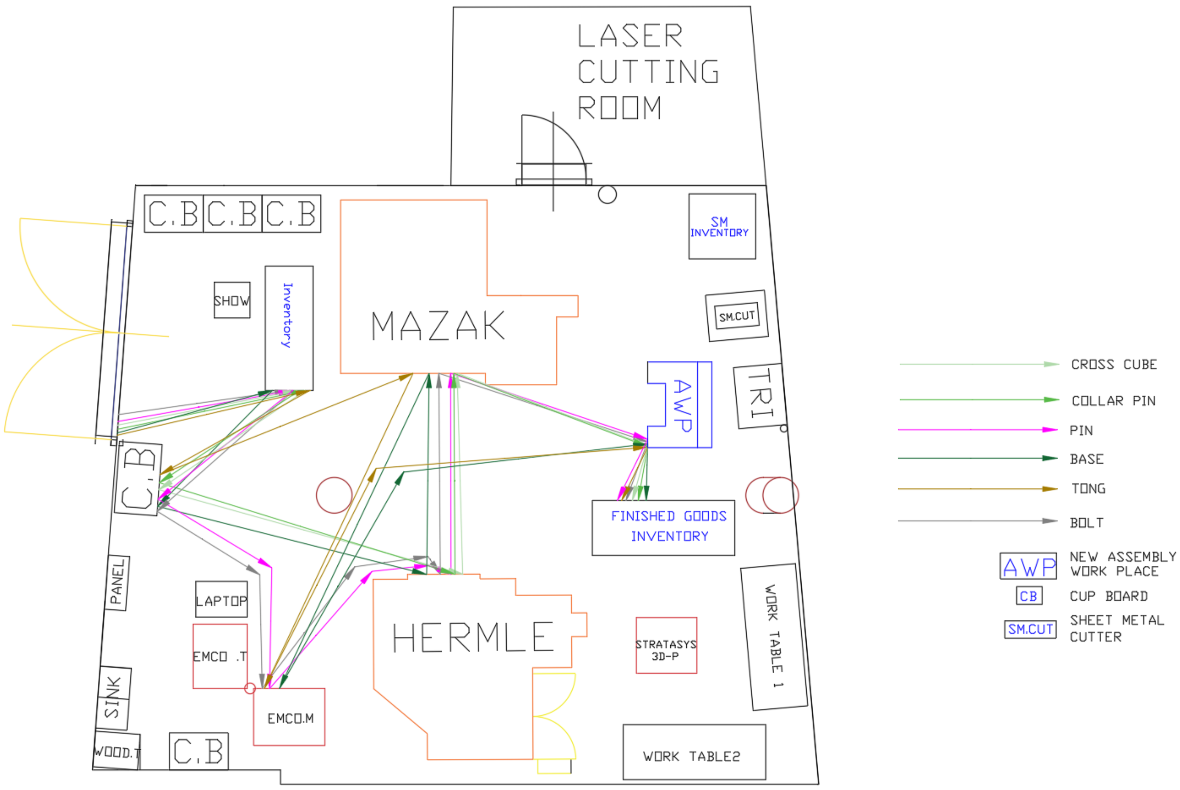


Figure 61: Variant 3 [Source: Own]

- New Finished goods Inventory of area 1.5 m^2 is added in the layout
- Position of the Raw material Inventory and Tool Cup boards are changed. This will make easy access of raw material and reduces the distance covered to access the raw material and tool to nearly 4.5 metre.
- New Assembly work place is designed and placed
- This layout has more space between the machines than current layout as it has minimum of 700mm clear distance between the machines
- The positions of MAZAK and HERMLE machines are changed to avoid the product flow crossings
- Sheet Metal Invetntory can be optimized by using horizontal Inventory Racks

VARIANT 4

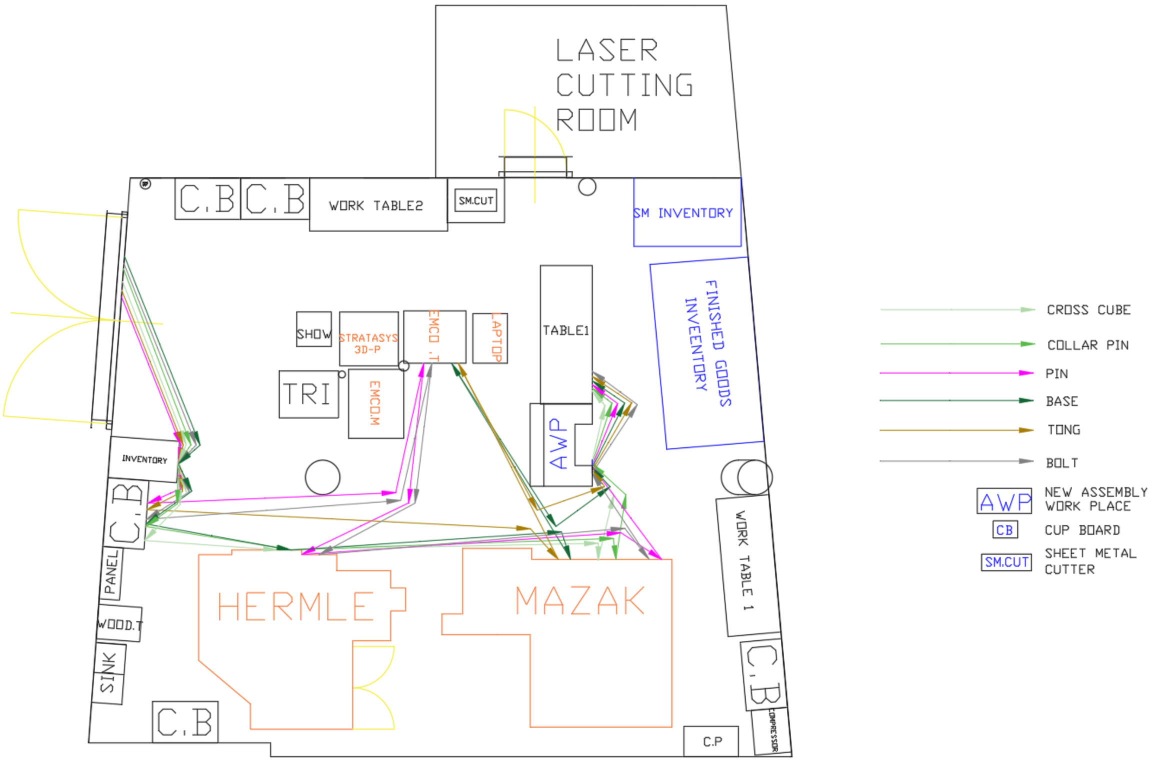


Figure 62: Variant 4 [Source: Own]

- New Finished goods Inventory of area 3.6 m^2 is added in the layout
- Position of the Raw material Inventory is changed. This will make easy access of raw material and this reduces the distance covered to access the raw material and tool to nearly 3 metre
- New Assembly work place is designed and placed
- This layout has more space between the machines than current layout as it has minimum of 750mm clear distance between the machines
- The positions of all three Machines are changed to reduce the product flow crossings
- Sheet Metal Invetntory can be optimized by using horizontal Inventory Racks

5.2 MULTI CRITERIA ANALYSIS

From the above 4 variants Multi criteria analysis has been done to find the best layout which meets the criteria most.

At first criteria taken from the Analysis has given Scale of importance from the range 1 to 5

Criteria	SCALE	1 to 5
Inventory for finished products	5	
Convenient tool and raw material access	5	
Machine placement	3	
Spacious work environment	3	
Inventory for sheet metal	2	
Assembly work place	5	

Table 9: Multi Criteria Table 1 [Source: Own]

In the next step the criteria have been measured and compared with the current layout and New layout variants

Criteria - Comparison	CURRENT LAYOUT	VARIANT 1	VARIANT 2	VARIANT 3	VARIANT 4
Inventory for finished products in Area m2	0	2.6	1.5	1.5	3.6
Convenient tool and raw material access- Distance to access tool and raw material in metre	6.5	3	3	4.5	3
Spacious work environment - minimum Distance between the machines	0.38	1.5	0.38	0.7	0.75
Inventory for sheet metal- space in m3	1.5	2.25	2.25	2.25	2.25
Assembly work place availability (Yes/No)	No	Yes	Yes	Yes	Yes
Machine placement changed - Product flow crossings reduced (Yes/No)	NA	Yes	No	Yes	Yes

Table 10: Criteria Comparison [Source: Own]

From the comparison, each variant is given score based on the criteria availability on the particular layout on a scale of 1 to 5

Criteria	Weight	VARIANT 1	VARIANT 2	VARIANT 3	VARIANT 4
Inventory for finished products	**5**	4	3	3	5
Convenient tool and raw material access	**5**	5	5	4	5
Machine placement	**3**	5	3	4	5
Spacious work environment	**3**	5	2	3	4
Inventory for sheet metal	**2**	3	3	3	3
Assembly work place	**5**	5	5	5	5
Total		**106**	**86**	**87**	**108**

Table 11: Multi Criteria Table 2 [Source: Own]

Then the variants are analysed and given score based on the selected criteria by 4 Experts E1, E2, E3, E4 who are my Project mates from the Design of Manufacturing System course.

Scale	1 to 10			
	E1	**E2**	**E3**	**E4**
Variant 1	8	9	8	8
Variant 2	7	7	7	7
Variant 3	8	7	8	7
Variant 4	9	9	8	9
Total	**31**	**32**	**31**	**31**

Table 12: Multi Criteria Table 3 [Source: Own]

	E1	E2	E3	E4	Nk	Vk	Percentage
Variant 1	0.258	0.281	0.258	0.258	1.055	0.264	**26.39%**
Variant 2	0.226	0.219	0.226	0.226	0.896	0.224	**22.40%**
Variant 3	0.226	0.219	0.258	0.226	0.928	0.232	**23.21%**
Variant 4	0.290	0.281	0.258	0.290	1.120	0.280	**28.00%**
Total					**4**	**1**	**100.00%**

Table 13: Multi Criteria Table 4 [Source: Own]

From the table (Table 14) it has been found that Variant 4 which satisfies most of the criteria with higher percentage chosen as the best among the other three Variants from the Multi Criteria Analysis and it can be used for optimization of the laboratory Layout.

6 ECONOMIAL EVALUATION

Overall expenses for changing the layout of laboratory and addition of new items is shown below

FOR ASSEMBLY WORK PLACE

Total material volume of assembly work table = 0.062 kg/m ^{3}

Material chosen is mild steel and its density = 7850 kg/ m ^{3}

Total weight of the table = 485 kg

Cost of mild steel = 20 CZK / kg

Total cost of the material = 9700 CZK

Manufacturing cost of worktable = 4000 CZK

Total cost for the assembly work table = 13700 CZK

FOR CHANGING THE POSITION OF MACHINES, EQUIPMENT AND OTHER ITEMS

Total number of days worked = 11

Labour cost per hour = 120

Number of workers = 2

Total cost of 8 working hours per day for 11 days = 21120 CZK

FOR NEW SHEET METAL INVENTORY

Size of the finished goods inventory rack = 1500mm * 1000 mm

Total volume of the material = 0.009845 m^{3}

Material chosen is mild steel and its density = 7850 kg/ m ^{3}

Total weight of the rack = 78 kg

Cost of mild steel = 20 CZK / kg

Total cost of the material = 1560 CZK

Manufacturing cost of Inventory racks = 2000 CZK

Total cost for the New sheet metal Inventory = **3560 CZK**

FOR NEW FINISHED GOODS INVENTORY

Size of the finished goods inventory rack = 2500mm * 1500 mm

Total volume of the material = 0.023 m^3

Material chosen is mild steel and its density = 7850 kg/ m^3

Total weight of the rack = 186 kg

Cost of mild steel = 20 CZK / kg

Total cost of the material = 3720 CZK

Manufacturing cost of Inventory racks = 2000 CZK

Total cost for the New finished goods Inventory= **5720 CZK**

The overall summary of the expected expenses for the new layout is shown in the table (Table 15) below

S.No	LIST OF WORKS	EXPECTED EXPENSES in CZK
1	ASSEMBLY WORK PLACE	13700
2	CHANGING THE POSITION OF MACHINES, EQUIPMENT AND OTHER ITEMS	21120
3	NEW FINISHED GOODS INVENTORY	5720
4	NEW SHEET METAL INVENTORY RACKS	3560
	TOTAL	**44100**

Table 14: Expenses List [Source: Own]

Totally 44,100 Czech koruna is the expected expenses for the overall optimization of the laboratory.

7 CONCLUSION

The primary objective of the thesis is to optimize the CNC machining workshop by using the Lean and Ergonomic tools.

The first task of the thesis commences from the literature review on the lean principles, classification of waste, manufacturing system analysis, 5S, layout composition rules and ergonomic rules for assembly work place.

The second task is to analyse the currently existing system on the laboratory. This includes the analysis of the existing machine tools on the laboratory in which machines and its operational parameters are analysed which is followed by the analysis of current layout in which all the major parameters in the laboratory are measured and an AutoCAD design on current layout is generated. Then product portfolio is done since the laboratory does not have proper records of jobs done. Since there is no ERP system, we had chosen two major products Drill Assistant and Adjustable spanner for the analysis purpose and is followed by the Pareto analysis method to find the typical parts of the products. Then Spaghetti diagram has been made for the typical parts of the products to analyse and detect any existing flaws in the flow. Then analysis of assembly has been done in which the current assembly system of the drill assistant is analysed and assembly diagram and R/L diagram is made. Finally, from the conclusion of analysis phase four major results has been drawn which states on changing the position of machines to avoid the product flow crossings, changing the position of raw material inventory and tool cup boards for easy and quick access, implementation of 5S for better working environment, addition of finished goods inventory and assembly work place.

The third phase of the thesis is improvement in which the 5S implementation steps to the laboratory has been detailed on what is done and what needs to be done and the set of rules to be followed to maintain the 5S implemented working environment. Then a new assembly work place has been designed for the laboratory, based on the ergonomic principles of the assembly work place in this phase.

Then in the final phase four different layout for the laboratory was designed to overcome the problems identified from the analysis step and by using the multi criteria analysis the best layout that satisfies the main criteria at higher percentage has been determined and it can be used for the layout optimization of the laboratory. Then the work is completed with the economic evaluation for the works and changes suggested to the optimization of the workshop.

As discussed above for the optimization, currently some of the suggested works has been implemented already in the laboratory which includes sorting of unnecessary materials and things, sorting of tools, change of raw material inventory and tool cupboards, sorting and fixing of equipment in the work tables and few more changes which are yet to be included is discussed in detail under action to be taken.

Thus implementation of Lean methodology and Ergonomic principles helps in optimization of the CNC machining workshop at Research Centre CXI and this helps in improve the efficiency, reduces the waste and will increase the productivity in the laboratory.

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