TALLINN UNIVERSITY OF TECHNOLOGY

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Chair of Mechatronics

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Chandra Kiran Kestwal

Implementation of Total Productive Maintenance (TPM) in a machine shop

Kogu tootmistegevuse hoolduse meetodi rakendamine masinatöökojas

The author applies for
the academic degree
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Author's declaration

I declare that I have written this graduation thesis independently.

These materials have not been submitted for any academic degree.

All the works and major viewpoints of other authors used in this thesis have been referenced.

The thesis was completed under..... supervision

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Author

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The thesis complies with the requirements for graduation theses.

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Student: Chandra Kiran Kestwal 156445

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(in English) Implementation of Total Productive Maintenance (TPM) in a machine shop

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2	Analysis of present manufacturing process of machine shop	March 2017
3	Implementation of 5S and pillars of TPM	April 2017
4	Proposed Layouts, comparison, and conclusion	April 2017
5	Format the thesis	Until 15 May 2017

Engineering and economic problems to be solved:

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Supervisor: Robert Hudjakov, robert.hudjakov@ttu.ee /signature Date 13.03.2017

ABSTRACT

Keywords: *Total productive maintenance, Lean manufacturing, Eksamo AS, 5S, Overall equipment effectivene, Industrial robot.*

This master thesis is done in collaboration with Eksamo AS's production plant. Eksamo AS is a Mechanical engineering company. It design, manufacture and repair parts, machinery, and operating equipment.

Now day's companies are investing a huge amount of money in buying new machines or equipment to increase the production, but because of not doing maintenance they are not getting hundred percent for what the machine is capable of. Now as the competition between companies is increased and demand for quality product at lower cost is increased, buying new machines is not a solution unless they are fully utilized. Therefore methodology like TPM is necessary to get a better result. TPM is a plan which concentrates on total involvement of entire workforce to implement a comprehensive maintenance program for all equipment or machines throughout their life. This plan results in maximum effectiveness of equipment's, tidier, neat and clean work place and morally boosted employees.

The main aim is to develop a framework with the capability of assessing the impact of implementing total productive maintenance in Eksamo manufacturing plant. By evaluating the effect of TPM, Factory can make smart choices to increase the efficiency and quality of the plant and the product.

So in order to accomplish the above stated aim, below are the main set research objectives:

1). To understand the Lean tools and processes applicable in manufacturing.

2). Identifying the key points for implementing TPM in Eksamo plant.

3). Investigating the existing operational activities in order to understand their manufacturing issues.

4). Exploring the current level of TPM usage within the company so as to categories users based on their levels of involvement.

5).Identifying factors that determine the assessment of TPM.

6).To recommends appropriate lean techniques and processes in order to simplify and standardize the work processes.

7). Validating the impact assessment framework and the developed knowledge based advisory system through real-life case studies, workshops, and supervisor, MD opinions.

FOREWORD

The motivation for the given master thesis came from the company Eksamo AS. There was a need to improve the production processes, the best way to achieve it by using some lean techniques like TPM. The thesis was done in the manufacturing plant in Tallinn, and most of the data was collected from there. Special thanks to all the employees of the Eksamo AS company for their great support.

The completion of any project involves valued contributions inputs from a number of people and such is true with this project as well. The completion of this thesis work would not be possible without the extremely relevant assistance and encouragement of supervisors named; Mr. Robert Hudjakov –PhD- Department of Engineering sciences : Electrical Power and Mechatronics Institute, Tallinn University of Technology, Estonia and Mr. Andres Soojarv – Managing Director, Eksamo AS, Estonia.

EESSÕNA

Ettepanek antud magistritöö tegemiseks tuli ettevõttelt Eksamo AS. Oli vaja parandada tootmisprotsessi. Parim viis selle saavutamiseks oli kasutada tehnikaid nagu TPM (total productive maintenance). Antud magistritöö tehti tootmisettevõttes Eksamo AS ja enamik andmeid koguti sealt. Eriline tänu kõigile ettevõtte Eksamo AS töötajatele nende suure toetutuse eest.

Iga projekti lõpetamiseks on vajalik mitmete inimeste kaasatus projekti lahendamisel. Sama kehtib ka antud projekti puhul. Antud projekti lõpetamine poleks olnud võimalik ilma järgnevate inimeste kaasabita: Teadur Robert Hudjakov, elektroenergeetika ja mehhatroonika instituudist ja Eksamo AS juhataja Andres Soojärv. Samuti suured tänud Tallinna Tehnikaülikoolile.

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ABBREVIATIONS

TPM: Total productive maintenance

KPI: Key performance indicators

OEE: Overall equipment effectiveness

OPE: Overall plant efficiency

CNC: Computer numerical control

LAN: Local area network

QA: Quality assurance

QC: Quality control

IR: Industrial robot

DOF: Degree of freedom

1. INTRODUCTION

In today's industrial situation huge loss of time and wastage of material occur in the machine shop floor. This time-loss and material-waste are because of unskilled operators, maintenance personnel, processes, tooling problems and non-availability of components in time. There are few other losses like idle machines, idle manpower, rejected parts, quality waste etc. The quality related waste is of great importance because it took all the time of the production process and get wasted when the product is done. Also, it matter in terms of time, material and the hard earned reputation of the company. There are few other invisible losses like operating the machines against its specification (e.g. below the rated speed), startup loss, bottle necks in the process and break down of the machines. To avoid the above-said losses, a revolutionary concept of TPM has been adopted by many industries across the world. Zero oriented concepts like zero inventories, zero lead time, zero defects, and zero tolerance for waste, breakdown and zero accidents are becoming the pre-requisite for the production plant which can be achieved by implementing TPM.

TPM is analyzed into three words;

- **Total**: This means that every individual in the company, from the top management level to the shop floor workmen level.
- **Productive**: This means no wasted activity or the production of goods and services that meet or exceed customer's expectation.
- **Maintenance**: Keeping equipment and plant in good working order i.e. in as good as they are in original condition at all the time. [1]

The aim of this thesis is to implement TPM methodology in the company Eksamo AS to improve both productivity and quality along with the increased employee morale and job satisfaction. The result of the thesis shows the improvement in the processes of the company and its goal to achieve certain outcomes. It also proves that TPM is not just some production tools, implementing and maintaining TPM is a long term process and in order to see big improvements, a company needs to put effort continuously.

1.1 Background:

The work will be conducted as per the Lean principles which mean first will be the study of current performance as it now and then analyzes the performance level after implementation of TPM methodology. In the end, there will be suggestions and implementation to the company with how to improve the company production and the current performance level, localization of the root cause.

The boundaries of this case study are time frame and limited information (data) as the time is limited to implement the TPM approach on the other hand TPM is not a short term program it's a long and continuous approach to improve the processes. Some information is confidential and cannot be used in this thesis work.

1.2 Research Methodology:

An informative research design was applied as the thesis involved an in-depth understanding of TPM on topics like the implementation plan, TPM modes, challenges and benefits of TPM implementation and finally TPM key performance indicators. Both quantitative and qualitative approach is used to assess the maintenance systems and to calculate OEE. Research data was collected using interviews, company records, designed questionnaires, and direct observations.

1.2.1 Interviews

The interviews were conducted with maintenance personnel, machine operators and other employees in the production department. The questions are mainly focused on:

- Types of losses company mostly experienced.
- Reasons of maintenance problems
- How much TPM concept existed in the company?
- Elements that can help in implementing TPM

The full questionnaire is in Appendix 1.

1.2.2 Direct observations

The research also was made by observing maintenance and production activities. Things have been observed like how the inspection and lubrication activities were conducted. Direct observation helped in collecting data without relying on others. Photographs have been taken for analysis and necessary changes have been made as per TPM methodology. [2]

The challenge of this thesis work is to study the implementation of TPM methods. Also in Eksamo the operators and technician did not know English, so making them understand, what to do was challenging. Eksamo AS runs in one or sometimes in two shifts depending on the work load. Usually, the shift is 9 hours which includes two small breaks each of 15 minutes and one lunch break of 30 minutes. My primary study involved tabulation of all factors leading to the calculation of the overall equipment efficiency of the system and its direct influence in determining the efficiency of the existing system.

1.3 Thesis structure:

The thesis comprises of nine chapters. The first chapter is the introduction that consists of background, research methodology, thesis structure and significance of the study. It tells us the problem facing by today's industries because of not applying TPM, an introduction to TPM and the aim of the thesis. The second chapter is the literature review that gives the overview of TPM methodology. It consists of TPM history and TPM methods. In chapter three the current manufacturing practices of the Eksamo manufacturing plant is analyzed. This chapter is consists of major manufacturing issues in the plant, difficulties faced during implementing TPM and what should be the target of implementing TPM. In

chapter 4, TPM is implemented in the shop floor and the comparison is done to check how it has improved the production or processes. In Chapter 5, a new work-shop is proposed based on the study of different layouts. In Chapter 6, a new workplace layout is proposed which makes working easier and help in increasing the production of the plant. Chapter 7 is about how the plant can be fully automated using IR. Chapter 8 shows the OEE calculation before and after implementing TPM and the last chapter 9, conclusion and discussion gives the conclusion for the thesis.

The remainder of this thesis is composed of 9 chapters as illustrated in Figure 1.

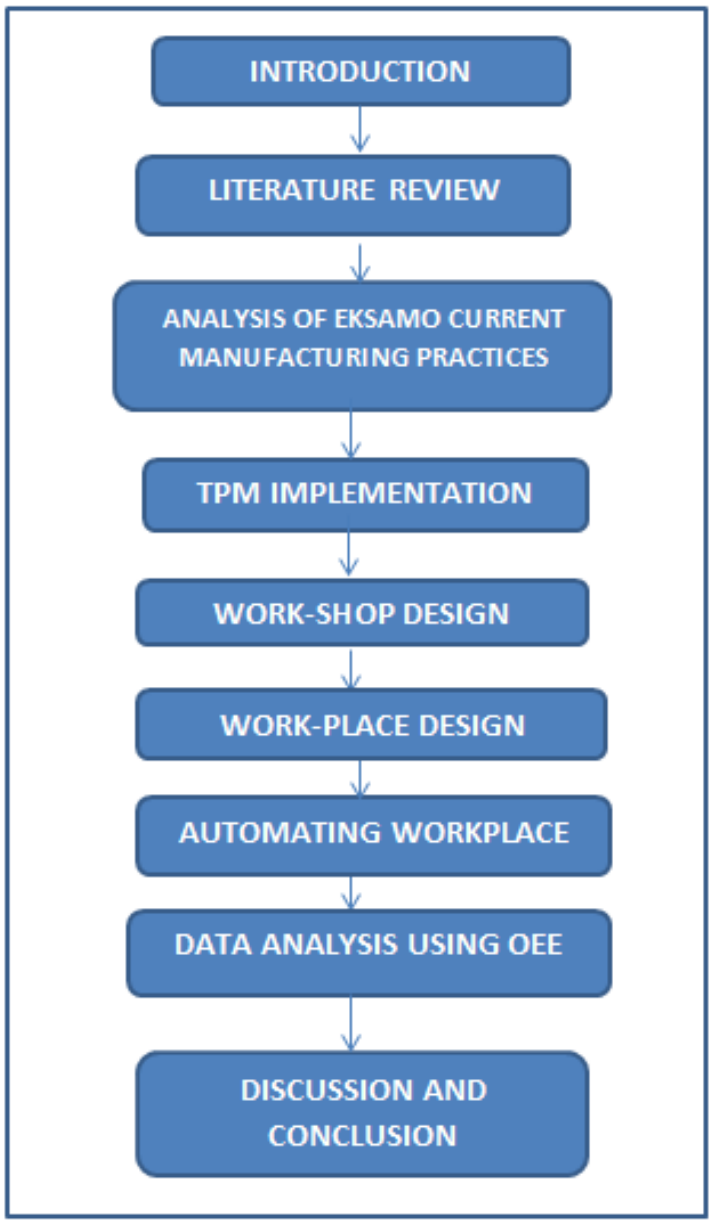


Figure 1 Thesis layout

2. LITERATURE REVIEW

The literature review is an overview about TPM. This section contains brief history of TPM and its techniques.

2.1 Brief history of TPM

TPM is originated from Japan as equipment management strategy designed to support the total quality management strategy. The origin of TPM can be traced back to 1951 when Japan introduced the preventive maintenance. The term TPM (Total Productive Maintenance) is attributed to Nippondenso, a company that created parts for Toyota. They introduced TPM in 1960. However, Seiichi Nakajima is regarded as the father of TPM because of his numerous contributions to TPM. [3]

In middle of 19th century, Japanese realized that using poorly –maintained equipment it is not possible to produce a quality product in time. When a new machine is installed the main focus was on implementing preventive maintenance recommended by the machine manufacturer. The machine works well without breakdown if it is being operated at designed specifications. In 1960s the traditional approach to TPM was developed which consists of 5S as foundation and eight Pillars. TPM focused on productive maintenance, recognizing the importance of reliability, maintenance and economic efficiency in plant design. [4]

2.2 TPM techniques/methods

TPM (Total Productive maintenance) is one of a lean tool, a maintenance program which gives a totally new approach for maintaining plant and equipment. This maintenance program is used for increasing the efficiency of the machines and the processes. TPM gives a way for excellent planning, organizing, monitoring and controlling practices through its unique eight-pillars and 5S foundation methodology. TPM is the approach to equipment maintenance that helps in achieving perfect production with:

- No breakdowns
- No small stops or slow running
- No defects
- No accidents

TPM emphasizes proactive and preventative maintenance to maximize the operational efficiency of the equipment. It increases the delay time for the maintenance of the equipment as the operator is cleaning and lubricating the equipment every day. For successful implementation of TPM greater involvement from everyone in the plant is needed. In right environment, this can be very effective if implemented correctly in a machine shop of the plant. This will help in improving productivity by increasing- up time, reducing cycle times and eliminating defects. [5]

Figure 2 below shows the TPM foundation and its pillars.

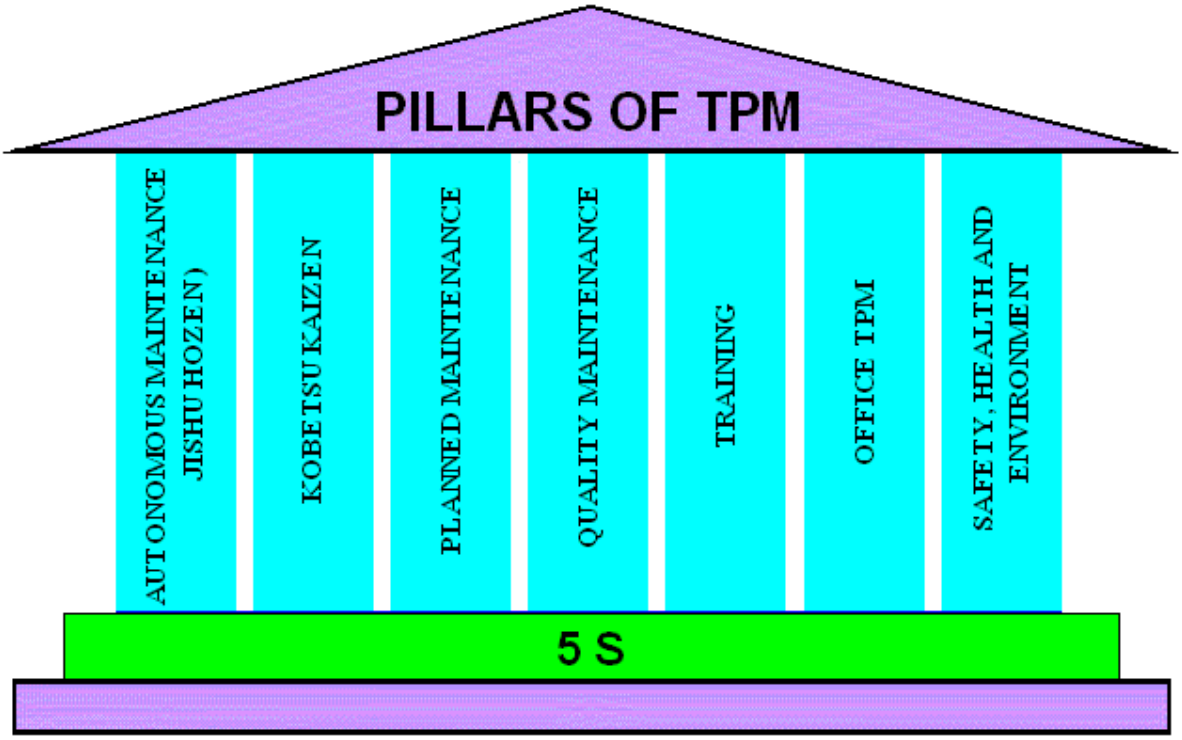


Figure 2 TPM foundation and pillars [6]

TPM 5S foundation

This refers to five Japanese words *seiri, seiton, seison, seiketsu, shitsuke*. These represent the guidelines to organize and manage the workspace so that a visual controlled and efficient production becomes possible. The main objective of 5S is to keep the workplace clean and organized. [7]

Autonomous maintenance

It follows the structured approach to increasing the skill levels of operators so that they can understand, manage and improve their equipment's and processes. [8]

Kaizen

It means adjusting the process (Kai) to become good (zen). Kaizen also stands for implementing small improvements, step by step to make the process easier. [7]

Planned maintenance

Its aim is to achieve zero breakdowns. Its approach is to establish a management system that extends the equipment reliability at best cost. [8]

Quality maintenance

It aims to assure zero defects conditions. It understands and controls the process interactions between man, materials, machines and methods that could enable defects to occur. This pillar prevents defects from occurring in the first place, rather than installing inspection system to detect the defect after it has been produced. [8]

Training

It is aimed to have multi-skilled employees. Education and Training is given to operators to upgrade their skills. Training is essential both for their personal development and for the successful implementation of TPM. [6]

Office TPM

Its aim is to improve productivity, efficiency in the administrative functions and identify and eliminate losses. Office TPM includes analyzing procedures and processes to increase office automation. [6]

Safety, Health, and Environment

This pillar creates a safe workplace and a surrounding area that is not damaged by the process or procedures. It is not just safety related but covers zero accidents, zero burdens (Physical or mental stress on employees) and less pollution. [8]

3. ANALYSIS OF EKSAMO CURRENT MANUFACTURING PRACTICES

In this chapter major manufacturing issues for implementing TPM in factory, what are the difficulties being faced at the time of TPM implementation, and what will be the direct and indirect benefits of implementing it are discussed.

3.1 Major Manufacturing issues

Below are some of the factors that hinder the application of TPM within the organization.

3.1.1 Cost of TPM Implementation

Financial incapacity is one of the major hindrances to adoption and implementation of successful TPM within a company. The fear of applying TPM, like any other productivity improvement initiative within a company, could require large sums of money to pay for a consultant, as well as the implementation of these ideas. The training is given to the people to utilize these techniques also requires money. In some instances, production of the company may be halted like if machine layout or plant layout need to be changed for smooth flow of material, then the production needs to stop. In the case of providing knowledge and training to the workforce production need to stop. A fact is that the company views it as an unnecessary loss of resources and time, more especially if they are not getting the immediate returns. [9]

3.1.2 Misapplication

As the current manufacturing market is very competitive, the company is postponing TPM with unpredictable future certainties, as a result declining manufacturing performance. In order to survive, managers have opted to adopt the TPM concept in rush. Like in Eksamo there are various places for storing raw material and waste, so that the production becomes much faster, which results in a waste of time as the area is not clear and it's hard to find which material is for which machine. Misapplication of many lean manufacturing tools by a company in rush of being lean resulted in many failures. For this reason, the implementation of TPM will definitely not impact on the overall company profitability as no change will occur in that respect. Therefore to achieve a successful implementation an early understanding of the TPM principles and its operational activities must be facilitated concurrently. [9]

3.1.3 Cost Drivers

To increase the profitability, it is very essential to identifying and ranking the factors that generate costs within the company. After finding these factors, both the cost saving exercises and TPM application that insist on waste elimination and performance improvement can be performed. The extent of implementation of TPM and other manufacturing practices that enable the effective lean depends on the plant size; plant age and the extent of people interest are the factors of successful or failure of TPM application. The size of a plant is an important factor that determines whether a company can achieve a successful TPM application. This is because implementing TPM takes into consideration a number of

issues like new plant layout, workplace layout, crane movements, etc. This could retard the transformation of current production strategy depending on the company's capacity.[9]

3.1.4 Employee Involvement/ Human Factors

The implementation and successful adoption of TPM can only be sustained in structured manner if and only when employees concerned are involved. Here in Eksamo only the senior management knows about the TPM methodology. Since the knowledge would have remained within the boundary of just a handful of people, mostly the seniors, resulting into no proper implementation.

3.1.5 Complex manufacturing parts:

The mechanical parts which Eksamo manufacture are of different shapes and sizes, so to manufacture these parts the machine need to set every day with different program and fixtures. Because of which the machines are not functioning with their full specifications and remain idle during the time of setting a new part.

3.1.6 Organizational Culture

The creation of a supportive Organizational culture is a most important platform for the successful implementation of TPM.

3.1.7 Miscellaneous

- Operators are not doing daily maintenance of the machine, which results in a breakdown of machines very often.
- Operators do not have knowledge of 5S, TPM or any other lean manufacturing techniques.
- No one is cleaning the workplace, which makes the working area messy because of which finding the tools or fixtures are difficult or time-consuming.
- The material of one machine is lying on the area of another machine.
- No proper sorting of tools in the work place area.
- No checklist, working instruction, and instructions for maintenance of the machine. Operators did not know how to do the maintenance.
- Most of the time wasted in setting the fixtures.
- There is no replacement of the worker; if anyone of the worker doesn't come, the production on that machine stops.
- Documentation is not proper as the hard copies and the software are showing a different result.
- No morning meetings (necessary for daily production planning).

The implementation of TPM will be failed if the entire workforce is not involved. This is because; workforces at strategic, managerial and operational levels have most different skills, therefore interlinking their interactions in the implementation of TPM only benefits the organization.

3.2 Difficulties of implementing TPM

- Most of the shop floor workers did not know English Language, making them understand the task is difficult. Therefore all the working instructions are prepared in Russian and Estonian language for them.
- CNC operators are working in the organization for a long time and they were not practicing any lean manufacturing principles during this time, so now asking them to implement the TPM is difficult. They think that cleaning; sorting, etc. is waste of time. According to them, there will be no production during this time as machines are idle during these practices.
- So making TPM as a culture of any organization will take a lot of time – a year or more. It is easy to implement TPM in new organization as they just started their production, so implementing TPM and making it a culture is easy. But for old organization implementing and making it a culture take a lot of time as you need to change the people's way of thinking.
- As the Machines are not serviced for a long period of time, so the maintenance will stop the production totally for some time during maintenance. Servicing one CNC machine will take at least a day. So the production for that particular day will totally stop. Maintenance can be planned on weekends or on Holidays so that the production goes smoothly on week days.
- The material flow inside the factory is not linear, resulting into waste of time. The material travels unnecessary distance because the raw-material, production, quality, and finished products locations are not linear. Making these areas linear required a lot of time and efforts as it will change the total layout of the machine shop.
- Proper planning or priority set of different projects is the problem. It needs to be prioritized that which part required more time and which required less. Some of the mechanical parts can be made on one machine, while some need to be processed in two or three machines. So priority should be set in such a way that the whole batch should be completed first than new parts should be processed, as the program will change every time whenever new parts will manufacture.

3.3 TPM Targets

A TPM structure to support the culture change needs to be defined with clear responsibilities and ownership. TPM targets will define what should be the motive, uniqueness, and objectives of TPM and how it will give direct and indirect benefits. [6]

Table 1 TPM targets.

Motive of TPM	• Adoption of life long approach for improving the overall performance of machines and equipment's. • Improving the productivity by highly skilled and motivated workers.

	• Small group activities to find out the cause of failure and giving the possible solution for plant and equipment modifications.
Uniqueness of TPM	The uniqueness of TPM over other concepts is that in TPM the operators are also involved in finding the problems and solutions during maintenance process which make the operators skilled operators.
TPM Objectives	• To achieve zero defects, zero breakdown and zero accidents in all functional areas of the organization • To increase the productivity of plant by improving the efficiency, reliability, and effectiveness of the machine. • To involve operators in smaller scale maintenance, such as machine visual inspection, checklist inspection before starting and after shutting down the machines. • To prevent the losses such as breakdown losses, setup & adjustment losses, speed losses, quality & rework losses, etc. • Minimizing waiting time, material handling time, and traveling distance during material flow.
Direct benefits of TPM	• Avoid waste and increase productivity, OEE and OPE (Overall Plant Efficiency) • Reduce the manufacturing cost. • Customer satisfaction by delivering the right quantity at right time, in the required quality. • Reduce accidents • Follow pollution control measures.
Indirect benefits of TPM	• Employee confidence towards work is increases. • A neat and clean work place. • Favorable changes in the attitude of the operators. • Work becomes easy as everyone works as a team. • Sharing of Knowledge and experience among the employees.

4. TPM IMPLEMENTATION

In this chapter various pillars are explained and approach taken to implement it is mentioned. It also discusses the analysis of data before and after implementation of the TPM.

To begin applying TPM concepts to plant, the entire work-force should know that the management had decided to implement this program. The first step in this effort is to make people understand that what actually TPM is. The workforce can be aware through an educational program, training or by giving seminars. To convince and to educate the entire workforce about TPM will take time, perhaps a year or more. [5]

Once the entire workforce is convinced for implementing TPM, the first study and action team is formed. This team is consisting of people who are directly having an impact on the problem being addressed. Upper management, supervisors, maintenance personnel, and operators should be included in a team. Each person will be given a task in the process and encouraged by everyone to do his best to contribute to the success of team effort. The team should be led by someone from the upper management because he knows the entire processes and the people.[9]

This team will be given a responsibility of finding problem areas, bottlenecks, finding the solution and initiating the corrective process. The main focus of the team is to recognize the problems and initiating the solution for the same. The idea is to first focus on the small problems and keeps records of their progress. After successfully solving the problem and analyzing its result, the team gets an idea of making the program success. Once the team shows his success by solving the small problems and become familiar with TPM processes, problems of ever increasing importance and complexity can be addressed.[10]

One of the idea to implement and getting a ‘world class’ manufacturing is making the machine to work with its full specification. The problem is operators did not know about all the machine functions and they are running machines with half of its capability. Machines life can be increased by regularly cleaning, painting, adjustment, and replacement of worn parts, belts, hoses, etc. After getting success with one machine the same thing should be implemented on another and another until entire production area become ‘world class’ and started producing with a significantly higher rate. [11]

TPM concept is implemented in a phased manner in a machine shop of a company manufacturing mechanical parts. In each phase, one TPM pillar is implemented. OEE is taken as a measure of the success of TPM implementation. The approach of implementation the foundation and of each pillar is discussed in following subsections. [10]

4.1 5S:

TPM foundation is 5S. If the work-place is not properly organized it is hard to find the problem quickly. Cleaning and organizing the work-place helps the operator to find the problem easily. Therefore making problems visible should be the first step.

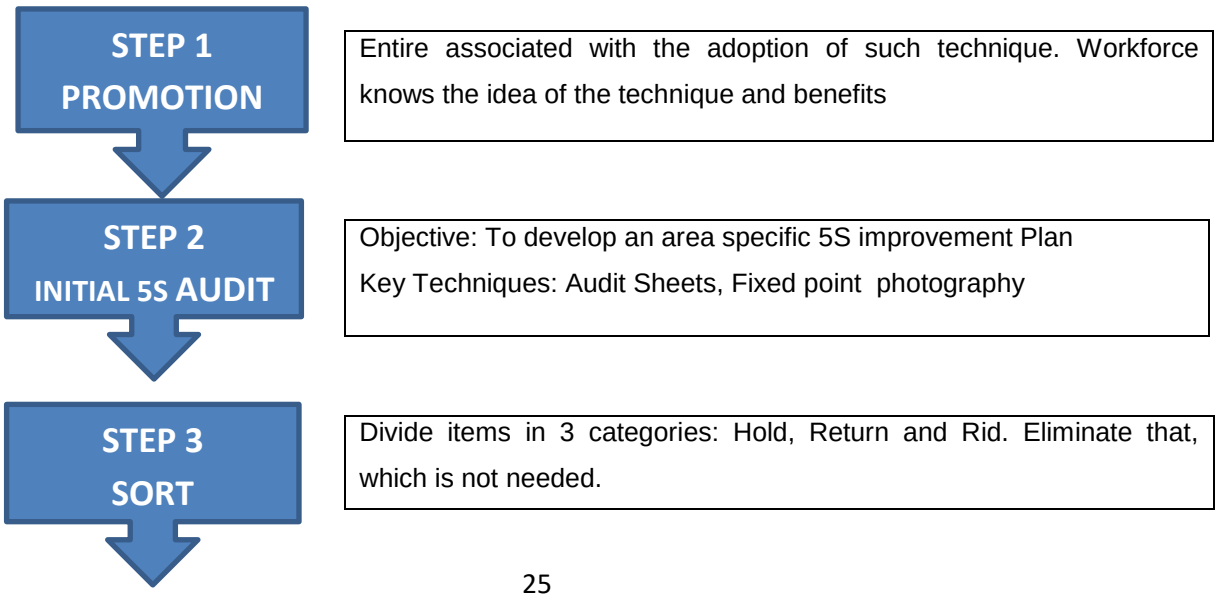
5S is a methodology to reduce waste and to improve productivity through maintaining a well-organized workplace and using visual signs to accomplish the more consistent operational result. Implementation of this method will start with the clean-up and organizing the work-place and it should be the starting point for the shop-floor transformation. The 5S pillars, Sort (Seiri), Set in Order (Seiton), Shine (Seiso), Standardize (Seiketsu), and Sustain (Shitsuke) provide a methodology for organizing, cleaning, developing, and sustaining a productive work environment. Below table 2, shows the 5S and there translation or meaning in English.

Table 2 5S translation

Japanese Term	**English Translation**	**Equivalent 'S' term**
Seiri	Organization	Sort
Seiton	Tidiness	Set in Order
Seiso	Cleaning	Shine
Seiketsu	Standardization	Standardize
Shitsuke	Discipline	Sustain

5S encourage the operators to improve the physical setting of their work and helps them in reducing the waste, unplanned downtime, and in-process inventory. A properly implemented 5S would result in significant reductions in the space, time and efforts needed for existing operations.

Below figure3 shows how the 5S methodology planned to implement in the factory.



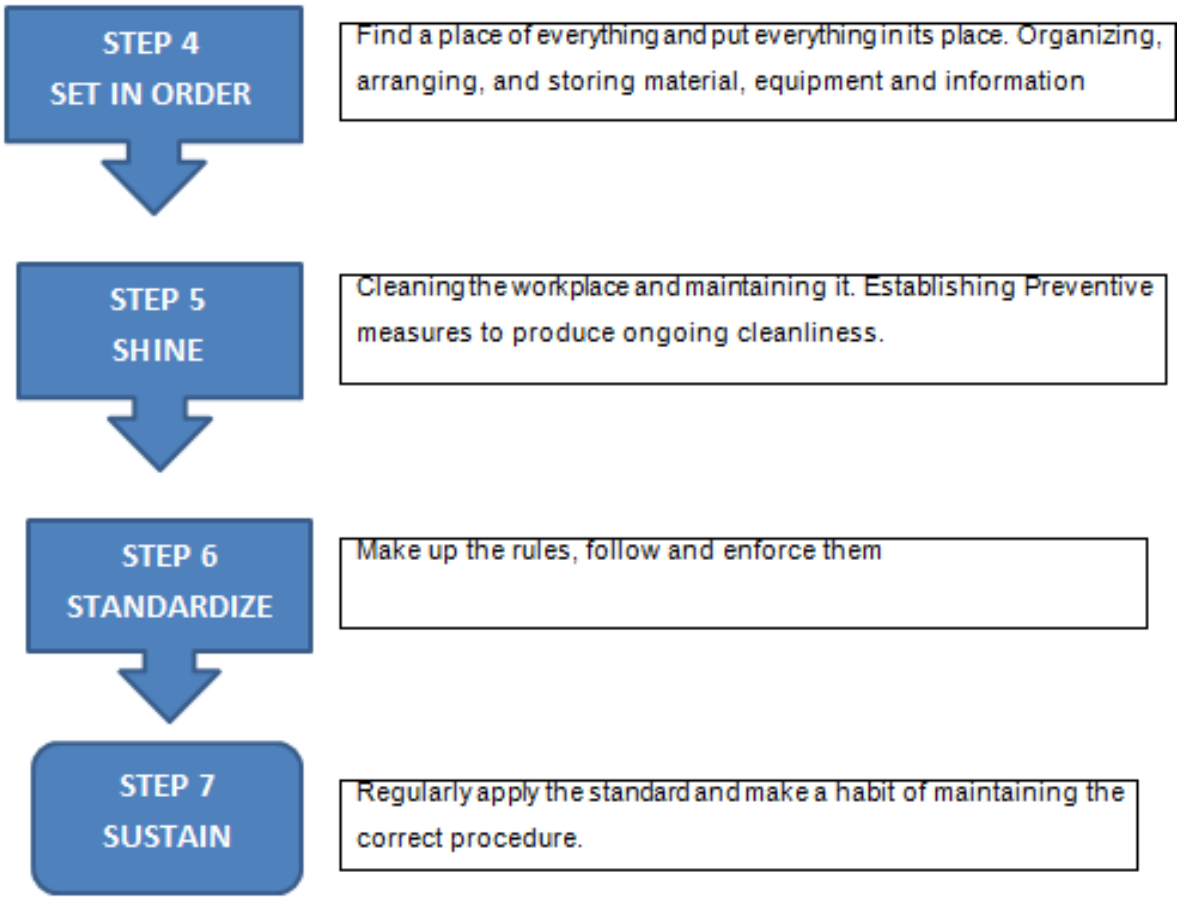


Figure 3 5S methodology system as used in lean production

Implementation of 5S in Eksamo factory:

Step 1: Promotion:

Entire associated with the adoption of such technique. Workforce knows the idea of the technique and benefits.

- Various presentations are given to the employees to make them understand what TPM is and how to implement it, the first step is to work on its foundation i.e. 5S.
- An interview of the employees has been taken to know the level of their understanding of TPM.
- Questionnaires are made to aware them about TPM.
- The 5S methodology system flow chart is put on factory notice board (Shown in Figure 4) as a part of promotion and makes operators know how to implement it. The flow chart is made in Estonian and Russian language so that every employee understands the implementation of 5S.

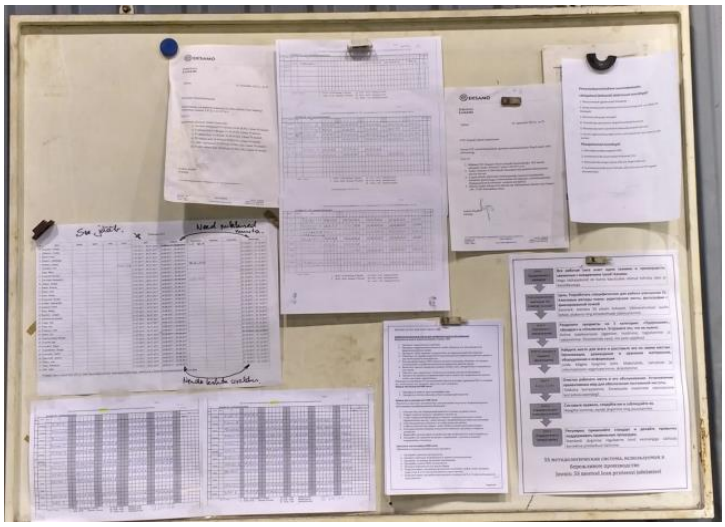


Figure 4 5S methodology on factory notice board

Step 2: Initial 5S Audits:

To develop an area specific 5S improvement Plan

- To develop an area specific 5S improvement Plan Key Techniques: Audit Sheets, Fixed point photography.
- Internal audits are made to find and divide the areas to implement the TPM
- Ownership is given to operators at the place where they are working. They need to maintain the 5S methodology in their area.
- Prizes, Incentives will be given to employee, who maintains it.
- Internal audits are made to check whether operators are following the TPM methodology or not.

Step 3: Sort

Divide items in 3 categories: Hold, Return and Rid. Eliminate that, which is not needed.

- The area next to machine is now divide items in 3 categories: Hold, Return and Rid. Eliminate items which are not needed.
- Coolant tanks are lying in the machine shop, where they are taking the unnecessary space and making it difficult for free movement as shown in figure in figure 5a and 5b. The tank is now stored at the designated place assigned for tanks as shown in figure 5c.

Figure 5a Figure 5b

Before (Coolant tanks are lying in the machine shop)

Figure 5c After (Tanks at designated place)

Step 4: Set in Order

- Find a place of everything and put everything in its place. Organizing, arranging, and storing material, equipment and information
- Proper places are assigned for each machine to put its raw material as shown in figure 6b. Earlier raw- material of one machine was lying on area of other machine (as shown in figure 6a) because of which the area becomes messed up and it became hard for operator to work there.

Figure 6a Before(Unorganized machine input)

Figure 6b After(Organized machine input)

- Materials were not properly arranged at the raw-material area as shown in figure 7a. Now the materials are arranged properly and it can been seen from figure that now there is enough space to put more material as shown in figure 7b

Figure 7a Before(Unorganized raw-material) Figure 7b After(Organized raw-material)

Another example of implementation of step 4 is shown in figure 8a and 8b.

Sharp metal pieces were lying inside the shop floor. The metal pieces are taken out from the shop floor and kept at the raw material area. Now there is enough empty space for other things to do here. Quality racks can be placed here which will help the shop to be more organized.

Figure 8a Metal-sheets in shop

Figure 8b Cleaned shop

Step 5: Shine

Cleaning the workplace and maintaining it. Establishing preventive measures to produce ongoing cleanliness

- The shop was not cleaned as the materials is lying everywhere. The materials are properly arranged and the shop is cleaned. Now it is easy to move around the shop as shown in figures 9a and 9b.

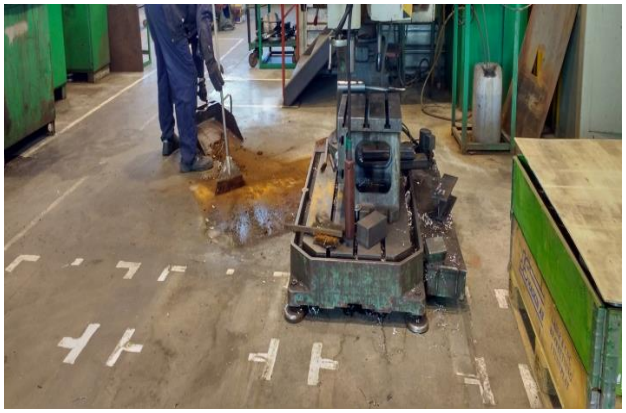


Figure 9a and 9b clean shop

Step 6: Standardize

Make up the rules, follow and enforce them.

- No operator was filling the real time update in the software which makes it difficult to understand that's what is happening in the machine. Real time updates show the present operation of the machine. There are different colors assign for each activity in the software and it is connected through LAN to office PCs. For e.g.-Black color is for offline, Red is for stopped, Blue is for

setting, green is for in-cycle, brown is for breakdown, purple is for maintenance, etc. Now operators are filling the real time details in the software, so that everyone can see online which operation is going right now in the machine. As shown in the below figures operators are not filling details during tooling , maintenance, etc. in the software earlier (as shown in figure 10a) but now we can see the different colors in the software for the real time status of the machine(as shown in figure 10b)

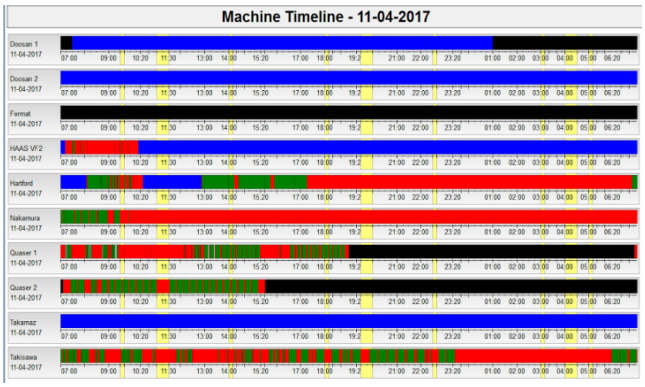


Figure 10a Before (Not updated software)

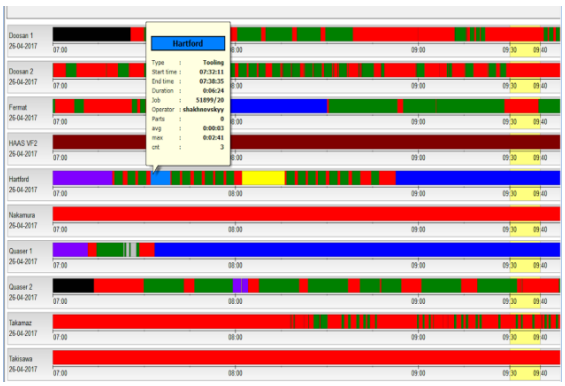


Figure 10b After (Real-time updated software)

- Employee's details are not displayed on the notice board. It was hard to find the correct information from the employees as their phone number and email addresses are hard to find. Employee's details are displayed on the notice board with all the details like name, designation, phone number, email address, Skype id, etc. As shown in below figure 11.

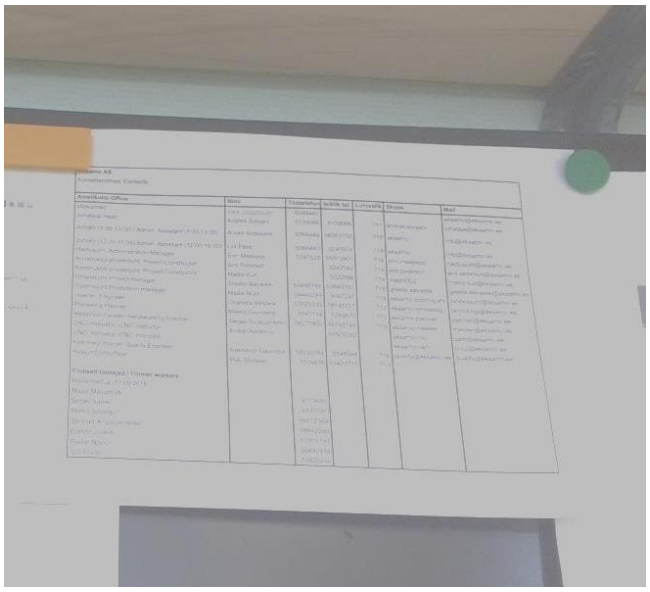


Figure 11 Employees information

Step 7: Sustain

Regularly apply the standard and make a habit of maintaining the correct procedure. The Supervisor has given the responsibility to check whether the operators are following the standard or not, If they are not following then it supervisors responsibility to make them follow it.

- Suggestion scheme stating that whoever gives the best suggestion will be given reward.

4.2 JISHU HOZEN (Autonomous Maintenance)

This pillar is based on the concept that if every operator takes care of small maintenance tasks on the machine where he is working then it will free up the skilled maintenance people to concentrate on more value-added activity and technical repairs. The operators are responsible for upkeeping their equipment on daily basis to prevent them to deteriorating. By use of this pillar, the aim is to maintain the machine in good condition. [6]

The maintenance activity that the operator should include is simple in nature like basic cleaning of machines, lubricating, oiling, visual inspection, and tightening of nuts and bolts, inspection, diagnosis of potential problems and other actions that increase the productive life of machine and equipment.

Approach:

- Operators are given training by the third party engineer who is proficient in the maintenance of machines. A checklist is prepared for maintenance. Now following the checklist is mandatory for all the operators. It is a responsibility of supervisor to see that every operator is following the checklist on time or not.
- Operators are not cleaning the machines and the working area, as a result of which machines are not working as per its specification and remain stopped most of the time.
- Ownership of a machine is given to each operator for the machine in which he is working. This changes the operator mindset towards the machine.
- To clean the small metal parts from the machine, air pressure is being used. The suggestion has been given to buy a vacuum cleaner so that the metal not stuck between the fixtures.

A checklist is made for daily, weekly, monthly and yearly maintenance of the machines. Now the operators have both a reminder and a record of what need to be done. For more complex maintenance there are clear instructions as to the best ways to undertake the operation. Instructions are made in English, Russian and Estonian language, so that it can be easily understood by the operator. This checklist is made with the help of CNC machine maintenance specialist, so by following these instructions, it will be easy to maintain the machine in new condition. Below Figure 12 shows the checklist attach on the machine.

Figure12 Maintenance checklist

Outcomes:

- Operators become more responsible and concerned about the condition of equipment they use on a daily basis. They know the condition of the equipment before using it and know how long it will last.
- The operators become more skilled as they gain an understanding of the general working of the machine thus achieving the multi-skilling objective of a lean organization.
- Machines operate at their optimal level because the basic maintenance such as cleaning, tightening of bolts and lubrication is carried out more regularly.
- Because of the daily maintenance, the problems are identified well before and corrected before they go out of control leading to the major breakdown of equipment.
- Maintenance Engineering staff are freed-up to carry out the higher levels of maintenance activities on critical and sensitive equipment's thus reducing the overall system downtime. [12]

4.3 Kaizen Rapid Improvement Process

Kaizen is the Japanese word for improve. It is one of the philosophies behind lean manufacturing operations. Lean manufacturing is found on the idea of kaizen, or continual improvement. The philosophy implies that the small incremental change applied every day and sustained for a long time will give the significant improvements. It directs workers from different functions and levels in the organization works together to address a problem or to improve a particular process. The team uses analytical techniques, such as value stream mapping, to quickly identify opportunities to eliminate waste in the targeted process.

Kaizen can be implemented by identifying the root cause of the problem. [13]

Getting to the Root Cause:

Key Points:

- By discarding conventional fixed ideas and try to find new ideas which help in getting results easier and faster.
- Making things work, not why it cannot be done.
- Avoiding making excuses, instead of questioning current practices.
- Doing things right away, even if it gives only 40% of success instead of seeking perfection
- Ensuring mistakes made are corrected right away.
- Making Lesson learned document for every project and try to implement it in next project, with some changes to get the result faster.
- Throwing wisdom at a problem, not money.
- Asking, ‘why we are getting this problem?’ five times and find the root cause.

One of the examples of Kaizen is implemented in the machine shop with the quality rack. The Quality rack legs were bends because of the excess weight put on the shelves as shown in figures 13a. The leg of the shelves are now fixed with the iron piece, attached it with the cable tie and the tapes over it. Attaching iron rods with the shelves leg made it much stronger and now the shelves can lift more weight as shown in figures 13b and 13c. This solution is only for temporary bases. These racks should be replaced by new and much stronger racks.

Figure 13a Before (Bend quality rack legs)

Figure 13b and 13c After (Fixed quality rack legs)

Another example of Kaizen pillar is shown in below figure 14.

The stairs were taking an unnecessary space. It is cut and made it in such a way that now there is enough space to keep other material. Also now it is easier to use the stairs as it is facing straight.

The space is made in such a way that one machine which was not in use in the shop floor can be put here and which can be sold later. The space occupied by this machine is lot and it is installed in the middle of the shop floor. Once the machine is shifted to this area, there will be space in the shop floor for other activities.

Figure 14 Modify stairs

4.4 Planned Maintenance:

Planned maintenance is the scheduling activities for maintenance based on the earlier observed behavior of machines such as maintenance, setting, breakdown and failure rates. By scheduling all these activities around such matrices, the cycle of failure and breakdown will be broken therefore resulting in a longer service life of a machine.

It is aimed to have trouble free equipment and machines without any breakdown and producing components to the quality level giving total customer satisfaction. Because there is a specific time for maintaining equipment, production is rarely interrupted as these activities are scheduled around the time when they are ideal or are producing little.

This is further divided into four groups' i. e. preventive maintenance, breakdown maintenance, corrective maintenance, and maintenance prevention. The objective of planned maintenance is to achieve zero breakdowns, and sustain the availability of machines all the time. This pillar helps in achieving optimum maintenance cost, improve reliability and maintainability of machines. It ensures zero equipment failure, breakdown and availability of spares, tools, fixtures, etc. all the time. Its approach is to establish a management system that extends the equipment reliability at best cost. This approach has a positive impact on company's profitability as the maintenance costs reduced dramatically. The productivity, as well as the output quality of the machine, is guaranteed from the very first day when the equipment is commissioned. [6]

Using the input from the people who works on these machines every-day, suppliers of the equipment can improve the maintainability and operability in the next iteration of their products.

Approach

- For preventive maintenance, all the operators, technicians of CNC shop floor along with the engineers of maintenance department are given training every month.
- Predictive maintenance should be done in collaboration with CNCs operators and engineers of the maintenance department.
- Operators should be given a training to identify the areas in CNC which are more likely to fail so that they can inform maintenance department in well advance and can take corrective action before any major breakdown happens.[10]

Outcomes

- By constantly scheduling maintenance activities, the number of breakdowns gradually decreases and this then increases the capacity for productive activities.
- Maintenance is done on Saturdays or Sundays or when the production floor is not very busy.

- Production functions can be continuing with their activities without any interruption because they know when exactly maintenance will take place.
- Capital investments in machinery are reduced as the machines are maintained regularly and can be utilized to its fullest potential.
- Expensive machine parts do not have to be put in stock as there is better control of the various categories of parts. [12]

One of the examples of implementing this pillar is shown in figures 15a and 15b.

Below are some factors which are considered during installation of new CNC machine in the factory.

- Making an ergonomic working space. So that the material flow should be smooth. The electrical and pneumatic connection should be in reach.
- Ease of cleaning and inspection.
- Ease of lubrication.
- Accessibility of equipment parts, fixtures, tools etc.
- Improving operability of machines in such a way that they are comfortable to use by operators.
- Increased safety features.
- Making it easier for the changeover to take place through eliminating the unnecessary procedures.
- Feedback mechanisms that will prevent out of specification situations along with clear instruction of the correct specifications for quality products.

Though the machine is designed and installed with the above considerations in mind (As shown in Figure 15b), it is still possible that there will be bugs that will need to remove before full commissioning.

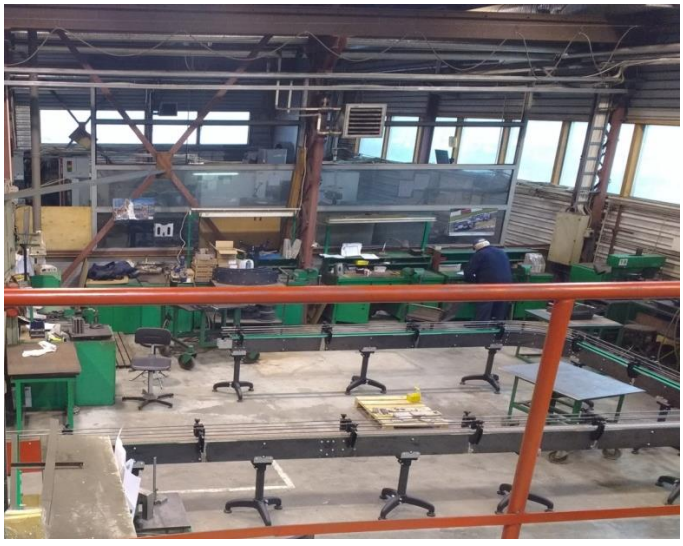


Figure 15a Before (Unorganized area)

Figure15b After (Planned CNC installation)

4.5 Quality Maintenance:

Quality maintenance pillar aims to assure zero defect conditions. It achieves this by understanding and controlling the process interactions between material, machines, manpower and methods that could enable defects to occur.

This pillar addresses the issue of quality by ensuring equipment is able to detect and prevent errors during production. By detecting errors before, processes become reliable enough to produce the right specification for the first time. It is geared towards achieving customer satisfaction through the delivery of highest quality of the product. Through improvement, the defects are eliminated from the process after identifying the parameter of a machine which affects the quality.

The quality aspect of maintenance is very important because it helps in preventing defects from tools such as root-cause analysis and Ishakawa diagrams which are structured ways of getting to the real reason why the problem occurs.[12]

Approach:

- The condition is checked and measured in time series to verify that measured values are within standard values to prevent defects. The transition of measured values is watched through charts to predict possibilities of defects occurring and to take counter measure beforehand.
- Preparation of quality assurance matrix and usage. [12]

Outcomes:

- It will reduce the cost of quality, as quality losses waste, rework, consumer complaints and the need of inspection is reduced.

- It will reduce cost by catching defects at the early stage as it is expensive and unreliable to find defects through inspection later. This happens because the errors are caught before they move down the amount of rework that has to be done to correct them.[5]

4.6 Education and Training

This pillar is basically concerned making the entire workforce more skilled. It fills the knowledge gap that exists in an organization when it comes to TPM. Lack of knowledge of how to use the tools can stand in the way of proper implementation leading to average results at best and failure at worst. Without proper training, TPM can be misunderstood by the employees who can result in negative results for the company.

As most of the operators do not know about TPM or any other Lean techniques, it is necessary to first provide them training and made them understand about these techniques. They should know the importance of the methodology and how they can gain more with fewer efforts. Training should be given to do the daily maintenance of the machines; things need to be taking care of before switching on the machine, at the time of working and after switching off the machine. There should be a team of the skilled employees who will give training to other employees. This team then designs, implements and improves a skill development system to enable ongoing development of all employees. The team then teaches higher level skills such as preventive maintenance and analytical skills to help become more proactive to problem-solving. [12]

Approach:

Continuous improvement is possible only through continuously improving the knowledge and skills of the people at different levels. To increase the plant efficiency and to reduce the defects training should be provided to the concerned.

Training to Supervisor (Quality Department):

- There should be monthly training for the quality department regarding quality check of tools. Tools should be calibrated periodically so that the tools give the correct result.
- Educating them how to use measuring instruments and how not to.

Training to Operators:

- Training should be given for 100 percent visual inspection to detect visual defects like checking the filters are free from dust, the glass windows are clean or not, there is proper pressure in the gauge, etc.

- Educating them how to use measuring instruments like Vernier caliper, screw and dial gauge etc. so that they can find the error made by machine at the beginning and can correct it at the same time.
- The supervisor should teach operators regarding necessary force required to clamp the part into the chuck.

Training to Managers:

- At the managerial levels, managers also learn the TPM skills so as to become competent mentors to their juniors as well as be involved in coaching programs.

Outcomes:

Training will increase the skills and performance of all the workers throughout the Organization. It is essential for the successful implementation of TPM. Without training and education, the impact of other pillars will not be sustainable.

4.7 Office TPM

TPM in administrative functions is the next logical step in the TPM program so as to make the whole organization speaking from the same page.

As office functions are the supportive functions, making them understand and apply the methodology of lean in their operations makes it easy for them to provide efficient service to the main value-creating processes.

This pillar also helps in spreading the initiative into other functions which help in removing the silo mentality and encourages parallel cooperation within the workforce. The company will also get benefit by having a larger pool of employees who understand the principles of TPM and can easily be called upon to play a positive role in its implementation. [12]

Office TPM must be followed to improve productivity and efficiency of the administrative functions. This includes analyzing processes and procedure which can be automated. It deals with the nine major losses that are processing loss, cost loss including in area such as procurement, accounts, marketing, sales leading to high inventories, communication loss, idle loss, set-up loss, accuracy loss. Office equipment breakdown, communication channel breakdown, telephone and fax lines and also time spent on retrieval of information. [10]

Approach:

- Operators should write daily rejected quantities in their daily production report, so that time required for getting data for daily rejection from quality department is reduced.
- Maintenance department should follow the maintenance activity and do the maintenance of the machine as per the dates and time mention in the company's software for maintenance

Outcomes:

- If the administrative functions are able to improve their order processing procedures, then the material will get to the shop-floor in a flawless manner which will have a positive effect on the workflow.
- If the suppliers are paid on time, they will have the ability to provide the services in a much smoother manner.

One of the examples of this pillar is shown in figure 16

New employee's details are displayed on the notice board having information like their names, designation, phone number, Skype-id, etc. so that whenever anybody need to consult them can reach them on their mobiles, without wasting time.

Also the employees who left the company their details still there in notice board. The details are updated with the new employees and the new updated document is made and put on the notice board.

1	**Eksamo AS**						
2	Kontaktandmed /Contacts						
3	**Ametikoht/ Office**	**Nimi/ Name**	**Töötelefon**	**Isiklik tel.**	**Lühivalik**	**Skype**	**e-Mail**
4	Üldkontakt/ General Contacts						
5	Juhataja/ Head						
6	Juhiabi / Admin. Assistant (9:00-13:00)						
7	Juhiabi /Admin. Assistant (12:00-16:00)						
8	Konstruktor-projektijuht/ Project-Constructor						
9	Projektijuht/ Project manager						
10	Tootmisjuht/Production manager						
11	Insener/ Engineer						
12	CNC-instruktor /CNC instructor						
13	Kvaliteediinsener/ Quality Engineer						
14	CNC-instruktor/ CNC instructor						
15	CNC Operatorid						
16	CNC Operatorid						
17	CNC Operatorid						
18	CNC Operatorid						
19	CNC Operatorid						
20	CNC Operatorid						
21	CNC Operatorid						
22	CNC Operatorid						
23	CNC Operatorid						
24	CNC Operatorid						
25	Metallitöö meister/ metalworking foreman						
26	Lukksepad / Locksmiths						
27	Lukksepad / Locksmiths						
28	Keevitajad / Welder						
29	Lõikajad / Cutter						
30	Treialid / Turner						
31	Freesijad / Miller						

Figure 16 Updated format for employees details

4.8 Safety, Health and Environment

The purpose of this pillar is that the workers must be able to perform their work in a safe environment without affecting their health and safety. It creates a safe workplace and surrounding area that is not damaged by any process or procedure. Utmost importance to safety, health, and environment is given in the plant. The main objective of this pillar is to achieve zero accident, zero health damage, and zero fires.

The health, safety and environment pillar of TPM ensures that all the employees are provided with an environment that is safe to work in all conditions. It eliminated all the harmful possible condition at work.

The goal of every organization is to produce values for the customer in an efficient and productive manner; this should be done in such a way that it does not put to risk the health and safety of the employees. It is therefore very important that any situations which are put in places should consider the well-being of the employee above all else. [10]

When employees are working in a safe environment, their attitude towards work changes with a resultant increase in productivity. This is because injuries or fatalities reduce when there is a concerted effort to make the workplace an accident-free environment.

The cross-functional team will make the machines safe to use by the workers by putting in place such features like guards, working standards, use of personal protective equipment and first-aid kits on the shop floor. Each of these measures is aimed to improve the safety of worker and machines so as to have a more production.

.Approach:

- Workers are given instruction to wear safety glasses, hard hat, safety shoes, gloves, etc while working on the machine.
- They should remove rings, chain or any loose clothes which might have chances to stick on the machine while working.
- There should be a sufficient number of fire extinguishers all over the shop floor.
- Training should be given to every employee how to use the fire extinguisher in case of emergency.
- Training for fire prevention and fire -fighting, personal surviving techniques, personal safety and social responsibilities, and elementary first aid should be given to every employee.
- The employees should know what to do in case of emergency? What should be the exit plan?
- Management is also given suggestion to conduct mock drill twice in a year.
- Workers are advised to maintain cleanliness of toilets, regular cleaning is also done.

One of the examples of implementation of this pillar is shown in figure 17b.

The crane which was not assembled from years is now fixed and is being used. Earlier it was lying down on the raw-material area (As shown in figure 17a) and unnecessarily taking space, which can be used to put raw-materials. The right place for installation of crane is found out. One of the CNC machine used to process the heavy parts, these parts are lifted by the operators and fixed inside the machine. If this is being practice for a long time, it will affect the operator's health. The crane is installed in such a way that it can cover the three CNC machines including the one which needed it the most.

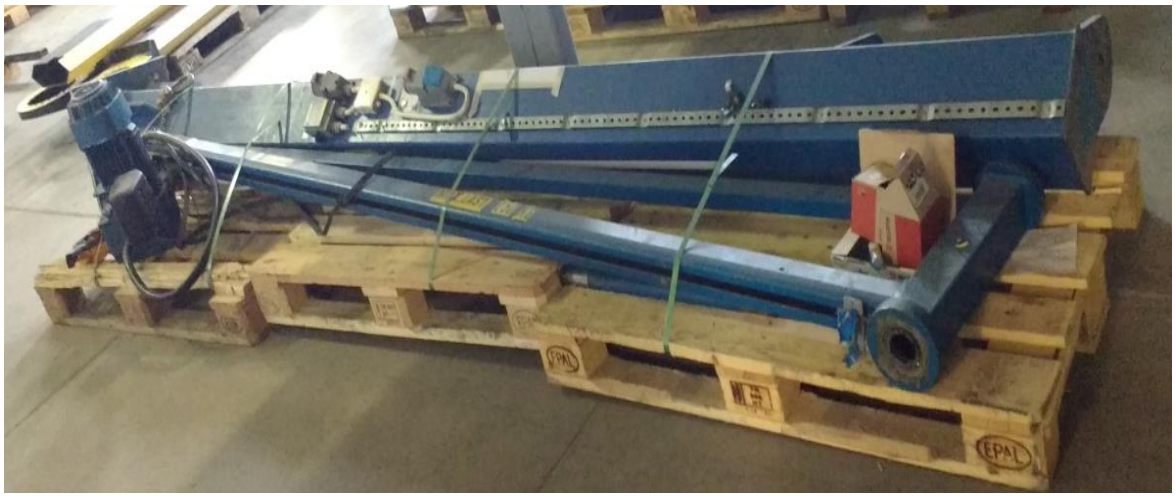


Figure 17a Uninstalled crane

Figure17b Installed crane

4.9 Summary Total Productive Maintenance Pillars

Table 3 below shows the summary of TPM pillars, their description and their outcomes after implementation.

Table 3 TPM summary

Sr. No.	TPM Pillars	Description	How Does It Help?
1	5S	Creating a work environment that is clean and well-organized.	• Eliminate anything that is not needed at work-place • Organize the remaining items • Clean and organized work place • Create standards for above three activities • Ensure they are regularly applied
2	Autonomous Maintenance(JISHU HOZEN)	Places responsibility to operator for carrying out basic maintenance of machine such as cleaning, lubricating, and inspection.	• A machine becomes more reliable as it is well-cleaned and lubricated. • Gives operators the ownership of their equipment. • Operator becomes more skilled by knowing more about its equipment. • Identifies rising issues before they become failures
3	Kobetsu Kaizen	Use of small group of cross-functional teams work together for improvement activities	• It improves problem solving capabilities of the employees. • Combines the collective talents of a factory for continuous improvement • Repeating problems are identified and resolved.
4	Planned Maintenance	Schedules maintenance task based on the historic failure rate of equipment or machines	• It reduces instances of unplanned stop time. • Maintenance can be scheduled when there is no or less production. • By controlling wear-prone and failure – prone parts, it reduces inventory
5	Quality maintenance	Design error detection and prevention into	• It targets quality issues with improvement projects mainly focused on removing root

		production processes so as to reduce defects.	cause of defects. • Reduces number of defective parts. • Reduces inspection cost by finding defects early
6	Education and Training	Fill in knowledge gaps and skills through training and educating workers.	• Operators gain the skills to maintain equipment and identify problems. • Maintenance people learn techniques for proactive and preventative maintenance.
7	Office TPM	Apply TPM principles to administrative functions within an organization	• Support functions understand the benefits of TPM and extend it beyond the plant floor by finding waste in administrative functions. • Helps in production through improved administrative operations such as Order processing, procurement and scheduling.
8	Health, Safety, and Environment	Providing safe and healthy working environment without any accidents and injuries.	• Elimination of harmful conditions, safety risks, resulting in a safer workplace. • Gives accident-free workplace.

5. WORKSHOP DESIGN

The new workshop layout is proposed on the basis of 4 different types' of layouts.

Process Layout: It is a design for the shop floor plan of a plant to improve efficiency by arranging equipment's according to its function. The production line is designed in such a way that it eliminates waste in material flows, inventory handling, and management. [14]

Product Layout: It refers to a production system where the work stations and equipment are located along the line of production, as with assembly lines. In this layout, work units are moved along a line by a conveyor. [15]

Cellular Layout: A lean method to produce similar products using cells, or groups of team members, workstations, or equipment, to facilitate operations by eliminating setup and unneeded costs between operations. [16]

Fixed Layout: In this type of layout, personnel, supplies, and equipment are brought to a site where the product will be assembled, rather than the product being moved through an assembly line or set of assembly stations. [17]

5.1 Layout Analysis

The analysis of the Plant layout is based on 10 criterions. 4 different types of Plant layouts are analyzed by the criterions. Each type of layout is scored according to each criterion and each criterion is weighted. The weight indicates the importance of each criterion for our layout. And weighted mean of all criterions is calculated for each type of layout. The score range is from 1 to 4, 4 is best and 1 is worst. Weight is from 1 to 4 too. The higher the weight, the more important this criterion is to our layout design. The weightage is given on the basis of author research study, and experience.
Table 4 below shows the analysis.

Calculation for weighted mean

Process Layout

Weighted Mean

$$= \frac{[(4X4)+ (1X1)+(1X2)+(2X1)+(3X4)+(3X3)+(3X3)+(2X2)+(2X2)+(2X2)]}{\text{Total weight}=[4+1+1+2+3+3+3+2+2+2]}$$

$$= \frac{63}{23}$$

$$=2.73913$$

Similarly the weighted mean is calculated for product layout, cellular layout and fixed layout

Table 4: Layout analysis

Criteria	Weight	Process Layout	Product Layout	Cellular Layout	Fixed Layout
Maximum flexibility	4	4	2	3	1
Maximum integration	1	1	3	4	2
Maximum use of volume	1	2	3	1	4
Maximum visibility	2	1	4	2	3
Maximum access	3	4	1	2	3
Minimum distance	3	3	1	4	2
Minimum handling	3	3	4	2	1
Minimum discomfort	2	2	4	3	1
Maximum security	2	2	1	4	3
Efficient process flow	2	2	4	3	1
Weighted mean		2.73913	2.521739	3.086957	2.391

As indicated in table 4 above, cellular layout and process layout has the higher score than other 2 types.

5.2 Classification

The proposed layout is a hybrid type layout which is the combination of both cellular layout and process layout.

5.3 Advantages and Disadvantages

Table below shows the advantages and disadvantages of the designed Hybrid layout.

Table 5 Advantage and disadvantage of Hybrid layout

Advantage	Disadvantage
• Higher utilization of machinery	• Longer production throughput time
• Flexibility of production types and ranges	• Balancing workload is uneven
• Reduced material handling and transit time	• Less accuracy in identifying product status
• Less floor space required	• Automation of production process is complicated
• Emphasized more on quality of products	
• Better utilization human resources	

5.4 Proposed workshop layout

The workshop is separated into 2 functioning areas by separation construction. The separation construction has gates which provide access to the other area.

In one part of the workshop, all machines is situated together with the quality check area and on the other part raw-material, packaging and finished product are situated.

Green blocks in each cell represent the temporary parts storage where parts are stored for different processes according to the process sequence. The storage area is divided into input storage and output storage so that the material flow is more efficient as shown in figure 18. All finished parts are sorted and stored next to the packing area and then finished products are stored in finished product area.

Based on section 5.1, 5.2 and 5.3 a workshop layout is designed and proposed as shown in figure18.

Figure18 Proposed floor plan of the workshop

The machine tools are grouped into 6 cells namely Raw material cell, Machining cell, Quality cell, Paint cell, finished product cell and the packaging cell. The raw material will be stored into input storage where it will be cut into smaller parts using saw-machine and the smaller parts are stored in output storage. From where it will sent to machining cell part storage area, where it will be divided into input and output buffers as shown in figure 21. After that quality check will be done and finished product will be sent to paint cell if needed. After painting Finished product will stored in finished product cell and then packing will be done at packing cell.

The material flow is indicated in the figure 19 below.

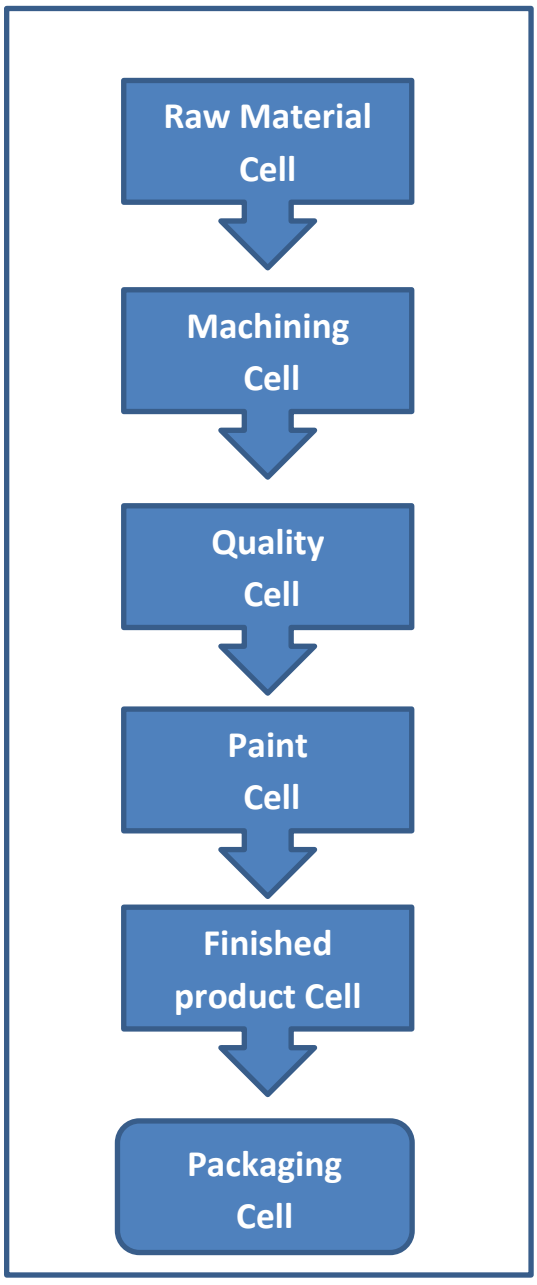


Figure 19 Flow of material

5.5 QA and QC

Quality management can be implemented as discussed in Chapter 4.5.

Quality assurance management is organized through continuous quality check process. Hand tools for dimension control are situated opposite to the Hartford machine and are intended to use during milling, turning, sawing tasks, to check dimensions between tool changes, etc.

After every CNC machine job, the part goes to final quality inspection procedure. This is done outside the workplace cell, in the designated area, central at the shop floor, where special fixtures and dimension measurement units are used for quality control. The central quality control procedure assures that the gearbox detail will fit together with allowed tolerances during the assembly.

For quality control, the measurement instruments and machines have regular maintenance and calibration. Quality control engineer will have opportunities for professional training.

6 WORKPLACE DESIGN

The workplace selected for proposed layout is the CNC machine (Hartford) workplace. The same layout can be used for other machines also.

6.1 Job Description

Table6 below is the job description of the workplace. The Hartford machine is used for all operations like Sawing, Turning, milling, drilling etc. Three parts are taken as an example which is being processed in the Hartford.

Table 6 Job description

Part	Part Description	Operation
Part 1	Wind sensor Brackets	Sawing, Turning, Milling
Part 2	Bow mounting block	Sawing, Turning, Milling
Part 3	Motor chaises	Sawing, Turning, Milling

6.2 Proposed Workplace Description

Presently the workplace looks like as shown in figure 20 below. The input and output buffers are not organized. These materials are put on the pallets and there is very less space for operator movement. There is no work table for preparation of tools and fixtures.

Figure 20 Hartford working area

Figure 21 below is the scheme of proposed workplace.

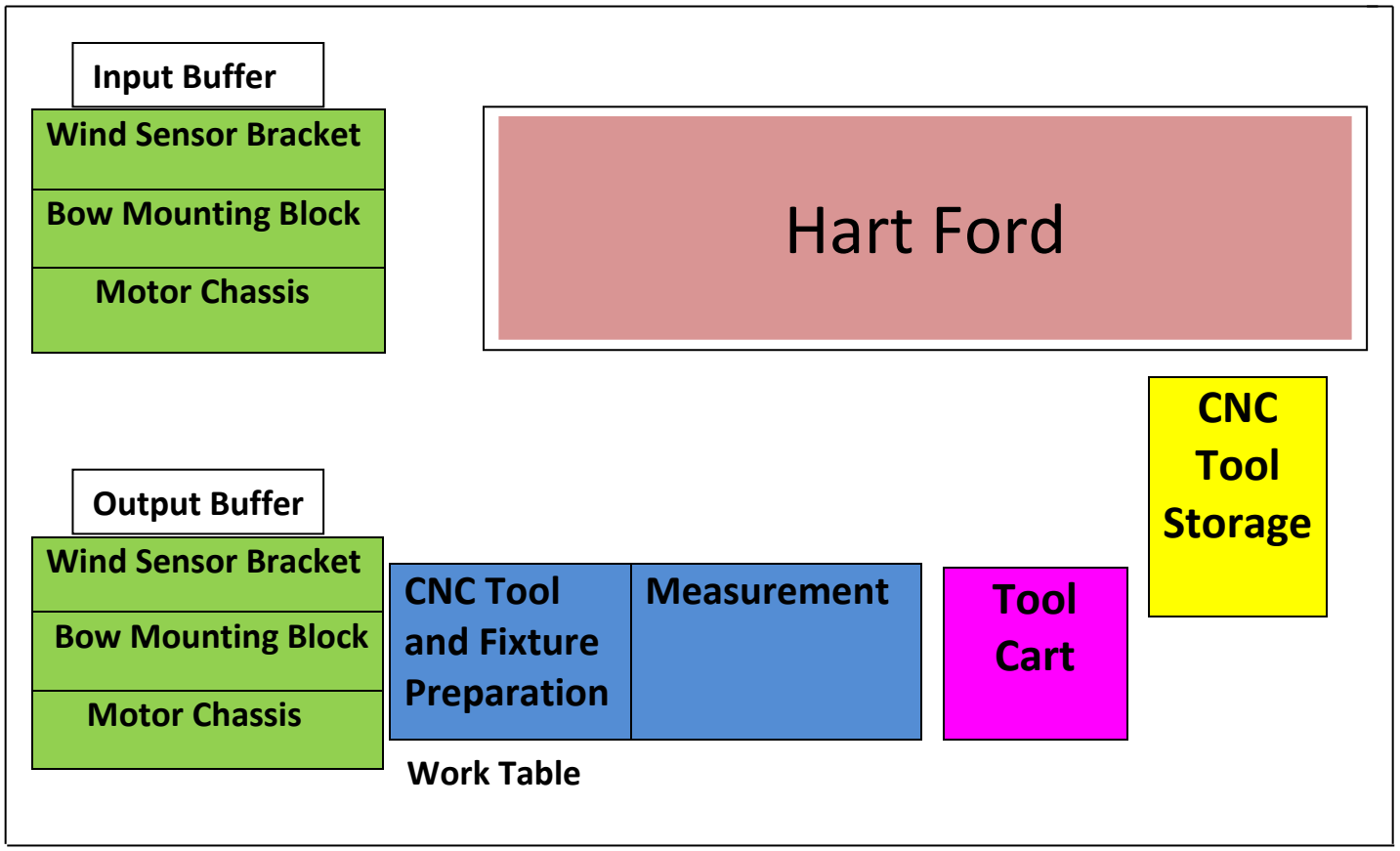


Figure 21 Workplace scheme

On the left side of the workplace is the input and output buffer area (small racks) for storing the 3 different parts. The yellow block is the storage area of CNC tool. On the worktable, Operator will prepare the tool and fixture and measurement and other possible manual work. The tool cart has all necessary tools for worker, like wrench, screw driver, etc.

Figure 22 below shows the flow of material and tools.

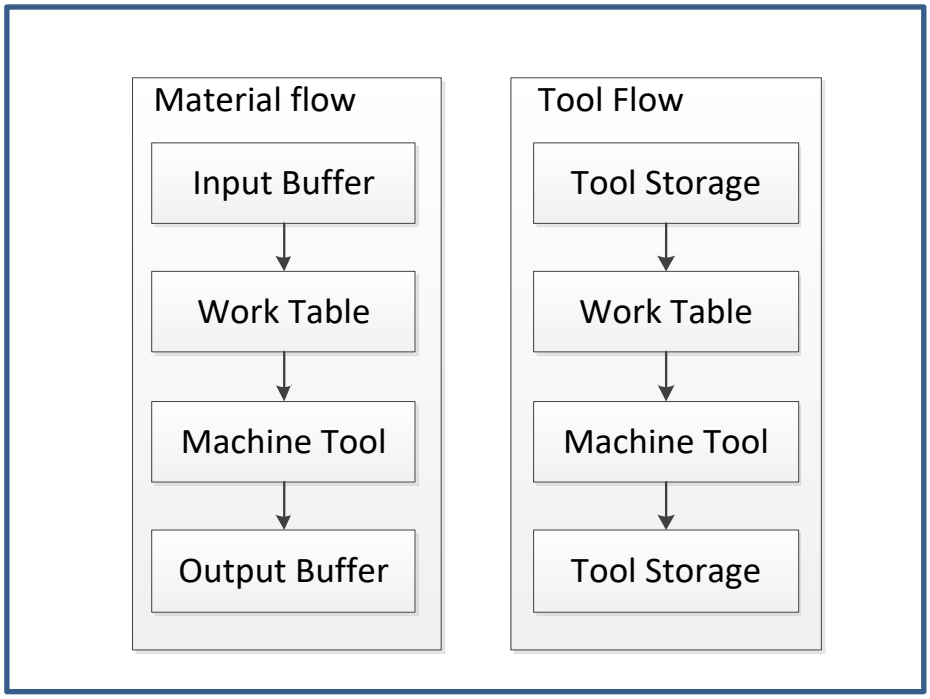


Figure 22 Material and tool flow

6.3 Workplace Justification:

The input and output buffers are divided into 3 different areas to store the 3 different parts which will be processed. This can save time for material transferring. This area is on the left side of the workplace. It is consistent with the cell design in the workshop layout as shown in figure18. Since all loading and unloading and tool change are done by worker, tool cart and work table is necessary to perform the relative task. The layout is in a ring shape so that the operations will not affect each other and increase the efficiency.

6.4 Tooling Organization

Production processes done on Hartford need various sizes of tools for edge-finding, drilling, milling and surface cutting. All the tools are manually changed (although automatic tool changers are an option to automate the production process in the future). To ease the tool changing process, all the tools are situated on the workplace next to the Hartford machine, on the right side (Shown in figure21), so they are easy to access to use in the CNC mill and for tool inspection. Figure23 below shows the idea of tool organization pipeline.

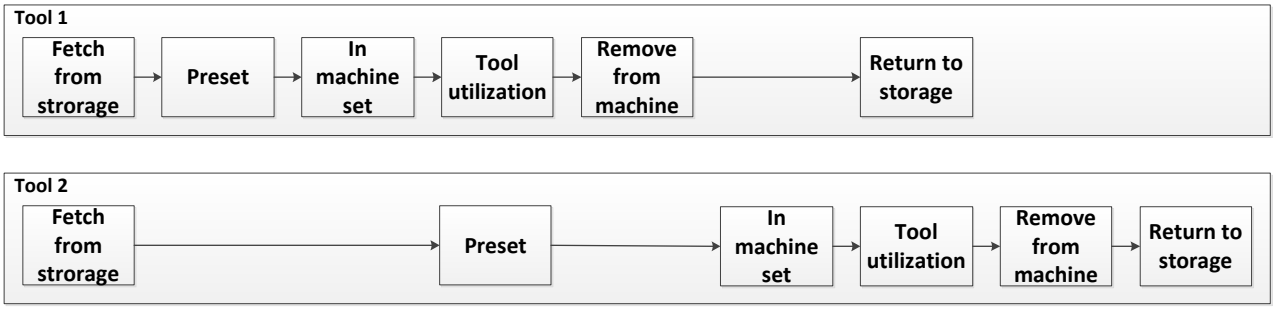


Figure 23 Tool organization pipeline

The tool flow cycle is indicated in the box. All the tools have the same cycle. The key point in tool management here is use the tool utilization time for preparing tasks for next required tool. If the utilization time is known, then it could be further improved. The figure shows pipeline for 2 tools. With the increased number of tools, the pipeline diagram will be more complicated. It will be optimized with different methods.

7. AUTOMATING WORKPLACE

7.1 Automating By Industrial Robot

Automating the workplace is accomplished by Industrial Robot (IR). Material handling, parts loading unloading, fixture of parts and tools changing will be performed by IR. The input and output buffer is changed into conveyor with separated compartment so that each part infeed and outfeed is at same position.

7.2 Robot Selection Procedure

The Robot will be selected considering following features as shown in below figure 24:

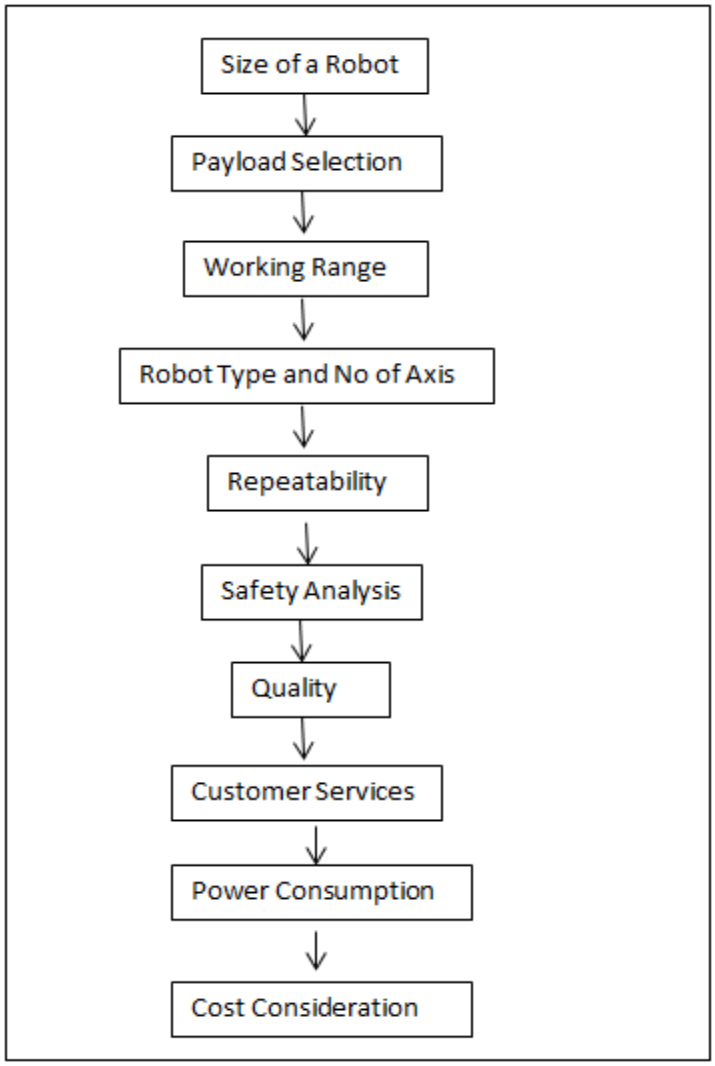


Figure 24 IR Selection procedures

7.3 Industrial Robot Manufacturer Justification:

Table below shows the results of factors in selection procedure.

Table 7 IR selection result

Selection Factor	Result
Payload	20 kg
Working Range	See robot technical data
Robot Type and No. of Axis	6 DoF Manipulator
Repeatability	<0.05mm
Safety Analysis	According to CE
Customer Service	Has local support
Cost	According to budget

IR payload should be large enough to handle all the manufacturing operation. In Hartford workplace, the maximum wait to be carried is 18 Kg. So the payload should be 20kg.

Working range should be big enough to cover the material handling and loading unloading range.

Dof manipulator meets the requirement of task in workplace. Both position and orientation need to be controlled. Thus 6 Dofs manipulator is a valid choice. Gantry or Cartesian or SCARA robots have enough DoF.

Safety technology should be compliant to CE regulation so that later the robot cell safety design can also be compliant to CE.

Customer service should also be considered. If IR manufacturer has local office and technical support, then it is better. Customer support will be easier and faster.

Cost is another factor to be considered according to the budget control.

7.4 Workplace Functionality Description

Figure 25 below shows the IR workplace

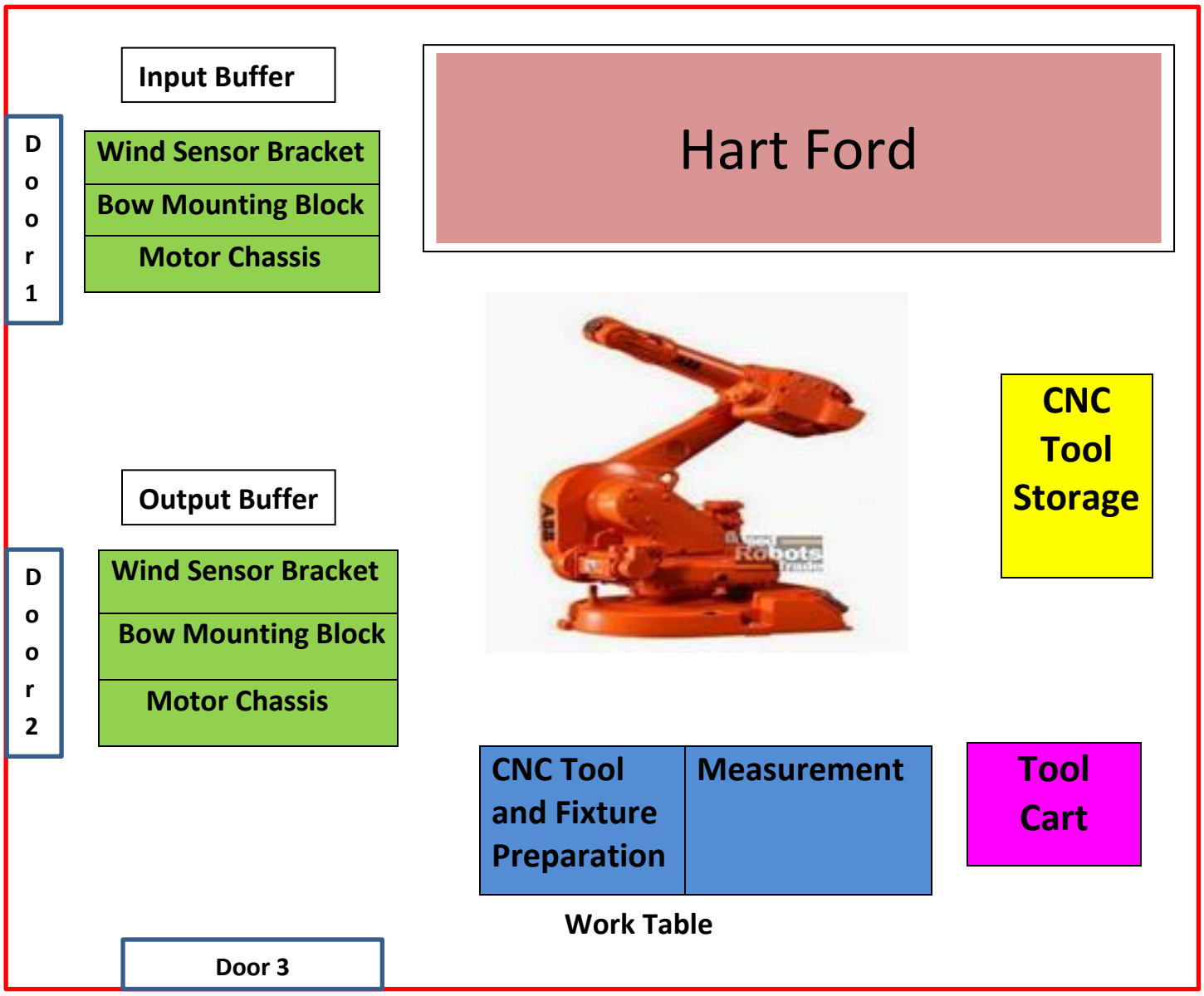


Figure 25 IR workplace

The IR based workplace layout is different with the original layout. The red line is the fence of the robot workplace. Around the workplace there are 3 access doors, one below the output buffer and other two are in front of input buffer and output buffer respectively. For the safety purpose, access door 3 has safety switches and access door 1 and 2 has safety light curtains. The reason is that door 1 and 2 has material flows and door 3 has not. All the cell safety design is according to IEC safety standards (IEC 61508, etc) in general.

The industrial robot is used for the automation of the work place. The robot should be such that it can reach to input buffer, output buffer and CNC machine (Hartford). It will pick the unfurnished part from Input buffer, fix it in the machine and after part is machined, it will take it back from CNC machine and keep the machined part into the output buffer. The workplace is covered with the fences so that no one can move inside when the robot is working.

7.5 Gripper Selection and Description:

The selection of the gripper is based on the task. Grippers can grasp work pieces, center and orientated them. It should include sensors to indicate, if a part is present or not. On the whole a gripper should be as lightweight as possible, for the maximum payload of a machine includes the weight of a work piece. Work-pieces should be held as close to the axis of grip as possible, so as to avoid high moments on the gripper.

Figure 26 IR End effector/Gripper [18]

The above shown figure 26 shows three finger grippers which is adequate end effector for performing task of taking parts from input buffer and put them into machine and then takes them out and keep them into output buffer.

7.6 Production Chart for Robot Cell:

Below figure 27 shows the work flow using IR robot.

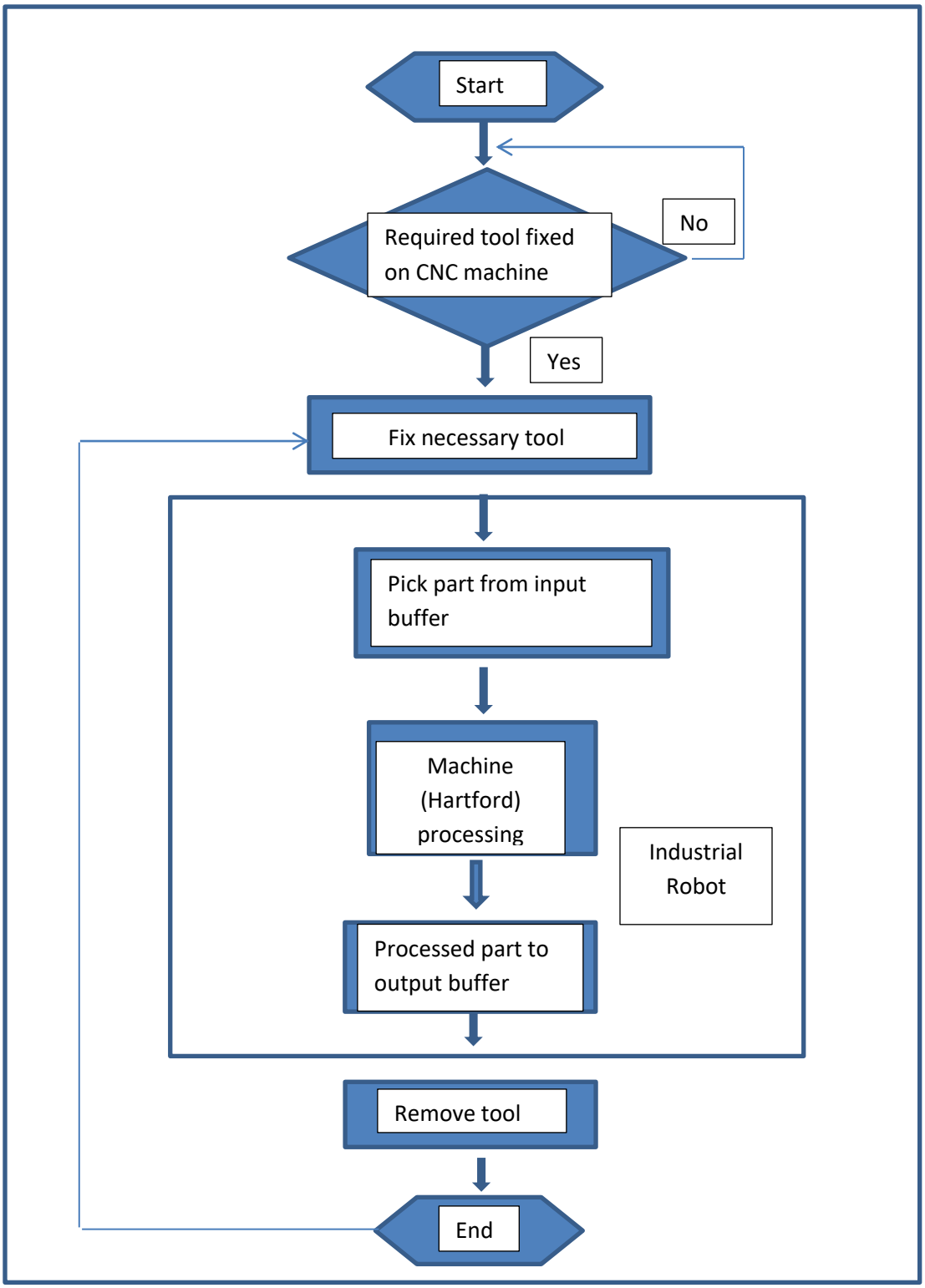


Figure 27 Production chart

7.7 Integration of IR to Manufacturing System:

The integration of the robot is divided into 3 parts i. e. mechanical, electronic and software. Each part of this robot is essential as it plays major role in building suitable robot to perform the pick and place operation. Mechanical part is the structure of the robot meanwhile electronic part acts as the interface or connection between PIC and equipment for the robot to perform its task such as motor or sensor. Programming is the commands or codes that send certain signal to activate specific motor to perform pick and place operation. Below flow chart shows how mechanical, electronics and software integration works together to complete the operation

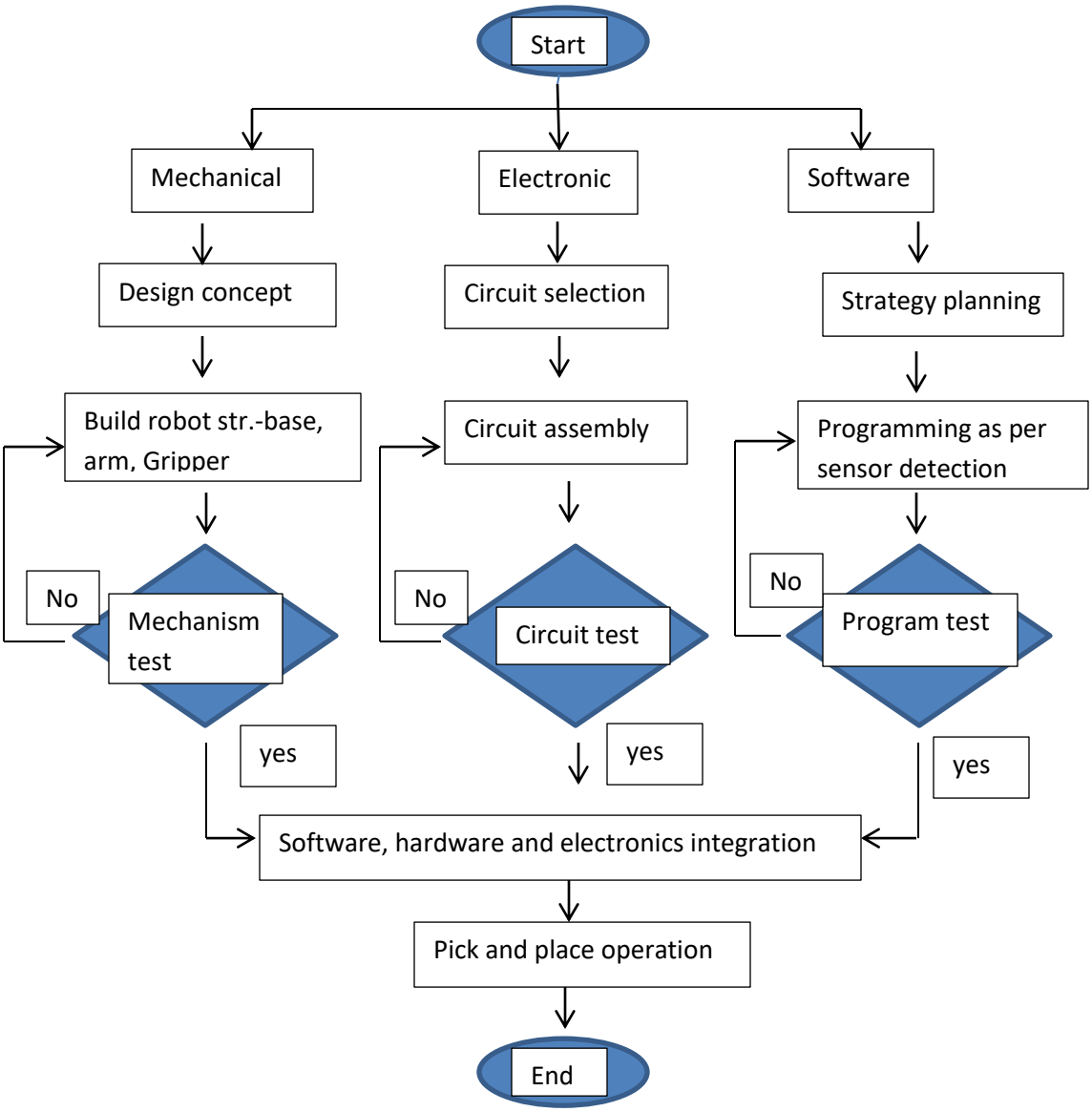


Figure 28 Software, hardware and electronics Integration flow chart

The productivity of the work place will increase and can be controlled remotely using robot. Production control helps technician to identify system errors, that once corrected can lead to process improvement. If implemented properly, production control can improve production turnaround times.

8. DATA ANALYSIS USING OEE KPI:

Key performance Indicators (KPIs) are variables that organizations use to assess, analyze and track manufacturing processes. These performance measurements are commonly used to evaluate success in relation to goals and objectives.

The KPIs selected to describe the work place are OEE. Overall Equipment Effectiveness (OEE) is widely use as the measure of success of TPM implementation. OEE tells us that how effectively a manufacturing operation is utilized. OEE value should be as high as possible to increase the productivity of a plant. [19]

8.1 Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) quantifies how well a manufacturing unit performs relative to its designed capacity, during the periods when it is scheduled to run.

OEE is a metric that multiplies availability by performance and quality to determine resource utilization. OEE values should be high because this indicates more efficient utilization of available personnel and machinery.

OEE = Availability x Performance x Quality

8.2 Production Definitions

To calculate OEE we need to understand few definitions stated below: [20]

Planned Production Time: The total time that equipment is expected to produce any product. Calculated by subtracting schedule loss from all time

Shift Time/Length: The period of time where a shift is scheduled to be running the machine.

Breaks: Unproductive time where the process is scheduled not to run because the crew is scheduled to be away from the line. Breaks are typically excluded from OEE calculations

Unplanned Stops: The manufacturing process is scheduled for production and is not running because of an event like an equipment failure or material shortage etc. It affects OEE availability**.**

Breakdowns: A type of unplanned stop where time is lost due to equipment failure. It affects OEE availability**.**

Planned Stops: The manufacturing process is scheduled for production and is not running because of a planned event such as a changeover, setup, or make ready event. It also affects OEE availability**.**

Stop Time/ Down Time: All time where the manufacturing process was intended to be running but was not due to unplanned stop (e.g. Breakdowns), or planned stops (e.g. Changeovers). It is also called Down Time.

Good Count: Production parts that meet quality standards (without rework). The quantity of good parts is referred to as good count which is used to calculate OEE quality.

Total Count: Total of all produced parts (including defects). The quantity of total parts is referred to as a total count and is used to calculate OEE performance and OEE quality.

Reject Count: Produced parts that do not meet quality standards right first time. It is calculated by subtracting good parts from total parts. Rejects parts are either produced during steady-state production (Process defects), or on startup after a stop event.

Small Stops: A brief pause in production, but not long enough to be tracked as stop time. It contributes to OEE performance.

Slow Cycles: A cycle that took longer than the ideal cycle Time, but less than a small stop. It also contributes to OEE performance**.**

Ideal Run Time: Theoretical maximum production rate. It is inverse of ideal cycle time and used to calculate OEE performance.

Run Time: The manufacturing process is scheduled for production and is running. Run time is calculated by subtracting down time from planned production time. Run time includes time when the process could be experiencing small stops, reduced speed and making reject parts.

OEE Availability: One of three OEE factors. Take into account availability loss (any events that stop planned production for a fixed interval of time). It takes into account all the losses because of the equipment failure and setup and adjustment.

OEE Performance: One of three OEE factors. Take into account performance Loss (factors that cause the process to operate at less than the maximum possible speed, when running. It includes losses because of idling, minor stoppages and speed loss.

OEE Quality: One of three OEE factors. Quality miss-match, in which the components or material used for assembling a part, does not match with the quality requirements.

8.3 OEE Calculations:

In Eksamo, Work center is scheduled to run for 9 hours (540 min) and had only one shift. Cycle time: 70 seconds.

Work center has two small breaks each of 10 minutes and one lunch break of 30 minutes, thereby experiences 50 min of total planned downtime.

Unplanned downtime are breakdown = 10 minutes, Equipment failure & inspection = 60 minutes, and Non- scheduled break = 10 min.

Net Available Time **/** Planned Production Time = Shift Length – Breaks

= 540 min- 50 min =490 min

Net Operating time / Run Time= Planned Production Time – Down Time

= 490 minutes – 80 min =410 min

Good Count = Total Count – Reject Count

= 235parts- 10 parts = 225 parts

a). Availability: The availability portion of the QEE Metric represents the percentage of scheduled time that the operation is available to operate.

It takes into account down time losses that includes any events that stop planned production. [21]

$$\text{Availability} = \frac{\text{Available time}}{\text{Scheduled Prod.time}}$$

$$\text{Availability} = \frac{410\ \text{Avaiable min.}}{490\ \text{Scheduled min.}} = 83.67\ \%\text{.....(1)}$$

b). Performance: The performance portion of the OEE Metric represents the speed at which the work center runs as a percentage of the designed speed.

Ideal operating time (IOT): 245 total parts* 70 seconds = 17150/60= 285.833 minutes

Lost operating Time (LOT): 10 scrap parts * 70 seconds = 700/60 = 11.666 minutes

$$\text{Performance} = \frac{\text{Ideal Operating time}}{\text{Available time}}$$

= (285.833/410)*100= 69.71%

c). Quality: The quality portion of the OEE Metric represents the Good units produced as a percentage of the Total Units started.

$$\text{Quality} = \frac{\text{IOT}-\text{LOT}}{\text{IOT}}$$

$$\text{Quality} = \frac{285.833-11.66}{285.833} \text{*100= 95.91 %.....(3)}$$

Substituting equation 1, 2, 3 in equation (A) we get

OEE = availability x performance x quality

OEE=83.67*69.71*95.91

OEE=55.94%

The OEE value shows how effective the workplace is. The OEE calculated which is 55.94% is not good and can be improved by increasing the good units, actual rate and available minutes, etc.

8.4 Summary of Observation:

Table 8 gives the summary of observation made before and after TPM implementation.

Table 8 summary of observation

Sr.No.	Category	Before Implementation	After Implementation
1	Shift Time	540 min.	540 min
2	Total Production in a shift	245 Nos.	232 Nos.
3	Scheduled Break	50 min	50 min
4	Non- Scheduled Break	10 min	0 min
5	Breakdown	10 min	10 min
6	Equipment Failure & inspection	60 min	30 min

7	Operator Absent	10 min	0 min
8	Non-Conformity Product	10 Nos.	6 Nos.
9	Cycle	70 seconds	70 seconds
10	Theoretical Cycle time	5 min.	5 min
11	Availability	83.67 %	91.83 %
12	Performance Efficiency	69.71 %	66.01 %
13	Quality Rate	95.91 %	97.41 %
14	OEE	55.94 %	59.05 %
15	Utilization	22.71 %	28.10 %

SUMMARY

The aim of this thesis is to study, learn, and to understand TPM methodology and to show how TPM approach can be implemented and what benefits it can bring in the process improvement of manufacturing of a plant. Since TPM is widely known for not easy to implement in a short period of time, so this study is also aim to enhanced my knowledge that what difficulties are being faced for proper TPM implementation and the barriers comes to execute TPM within the organization.

In conclusion I will say, to implement TPM in an organization the entire facility not only a production line workers but also sourcing, sales, logistics, research and development all the department should put their efforts to implement it. If any one of the department will not follow TPM than the entire company will be completely lost on what they are searching for development. The success of TPM totally depends on the nature of company, especially the processes that a company owned and wants to implement TPM on them.

This thesis assessed the maintenance systems at mechanical parts manufacturing company. It identified the gaps in the maintenance system; determine the KPIs to be included in the TPM model for effective maintenance. OEE was calculated before and after implementation of the TPM. The time for analysis of present manufacturing process of machine shop and implementation of TPM in their manufacturing processes was very less. From study it is showed that company want change in terms of improvement but they are not ready to spend resources to achieve it, TPM does not support such a way of working as it requires daily and continuous practice.

Some of the conclusion is derived from implementation of TPM in the machine shop of Eksamo AS.

- Success of TPM depends on pillars like 5S, Jishu Hozen, Planned maintenance, Quality maintenance, Kaizen, Training, Office TPM, and Safety, Health, & Environment. TPM can be used as a tool to enhance OEE.
- Proper implementation of TPM can reduce rework and reduce losses to or below the acceptable levels. It can help the company to increase efficiency and profitability, which will ensure its competitiveness in the current industrial situation.
- Approaches and outcomes for each pillar is discussed and proposed. Some of the examples are made to show how it makes work easier and faster. The success of these approaches is totally depends on the nature of the employees of the plant
- OEE has improved from 55.94% to 59.05%, Showing the improvement in productivity and improvement in quality.
- To improve the productivity of the plant a proposed shop floor layout and proposed workplace area is suggested. The workplace can be automated using industrial robot, which can increase the plant efficiency is also proposed.

- The main factors for TPM implementation are employees involvement and top management support. The company can achieve its goal through the proper implementation of operator initiated daily maintenance consisting of cleaning, adjustment, and regular inspections along with the improvement activities and minor renovation of the equipment's.

Thus it can be concluded that a world class TPM implementation is possible with continual support at all the levels along with necessary resources.

KOKKUVÕTE

Selle lõputöö eesmärk on uurida ja õppida TPM metoodikat, näidata, kuidas TPM lähenemist saab rakendada ning millist kasu võib tuua protsessi parandamine tootmisvõimele. Kuna TPM on laialt tuntud kui raskelt juurutatav meetod, siis see uuring on suunatud ka oma teadmiste tõhustamisele, mõistmaks raskusi, mis tekivad organisatsiooni struktuuri muutmisel.

Kokkuvõtteks ütlen, et TPMi rakendamiseks tuleb kaasata kogu organisatsioon – mitte ainult tootmisliini töötajad, vaid ka allhange, müük, logistika, teadus ja arendustegevus ning ka kõik teised osakonnad. Kui mõni osakond ei järgi TPMi, siis kaotab kogu ettevõte sihi. TPMi edu sõltub täielikult ettevõtte loomust ning ennekõike konkreetsetest protsessidest, kus TPMi soovitakse rakendada.

See töö analüüsis hooldussüsteeme mehaanilisi detaile tootvas ettevõttes. Tehti kindlaks lüngad hooldussüsteemis; avastati, et KPI tuleb lisada TPM mudelisse saavutamaks masinate tõhusat hooldust. Ennem ja pärast TPMi rakendamist arvutati masinate üldine sooritusvõime, masinate tööaja analüüs näitas sooritusvõime tõusu peale TPMi juurutamist. Uuring näitas ka, et TPMiga edu saavutamiseks tuleb tuleb pühendada ressursse, see on protsess mida tuleb käitada igapäevaselt.

Järgnevalt on toodud mõned konkreetsed järeldused TPM rakendamisest Eksamo AS masinatehases:

• Edu sõltub TPMi sammaste rakendamisest nagu 5S, jishu hozen, planeeritud hooldus, kvaliteedijuhtimine, kaizen, koolitus, kontori TPM ning turvalisusest, tervisest ja keskonnast. TPMi saab kasutada vahendina, mis suurendab OEE.

• Korralik TPMi rakendamine võib vähendada praaki ja kadusid allapoole nõutavat taset. See aitab ettevõttel suurendada efektiivsust ja kasumlikkust, mis tagab konkurentsivõime praeguses tööstuse olukorras.

• Töös on välja toodud iga samba lähenemisviis ja tulemus . On toodud näiteid illustreerimaks, kuidas need muudavad töö lihtsamaks ja kiiremaks. Lähenemisviiside edu sõltub täielikult ettevõtte töötajate pühenumisest reeglite täitmisele.

• OEE paranes 55,94% -lt 59,05% - ni, näidates tootlikkuse ja kvaliteedi paranemist.

• Parandamaks tehase tootlikust on esitatud uus töökoja plaan. Lisaks on esitatud tööstuslikul robotkäel põhinev lahendus, mis võimaldab osasid töökohti automatiseerida.

• Peamised tegurid TPMi juurutamisel on töötajate kaasamine ja juhtkonna toetus. Ettevõte saab saavutada edu läbi operaatorite kaasamise igapäevasesse hooldusesse. me.

Seega võib järeldada, et maailmatasemel TPMi rakendamine on võimalik, kui sellele pidev toetus kõigil ettevõtte tasanditel koos vajalikke ressursidega.

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APPENDICES:

Research Questionnaires

The aim of this questionnaire is to collect information for the purpose of understanding Eksamo AS apply TPM approach within their Organization. The interview exercise is intended for all employees within the company. The main objective of the interview is to obtain information that assist in assessing the production-benefit analysis that is involved in TPM implementation in Eksamo As.

Company Name-Eksamo AS

Date-……..

Questionnaire No.-……..

Employee Name –……..

Department-……

Job Title-…….

TPM Methodology

a) What is company's culture?
b) What is your job description?
c) What kind of products company manufacture?
d) How you measure Production Efficiency?
e) What is the volume level of the products of the company?
    1) Low
    2) Medium
    3) High
    4) Other: Please specify
f) Who are your Customers?
    1) Retailers
    2) End Users
    3) Other: Please specify
g) What is your current Lead-time?
h) What are the major drivers of your business?
i) What is TPM?
j) What has motivated the company to implement TPM?

k) Presently how you are implementing TPM?

l) What are the outcomes?

m) Where is TPM implemented in your Organization?

n) What are the criteria for choosing that area?

o) Explain how TPM is practicing in the company?

p) How long it will take to implement TPM in the factory?

   1) 1 week
   2) 1 month
   3) 6 months
   4) 1 year
   5) Other

q) What were the direct and indirect costs involved in the implementation of TPM?

r) How much company spends on TPM?

s) What tangible and intangible benefits has TPM brought to the company?

t) Any Other comments on implementation of Lean?

u) Was the implementation process of TPM should be continuous?