

CHAPTER 2 - LITERATURE REVIEW

2.1 Maintenance Management

Maintenance terminology (EN 13306, 2001) understands maintenance as a process which includes management, administrative and technical activities in order to maintain or restore equipment into the required state. In the introduction requirements on safe and quality maintenance are pointed out. Into account are also taken requirements on control of environmental impacts and costs effectiveness. In some literatures (Pacaiova et al. 2011, Dhillon 2008) states, that maintenance costs are in range from 20% to 35% of production costs. More than 25% of accidents in underground mines happen during maintenance. More than 10% of loss of production time happens due to corrective maintenance, etc.

Maintenance works as an important support function in a business with significant investment in physical asset and plays an important role in achieving organizational goals (Tsang, 2002). The performance of an engineering asset needs to be assessed in order to be managed. To improve the maintenance function, in any context, it is essential that its performance both from external (the impact on customers' business process that is the value generated for the customer) and internal (the work processes in maintenance itself and its integration with in the organization) are assessed. The multiple criteria of performance measurement (PM) like the; hierarchical needs, decision making needs and integration amongst various functional agencies with in the organization are critical to meet the divergent needs of the stakeholders for performance measurement (Parida and Chattopadhyay, 2007). In the UK manufacturing industry, maintenance spending ranges from 12-23 per cent of the total factory operating costs (Cross, 1988). Campbell (1995) reported that the maintenance cost for mining industry is up to 40-50 % of the total operating cost.

Assessment of performance of engineering asset is essential, so that it can be managed properly while using corrective and preventative measures. Industries have developed their own framework/model or have adapted the existing framework to

assess the performance of their engineering asset linking it to the business objectives. Performance indicators (PIs) are used for assessing the performance and indicating the effectiveness of a process. The Maintenance performance indicators (MPIs) are used for comparing the actual conditions with a specific set of reference conditions (requirements/targets) (EEA, 1999).

MPIs are a set of measures used for the measurement of maintenance impact on the process performance for the engineering asset (Wireman, 1998). MPIs are linked to the reduction of down-time, costs and wastes, and the enhancement of capacity utilization, productivity, quality, health and safety (Parida and Chattopadhyay, 2007). A need thus exists to consider the multi-criteria of performance from hierarchical perspective of the organization for its engineering asset while developing the MPA framework. The MPA framework needs to be integrated, in a holistic and balanced manner to match the complex structure of engineering asset for the production/process.

Maintenance performance measurement is a complex task involving measurement of multiple inputs and multiple outputs. One way of measuring the performance is to develop performance indicators and implement them with a total involvement of entire organisation. It's more or less similar to implementing Total Productive Maintenance (TPM) [8]. Maintenance performance indicators (MPIs) are used for the measurement of maintenance performance, as performance indicators are an indication of performance [9]. Also, an indicator is a product of several metrics (measure), when used for measurement of maintenance is called a MPI. Maintenance Performance Indicators (MPIs) show the value of the contribution of maintenance process towards the ultimate objective of the company as a whole. The structure of the MPIs needs to be considered from different aspects, like the multi-criterion and hierarchical levels and from total maintenance effectiveness.

Measurement tells us the status of the job carried out and what action to be taken there after, and to indicate where those actions should be targeted. The selection of MPI depends on the way in which the maintenance performance measurement

(MPM) system is designed and developed for application. For example, the MPIs could be used for financial reports, for control of performance of employees and other resources like the costing and appraisal system, for finding competitive position within business organizations like the customer satisfaction and competitor ranking, for health, safety and environmental (HSE) rating for production industry.

and finding internal effectiveness, like the overall equipment effectiveness (OEE) for the manufacturing and process industry. The selection of maintenance performance indicators to follow up the contribution of maintenance is an important but a complex issue. The structure of the performance indicator needs to be considered from different aspects.

Each of these indicators appeals to "backlog" (reserves), which results not only from the so-called: direct maintenance costs but mainly from so-called: induced costs, which result from deficiency of maintenance planning. It is important that maintenance management is aware of not only the principles of system's management, but also the tools and sources for strategy decision and maintenance activities based on analytical approaches and methods, such as:

1. Root Cause Analysis (RCA)
2. Failure Modes and Effects Analysis (FMEA/FMECA Criticality Analysis)
3. Fault Tree Analysis (FTA)
4. Hazard and Operability Analysis (HAZOP)
5. Human Error / Reliability Analysis (HEA/HRA).

Certain methods are indicated as standard analytical methods and are usually accompanied by the criticality analysis, i.e. analysis of critical equipment which criteria correspondent to those areas where management of the company points out steps by its policy or through company goals (sources and responsibility).

In these areas will be used precautions to prevent unwanted - uncontrolled loss (safety, environment, quality, information safety, cost, etc.). are therefore focused on prevention of the failure mode, where failure of equipment has its "critical" impact on desirable results (goals) or at a "tolerable" risk is a maintenance strategy focused on repair in case of failure occurs (Pacaiova et. al 2009).

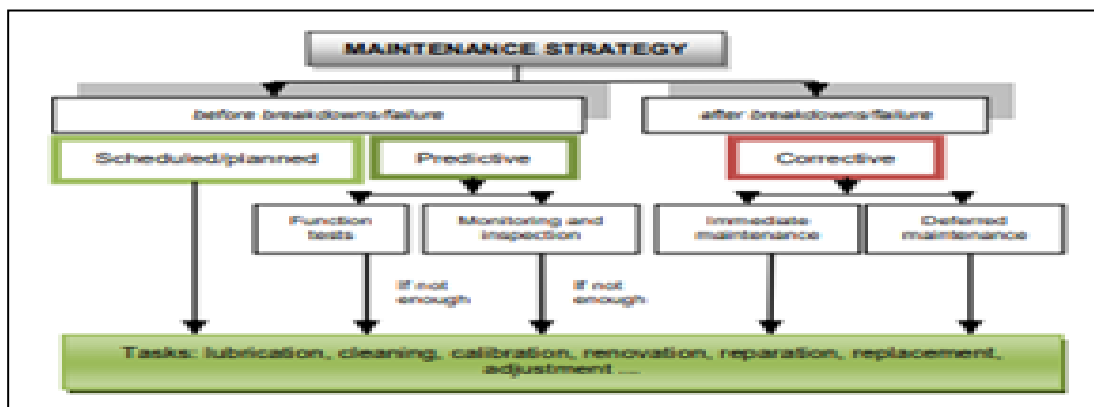


Figure 2.1 Two Basic Maintenance Strategies

We know two basic maintenance strategies as Figure 2.1:

- Preventive Maintenance focused on prevent of failures
- Corrective focused on efficient repair of equipment after the failure occurrence

Preventive strategy in a simplified context may be scheduled "fixed" by time, mileage, cycles, etc., or may be performed when "monitoring state" of equipment would lead to an accident (we call it predictive maintenance strategy). Criteria of choosing the maintenance strategy in the planning phase are specified areas of seriousness losses, as a result of failure – i.e. loss of equipment function, and may be threat of set goals of the company. It is mainly in areas of:

1. Safety of company employees
2. Public safety close to company surroundings
3. Threat of environmental requirements

4. Loss of production quality or delivery delay
5. Loss of company property or foreign ownership
6. The high costs spent on equipment repair in case of failure
7. Losses affecting the region's economy or economy of all society

Nowadays in the maintenance management are well known mainly the following philosophies, which are completely or with minor editing suitable for most industrial companies, as described in Table 2.1:

1. TPM Total Productive Maintenance developed in Japan as a conception of maintenance management including all departments, i.e. from management to manufactory, controlling support of company's maximum productivity based on increase principle of production equipments effectiveness. Author of the TPM conception is Seichi Nakajima, who gradually studied systems for preventive maintenance in 50ties a 60ties years (Preventive Maintenance) in the USA a Europe (Rakyta, 2010).
2. RCM Reliability Centered Maintenance presents systematic approach for identification of effective and preventive equipments and their elements maintenance activities according to specific procedures and proceedings based on intervals defined to perform single maintenance activities. It was developed when maintaining planes of Boeing 747 a 777 type in the USA and in 1960 - 1970 it was officially elaborated as a base for maintenance management mainly in aircraft industry (technical standard SAE JA1011).
3. RBI Risk Based Inspection is an assessment and risk management process, which evaluates loss risk of pressure equipment's content influenced by materials deterioration. This risk is controlled by equipment's inspection. That means that the priorities of maintenance activities are defined according to analyses and risk assessment.

4. RIMAP Risk Based Inspection and Maintenance Procedures is a result of European project (5 framing project EU 1998-2002), which goal was to develop unitized optimal approach to inspection and maintenance activities based on risks assessment in industrial companies).

	RCM	TPM	RBI
USED IN PHASE OF LIFE CYCLE	Design, Operation and maintenance	Operation and Maintenance	Design, Operation and maintenance
MAIN USED IN INDUSTRY	Chemical, petrochemical, gas, nuclear	Automotive, brewing, food, manufacturing	Chemical, petrochemical, gas, nuclear
CRITICALITY FILTER	ABC*	ABC	ABC
OBJECTIVE	Max. reliability and safety	Max. effectiveness and availability	Health, safety and environment
METHODS	FMEA, Ishikawa	OEE*, P-M*	FTA, ETA, social risk assessment

**ABC - equipment categories - A, B, C, OEE - Overall Equipment Effectiveness, P-M - Analysis*

Table 2.1 Effectiveness RCM, TPM, and RBI

2.2 Maintenance Backlog

Maintenance Backlog (MB) is defined as the total number of pending maintenance activities during a certain period, which are awaiting execution, and is expressed as the number of work requests. Can be used for corrective or preventive maintenance (IAEA, 2006). Maintenance Backlog which includes a maintenance scheduling perspective. Scheduled maintenance is also known as preventive maintenance which is carried out according to a predetermined time schedule.

Systematic maintenance scheduling is identified in Reliability Centered Maintenance (RCM) which classifies scheduled maintenance tasks into tasks according to scheduled conditions, scheduled overhaul, scheduled replacement, scheduled testing (Afefy, 2010). MB will occur when there is non-compliance with this maintenance schedule.

Maintenance Backlog is used as a leading KPI, which means that corrective maintenance is not included in the MB. Instead, corrective maintenance will be used as input data when the PLI (Profit Loss Indicator) is calculated (Rødseth, 2017).

A maintenance backlog is a list of maintenance tasks that need to be completed but have not yet been addressed. It is a common term in maintenance management and is used to prioritize, plan, and schedule maintenance activities. The backlog typically includes preventive maintenance tasks, corrective maintenance tasks, inspections, repairs, and other activities related to maintaining equipment, facilities, or systems.

Here are some key aspects related to maintenance backlog:

1. **Task Prioritization:** The maintenance backlog is often prioritized based on factors such as the criticality of the equipment, safety concerns, regulatory requirements, and the potential impact on operations. Critical tasks are usually addressed first to minimize downtime and prevent more significant issues.
2. **Management System:** Organizations often use computerized maintenance management systems (CMMS) or enterprise asset management (EAM) systems to manage and track their maintenance backlog. These systems help organize, prioritize, and schedule maintenance tasks efficiently.
3. **Preventive vs. Corrective Maintenance:** The backlog may include both preventive maintenance tasks (scheduled activities to prevent equipment failure) and corrective maintenance tasks (addressing issues that have already occurred). Preventive maintenance helps reduce the likelihood of breakdowns, while corrective maintenance addresses immediate issues.
4. **Resource Allocation:** The maintenance backlog helps management allocate resources effectively. It assists in planning work schedules, assigning personnel, and ensuring that the necessary materials and tools are available to complete the tasks.

5. **Continuous Improvement:** Regularly reviewing the maintenance backlog allows organizations to identify patterns and trends. This information can be used for continuous improvement initiatives, such as optimizing maintenance processes, updating preventive maintenance plans, or investing in more reliable equipment.
6. **Communication and Transparency:** Clear communication regarding the maintenance backlog is essential. Maintenance teams, as well as other relevant stakeholders, should be aware of the tasks, priorities, and timelines. This transparency helps in effective collaboration and decision-making.
7. **Documentation:** Proper documentation of the maintenance backlog is crucial. This includes details about each task, its priority, estimated time for completion, and any other relevant information. Documentation facilitates accountability and historical tracking.

Efficient management of the maintenance backlog is crucial for organizations to ensure the reliability, availability, and performance of their assets while minimizing downtime and operational disruptions. Regularly updating and addressing the backlog is a key aspect of effective maintenance planning and execution.

2.3 Maintenance Performance Indicator

Maintenance performance indicators (MPI) can be used to evaluate the effectiveness of maintenance that has been carried out (Parida, 2008). Performance indicators are measures that can produce measurable values to indicate performance levels. MPI can be used for financial reports, for monitor customer satisfaction, employee performance, health ratings, overall equipment effectiveness (OEE) and safety and environment (HSE) and more. When developing MPI, it is important to

look at the input and output of the process. If the process runs well, MPI can describe resource allocation and control, personnel performance, maintenance contribution, area, and contribution to maintenance and overall business goals (Kumar U and Ellingsen HP, 2000).

2.3.1 Availability

Availability is the level of ability or availability of a system to operate normally within a specified time period (Rinoza et al., 2021). For work efficiency, it is also necessary to know about the use and availability of mechanical equipment. Because this has work value in question. Some understandings regarding the availability and use of tools are as follows:

Mechanical of Availability is a value that shows the value of mechanical availability, which can be known from the number of repair hours, and from the tools that are being used, the value of mechanical availability can be determined (Silalahi et al., 2018).

Physical Availability is a record of the physical condition of the equipment being used. Physical readiness is generally always greater than mechanical readiness, which can be expressed using the formula (Silalahi et al., 2018):

$$PA = \frac{W + S}{W + R + S} \times 100\%$$

(2.1)

PA : Physical Availability (In Percentage)

W : Number Of Working Hours (Hour)

R : Number Of Repair Hours (Hour)

S : Number Of Hours Unit Was Not Used (Hour)

Mean Time Between Failures is the average time interval for damage that occurs when a machine or component has been repaired until the machine or component experiences damage again (Fatma et al., 2020). Basically, this is a

reliability term used to measure the number of failures per certain time (Syahrudin, 2019).

2.3.2 MTTR (Mean Time to Repair)

Mean Time Between Failures is the average time interval for damage that occurs when a machine or component has been repaired until the machine or component experiences damage again (Fatma et al., 2020). Basically, this is a reliability term used to measure the number of failures per certain time (Syahrudin, 2019).

$$MTBF = \frac{\text{Total Operation Time}}{\text{Frequency Breakdown}} \quad (2.2)$$

2.3.3 MTTR (Mean Time To Repair)

Mean Time To Repair is the average time to carry out repairs required by a component, until the component can be used again normally (Fatma et al., 2020). This also includes the time required to diagnose the fault, the time to get a repair technician on site, and the time to physically repair the system. MTTR is obtained using the following formula (Syahrudin, 2019)

$$MTTR = \frac{\text{Breakdown Time}}{\text{Frequency Breakdown}} \quad (2.3)$$

2.4 Maintanance Planning

Maintenance planning is the process of selecting input information and making output assumptions about future conditions that can be used to develop a trajectory of maintenance activities, overhaul work and repairs. Maintenance planning needs to account for all related factors, for example, time-variant damage, functional requirements, structure type, and maintenance strategy (Wang, 2018).

Maintenance planning is a crucial aspect of asset management that involves the systematic and strategic preparation for maintenance activities to ensure the reliability, availability, and performance of equipment, facilities, or systems. Effective maintenance planning helps organizations optimize resources, minimize downtime, and extend the life of their assets. Here are key steps and considerations in maintenance planning:

1. **Asset Inventory:** Develop a comprehensive inventory of all assets that require maintenance. This includes equipment, machinery, facilities, and other relevant assets. Document key information such as serial numbers, specifications, and historical maintenance records.
2. **Asset Criticality Analysis:** Prioritize assets based on their criticality to operations. Identify assets whose failure could have a significant impact on production, safety, or other key performance indicators. This criticality analysis informs the prioritization of maintenance activities.
3. **Maintenance Strategies:** Define appropriate maintenance strategies for each asset based on factors such as criticality, asset type, and industry best practices. Maintenance strategies may include preventive maintenance (scheduled tasks to prevent failures), corrective maintenance (addressing issues as they arise), predictive maintenance (using condition monitoring to predict failures), and reliability-centered maintenance (RCM).
4. **Work Identification:** Establish processes for identifying maintenance work. This includes recording and analyzing equipment performance, conducting inspections, and addressing feedback from operators and maintenance personnel. Work identification ensures that all necessary maintenance activities are captured.
5. **Work Prioritization:** Prioritize maintenance tasks based on factors such as criticality, safety, regulatory requirements, and resource availability. High-priority tasks should be addressed promptly to minimize the risk of equipment failure and operational disruptions.
6. **Resource Planning:** Allocate resources, including personnel, tools, equipment, and materials, based on the planned maintenance activities. Ensure that the necessary resources are available when needed to carry out maintenance tasks efficiently.
7. **Scheduling:** Develop a maintenance schedule that optimizes the use of resources while minimizing downtime. Coordinate maintenance activities with production schedules to minimize the impact on operations. Consider seasonal factors, production cycles, and other relevant variables.

8. **Documentation and Data Management:** Maintain accurate and up-to-date documentation for each asset, including maintenance history, manuals, and work procedures. Use computerized maintenance management systems (CMMS) or enterprise asset management (EAM) systems to organize and manage maintenance data efficiently.
9. **Training and Skills Development:** Ensure that maintenance personnel have the necessary skills and training to carry out their assigned tasks. Invest in ongoing training programs to keep staff updated on new technologies, equipment, and maintenance best practices.
10. **Performance Monitoring and Continuous Improvement:** Monitor the performance of maintenance activities through key performance indicators (KPIs) such as equipment uptime, mean time between failures (MTBF), and mean time to repair (MTTR). Use this data for continuous improvement initiatives, refining maintenance strategies, and optimizing processes.
11. **Budgeting and Cost Control:** Develop and manage a maintenance budget that aligns with the organization's strategic goals. Monitor and control costs associated with maintenance activities, balancing the need for reliability with financial constraints.

By implementing effective maintenance planning, organizations can enhance the overall efficiency of their operations, extend the lifespan of assets, and reduce the risk of unplanned downtime. It also contributes to a proactive approach to maintenance, shifting from reactive practices to a more strategic and systematic framework.

2.5 Seven Basic Tools of Quality

Graphic-based tools that can help organizations solve problems and improve processes are known as the Seven Basic Tools of Quality. Dr. Kaoru Ishikawa in 1968 introduced seven basic tools, by publishing a book "Gemba no QC Shuho". Which discusses managing and regulating quality, through techniques and practices for Japanese companies. The aim is to be able to implement independently, employee training carried out by superiors or in QC groups in Japan (Neyestani, 2017).

It is very important to apply all the Seven Basic Tools of Quality to solve problems in the production process in the organization. Undoubtedly, all the quality tools mentioned above should be used and considered by management to analyze,

identify and solve quality problems during the production process of products and services. Thus, the production process can be changed and improved by many factors from the Seven Basic Tools of Quality tool. The seven tools are as follows:

2.5.1 Check Sheet

Check Sheet is a simple form with a certain format that helps users to record company data systematically. The main advantage of a Check Sheet is that it is very easy to understand and apply, and can provide a clear picture of the situation and conditions of the organization. Check Sheets are an efficient tool for identifying frequently occurring problems, but do not have the ability to be effective in analyzing quality problems in the workplace (Neyestani, 2017). Check Sheets come in several, three main types such as defect-location Check Sheet, calculation Check Sheet, and defect-cause Check Sheet.

2.5.2 Pareto Problem

The Pareto Problem was introduced by an Italian economist, named Vilfredo Pareto, who worked with distribution and other unequal income. In the 19th century, he saw that 80% of the wealth was owned by only 20% of the population. Continuing with, the Pareto principle was developed by Juran in 1950. Pareto is a special type of histogram that can easily be applied to prioritize and find problems, conditions, or causes of quality in an organization.

On the other hand, Pareto is a type of bar chart that shows the relative importance of variables, prioritized in descending order from left to right of the graph. The goal of Pareto is to determine variations in the type of "nonconformity" from numbers, maintenance data, repair data, remaining spare parts levels, or some other source. Figure 2.1 an example of a Pareto increase in production before and after improvement.

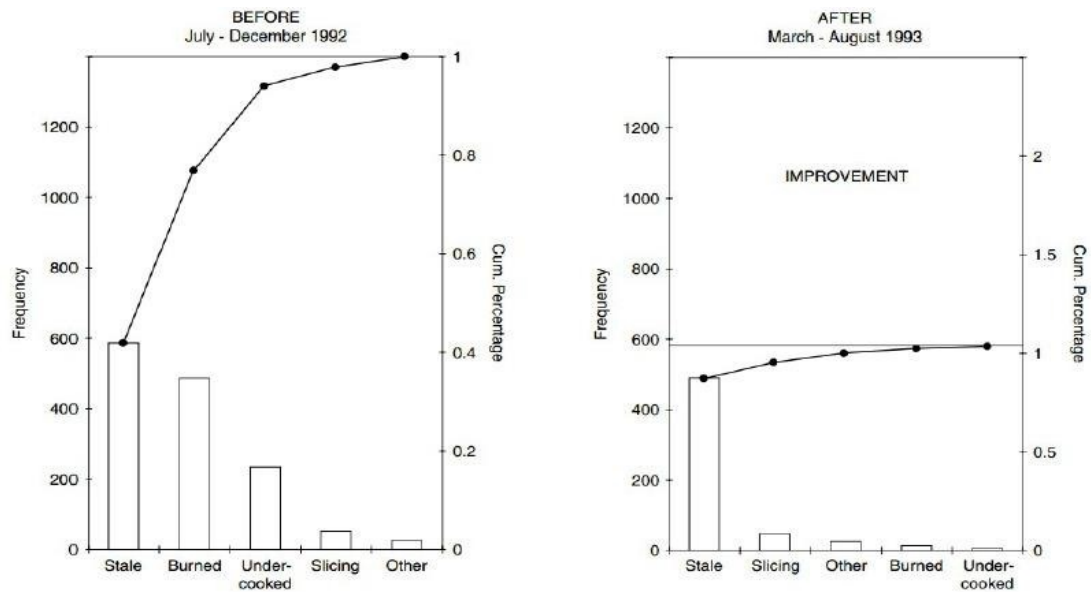


Figure 2.2 Pareto Production Before and After

2.5.3 Cause and Effect Diagram

Kaoru Ishikawa is considered the founder and first promoter of the Cause-Effect Diagram or Fishbone diagram for root cause analysis and the concept of Quality Control Circles (QC). The cause and effect diagram was then developed again by Dr. Kaoru Ishikawa in 1943. This diagram has two other names

Ishikawa and Fishbone diagrams because the shape of the diagram looks like the bones of a fish, to identify quality problems based on similarities in importance (Neyestani, 2017). A cause and effect diagram is a problem solving tool used to systematically investigate and analyze all potential or real causes that produce a single effect. Figure an example of a fishbone diagram. In this diagram you can also see factors to analyze the root of the problem.

Structure of the Ishikawa Diagram:

1. **Problem Statement:** Start by clearly defining the problem or effect that you are trying to analyze. Write this at the head of the fishbone diagram.
2. **Main Categories (Fishbone 'Bones'):** Draw a horizontal line extending from the head, resembling the spine of the fish. On this line, draw several diagonal

lines (the "bones") that represent different categories of factors that could contribute to the problem. Common categories include:

- People
 - Processes
 - Equipment
 - Materials
 - Environment
 - Management
3. **Sub-Causes (Fishbone 'Fins'):** Extend lines from each main category to represent sub-causes or factors within each category. These are the specific elements that could be contributing to the problem.

Steps to Create an Ishikawa Diagram:

1. **Identify the Problem:** Clearly define the problem or effect you are analyzing. This becomes the "head" of the fishbone.
2. **Brainstorm Causes:** With a team, brainstorm all the potential causes of the problem. Encourage open and creative thinking.
3. **Categorize Causes:** Group the identified causes into the main categories (bones of the fish) that you've drawn. This helps organize the factors for a more systematic analysis.
4. **Identify Sub-Causes:** Break down each main category into sub-causes or specific factors. This provides a more detailed understanding of the potential root causes.
5. **Analyze Relationships:** Explore the relationships between different causes and how they may interact to contribute to the problem. This can help prioritize which factors to address.
6. **Prioritize Causes:** Once you have a comprehensive list of potential causes, prioritize them based on their significance and impact on the problem.

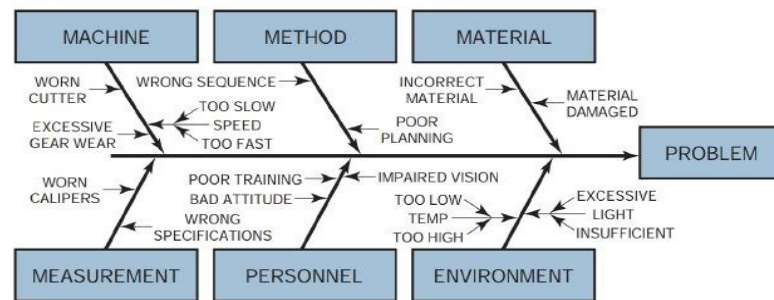


Figure 2.3 Fishbond Diagram

2.5.4 Histogram Tool

A histogram is a tool that can be useful for describing the process of observed distribution frequency values of a variable. A histogram is a type of bar chart that can visualize attribute and variable data for a product or process, and can also help users show the distribution of data and the number of variations in a process. Histograms can be applied to identify distributions and fundamentally investigate variables that are still being explored (Neyestani, 2017). Figure 2.4 is an example illustrating a defect frequency histogram in a manufacturing process.

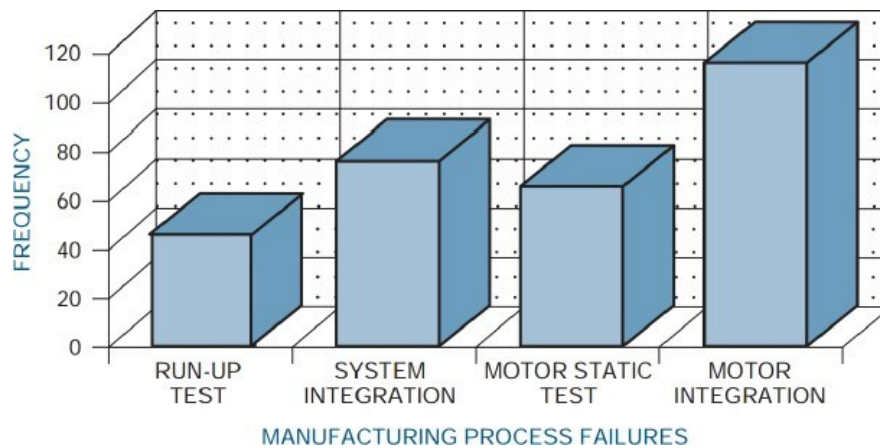


Figure 2.4 Histogram Tool

2.5.5 Control Chart

The Control Chart or Shewhart control chart was developed and introduced by Walter A. Shewhart at Bell Telephone Laboratories in the 1920s, and is the most "technically sophisticated" for quality management. A control chart is a special form

of "run chart that depicts quantities and variations in the form of processes from time to time" (Neyestani, 2017). Also, can draw and describe what has happened in the process.

Therefore, it is very important to apply control charts, because they can monitor and observe processes to study processes that are in "statistical control" according to sampling between UCL and LCL (upper control limit (UCL) and lower control limit (LCL)). Figure 2.5 is an example of a control chart, it depicts changes over time but does not show the cause of the deviation.

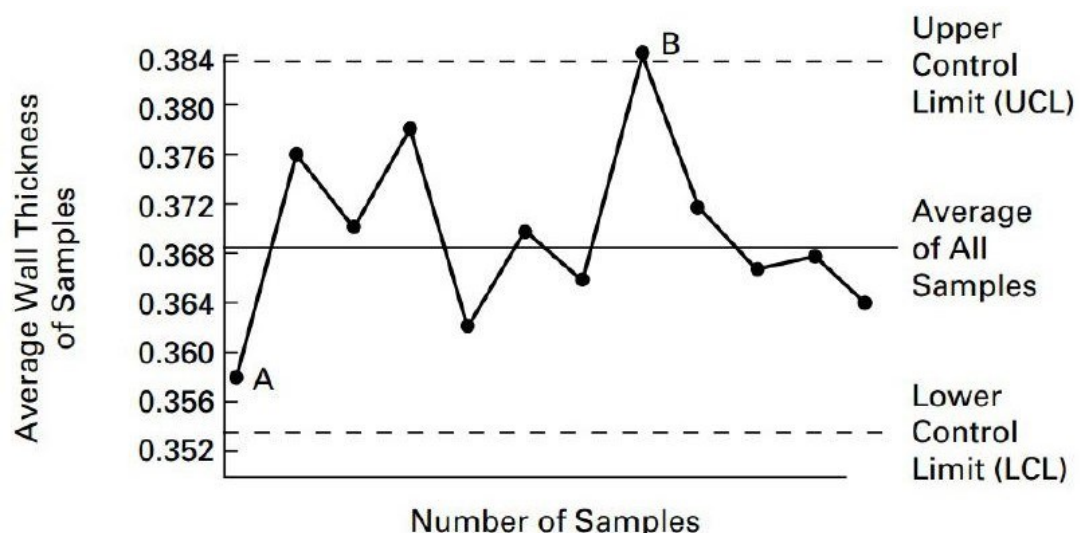


Figure 2.5 Example of control charts

2.5.6 Scatter Diagram

Scatter diagram is a tool used to draw distribution information in two dimensions, which helps to detect and analyze relationship patterns of quality and compliance variables (as independent and dependent variables), as well as understanding if there is a relationship between the two, what the relationship is like (strong or weak and negative or positive). The shape of a scatter diagram often shows the direction of the relationship and degree between two variables, and this correlation can be used to reveal the cause of a problem (Neyestani, 2017). Figure 2.6 shows that there is one of the following correlations between two variables: the left shows

positive correlation; the middle one shows negative correlation, and the rightmost one shows no correlation.

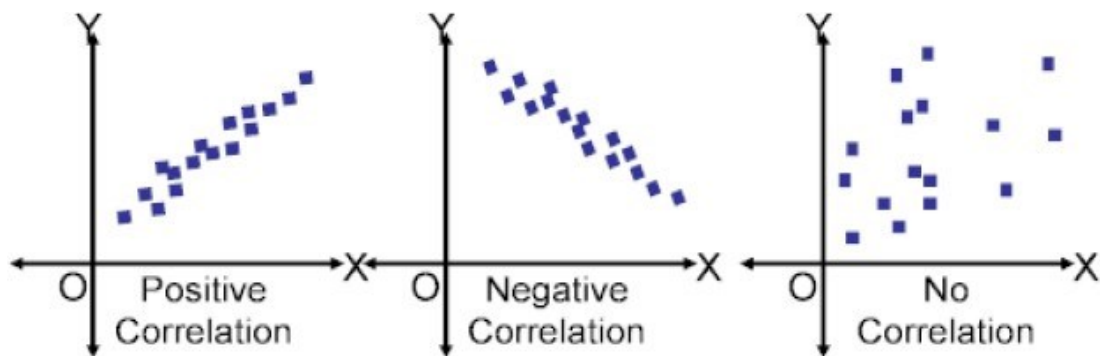


Figure 2.6 Example of Scatter Diagram

2.5.7 Flow Charts

Flow Charts present diagrams that will show a series of symbols to describe several sequences of steps in a process or operation. On the other hand, Flow Charts visualize multiple images including inputs, activities, decision points, and output results for easy understanding and use of the overall goal of the process. This chart as a problem solving tool can be used methodically to analyze and detect areas or process points that may have potential problems by explaining and documenting operations, so it is very useful for improving and finding quality into the process as shown in Figure 2.7.

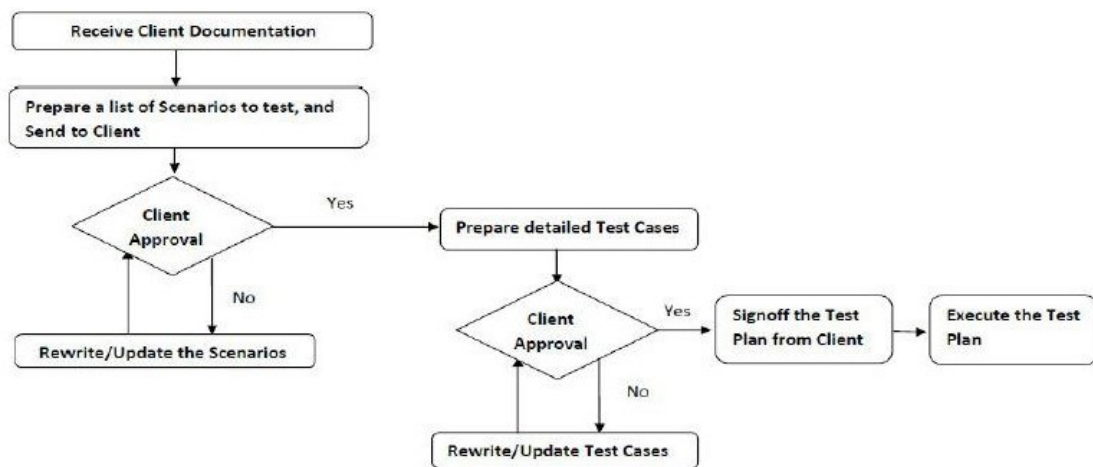


Figure 2.7 Example of Flow Charts

2.6 Six Steps of Kaizen

Kaizen is a Japanese philosophy which means continuous improvement. The improvement in question is by using common sense and well, using statistical quality control, scientific methods and an adaptive framework that contains organizational values and beliefs that make workers and management focus on zero defects (Thessaloniki, 2006). Kaizen is also defined as a philosophy that involves all employees and defines management's role in continuously encouraging the implementation of small adjustments that make processes more efficient, effective, manageable and adaptable (Abdulmouti, 2018). The six steps to implementing Kaizen are:

1. Determine potential improvements.
2. Analyze the methods currently used.
3. Spark original ideas.
4. Develop an implementation plan.
5. Implement the plan.
6. Evaluate new methods

2.7 W1H (What, Why, When, Who, Where, How)

5W1H is a method that contains several questions aimed at gathering information or as a means of solving problems (Griffin, 1949). Details of 5W1H can be seen in Table 2.2.

5W1H	Deskripsi	Tindakan
<i>What</i> (apa)?	What are the main targets for improving or improving quality?	Formulation of targets according to needs
<i>Why</i> (mengapa)?	Why do you have to do this action or activity?	
<i>Where</i> (dimana)?	Where is this action carried out?	Adjustment of activities so that they can be carried out together
<i>When</i> (kapan)?	When is the time to carry out this action?	
<i>Who</i> (siapa)?	Who will carry out the action?	
<i>How</i> (bagaimana)?	How to implement the action?	Implementation of existing activities

Table 2.2 Detail 5W1H

2.8 Root Cause Analysis

The root cause analysis method can be one of the alternatives to strengthen PBL in overcoming the weaknesses of PBL. Root cause analysis is a way to find the underlying cause. The investigation should be able to identify specific underlying causes. The more specific causes can be investigated, the better the disaster prevention recommendations. Specific causes can make effective changes. Knowing the exact cause of failure before action is taken can prevent the recurrence of the failure or error (Rooney et al., 2004). Root cause analysis was originally a problem-solving technique used in quality management and is a powerful tool to pinpoint obstacles for improvement (Andersen & Fagerhaug, 2006; Wilson et al., 1993). It is usually used in a reactive mode to determine the causes of problems that have already occurred.

Root cause analysis using 5 Whys, Pareto, and fishbone diagrams can be performed. These techniques help users to identify the root causes that need to be addressed to solve 80% of the problems. Once the root causes are identified, tools such as the Ishikawa diagram or fishbone diagram can be used to illustrate the root

causes of the problem. Then efforts can be made to remove the main bottlenecks to develop a more sustainable process (Jayswal et al., 2011). RCA can quickly identify the side effects of problems so that management or groups can design individual evaluations and develop evidence-based evaluation tools to measure improvements in work effectiveness (Taitz et al., 2010).

2.8.1 Problem-based Learning with Root Cause Analysis

This research uses the PBL learning model combined with RCA. PBL is a coaching method that "simultaneously develops complexity-fixing techniques, disciplinary understanding, and skills by placing students in active positions as problem solvers faced with dependent problems that reflect actual-global situations" (Barrett, 2006). PBL is used based on its success in solving problems for medical students.

This model makes students understand how to think critically, solve problems, and gain essential knowledge and concepts from lectures or subject matter. At the same time, RCA, according to the American Society for Quality (2020) defines "A more thorough approach to problem-solving and continual improvement both require root cause analysis. Therefore, one of the key tenets of an organization's continuous improvement initiatives is root cause analysis. It's critical to keep in mind that root cause analysis by itself won't lead to quality improvement; instead, it needs to be included in a larger effort to address issues".

RCA does planning and extracting from problems to their causes. Pham et al., (2010) state that Root cause analysis (RCA) is a process used to investigate adverse effects. Combining PBL with RCA will strengthen the advantage of PBL in deeper data mining. PBLRCA is necessary for investigating and discovering pressing problems, understanding the main causes of the situation, and treating the problem correctly and appropriately through the deep-digging steps of RCA to prevent the same problem from arising again. Such data mining in the RCA stage is also likely to develop the investigator's knowledge. Meanwhile, the work effectiveness measured in

the RCA can also improve one of the literacy indicators: skills. As a result, it can include identification and procedures, process management, activities, activities, conditions, or behaviors (Figgins, 2012).

2.8.2 Several Types and Methode for Root Cause Analysis

There are several methodologies and techniques for conducting Root Cause Analysis (RCA), each with its own approach and tools. Here are some of the commonly used types of Root Cause Analysis:

1. **5 Whys:** This is a simple but powerful technique where the analyst asks "why" repeatedly (usually five times) to drill down to the root cause of a problem. The idea is to identify the underlying issues that contribute to the observed symptoms.
2. **Fishbone Diagram (Ishikawa or Cause-and-Effect Diagram):** This graphical representation helps visualize the various potential causes of a problem. The main categories, such as people, processes, equipment, materials, and environment, are depicted as fishbone "bones," and potential causes are listed under each category.
3. **Failure Mode and Effect Analysis (FMEA):** FMEA is a systematic method for evaluating processes to identify where and how they might fail and assessing the relative impact of different failures. It helps prioritize areas for improvement based on the likelihood and severity of potential failures.
4. **Fault Tree Analysis (FTA):** FTA is a top-down deductive approach that explores the possible causes of a specific system failure. It uses a graphical representation of the logical relationships between different events and conditions that could lead to the failure.
5. **Barrier Analysis:** This approach focuses on identifying the barriers that should prevent an undesired event from occurring. It involves analyzing the layers of defense in a system and evaluating their effectiveness.
6. **Change Analysis:** Change analysis looks at the changes in a system or process to identify potential causes of a problem. It assesses whether recent modifications or alterations contributed to the observed issue.
7. **Event and Causal Factor Charting (ECFC):** ECFC is a method that involves creating a chronological chart of events leading up to an incident or problem. It helps identify the sequence of events and the factors that influenced each step.
8. **Bowtie Analysis:** Bowtie Analysis combines elements of FTA and barrier analysis. It visually represents the relationship between a potential event and

its causes and consequences, along with the preventive and mitigative barriers in place.

9. **Root Cause Mapping:** Root Cause Mapping involves visually mapping out the relationships between different causes and their effects. It provides a comprehensive view of the factors contributing to a problem.
10. **Apollo Root Cause Analysis (ARCA):** This methodology is used in the aerospace industry and is similar to the 5 Whys. It involves asking a series of questions to identify the causes of an issue and determine corrective actions.

The choice of a specific Root Cause Analysis method depends on the nature of the problem, the complexity of the system, and the preferences of the organization conducting the analysis. Often, a combination of techniques may be used for a more thorough investigation.