A TOPSIS-BASED METHODOLOGY FOR PRIORITIZING MAINTAINANCE ACTIVITIES: A CASE STUDY OF CHANCHAGA MUNICIPAL WATER WORKS

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A THESIS SUBMITTED TO POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN DEPARTMENT OF MECHANICAL ENGINEERING

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ABSTRACT

Maintenance is performed on industrial plants to ensure that they continue to function up to the designed capacity. In most instances, scheduled maintenances are hardly fully implemented owing to budget fluctuations/constraints. Budget shortage has negative impact on maintenance strategies and results in the undesirable deterioration of production plant's components and increased risk of accidents and downtimes. In most traditional maintenance practices, the choice of "which maintenance location that should be addressed urgently and which to delay" is left to the subjective discretion of the maintenance manager. One of the dangers of such discretional judgment in maintenance is that the risk of delayed maintenance is different for different components even for the same plant. The Thesis developed and implemented a methodology to minimize the impact of budget fluctuation by quantifying the risks associated with failure of components of a municipal water works plants as a basis for prioritizing the maintenance activities. TOPSIS algorithm uses a value system to estimate the risks related to failure and repair of the various components of the plant under various criteria and to integrate the scores to arrive at a prioritization metric as an alternative to risk priority number of the traditional failure mode and effect analysis (FMEA). The framework is implemented on a real case study of municipal water works and the conclusions proved well for wider applications in varied and allied industrial settings. From the results obtained, the pipeline component (herein coded as alternative A2) has relative closeness coefficient of 0.79592 which shows its highest maintenance priority. This is attributed to age of the pipes, high pressure in the system during the period of low water consumption, environmental and soil condition. Therefore, this component requires urgent attention for maintenance. The alternative A1 (the pumping machine) has relative closeness coefficient of 0.56815 which shows it is less criticality when compare with the components like valve, reservoir, pipe and power source. Therefore, the maintenance can be delayed on this component.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

A sufficient supply of water is necessary for life and civilisation to exist. Air, water, food, shelter, light, and heat are the six basic human requirements. The other five factors all have something in common with water. This is due to the fact that it makes up a significant component of all living organisms, including humans. Water is, in fact, vital to human survival. About 80 % of animal cells are made up of water. Water makes up around 70 % of the human body's weight, and various biological functions rely on it. (United Nations report, 2006). The problem of portable water supply in Minna metropolis has posed a number of challenges, with the task of collecting water falling primarily on women and children, and their journey to collect water is long, exhausting, and often dangerous, preventing millions of mothers from working and lifting their families out of poverty. It keeps millions of children out of school and out of play, robbing them of the health and education they need to grow into healthy adults (Feynman, 2001).

According to a United Nations report from 2012, 783 million people, or 11 % of the world's population, still lack access to a better source of portable water. Water is essential to our way of life, regardless matter where a place is on the socioeconomic scale. The fundamental paradox of water supply in developing countries is that, while everyone has access to water, the majority of people do not. Water is necessary for life, and all human groups require access to some form of water. It may be filthy, insufficient in volume, and several hours away, but some water must be provided. However, if a realistic criterion of adequacy in terms of quantity, quality, and availability of water is used, the majority of people in underdeveloped countries will not have enough (Cairncross and Feachem, 1988).

TOPSIS means the Technique for order of preference by similarity to ideal solution. This is one of the multiple – criteria decision making technique that deals with the selection of the best alternative usually have the closest distance to the ideal solution and farthest distance from the negative ideal solution. TOPSIS allows for trade-offs between criteria, allowing a bad result in one criterion to be offset by a good result in another. This results in a more realistic model than non-compensatory techniques. The TOPSIS method is often used to tackle decision-making difficulties. This method is based on a comparison of all the possible solutions to the problem. This technique is particularly beneficial for large-scale decision-making challenges such as water quality evaluation, disaster risk assessment, environmental risk assessment, real estate management, and sustainability assessment and supplier selection. TOPSIS also provides the following benefits: simplicity, rationality, high computational efficiency, and the ability to quantify relative performance for each choice in a simple mathematical form, as well as a strong ability to combine other approaches.

The integrity of the distribution system is even more important in delivering a safe and reliable supply of drinking water to consumers' taps. Pipe networks, often cover extensive areas and include various connections and points of access, make up the majority of water utility assets. Water system management is critical for guaranteeing the long-term viability of a given water resource, assuring high-quality water supplies, and enhancing the utility's ability to respond to extreme operating conditions (Punmia *et al.*, 2001). Water production firms must make smart selections in order to survive in the current market. Improper decisions increase the costs of businesses in terms of resource waste and have an impact on customer satisfaction. Modern water production firms are currently confronted with a number of significant issues, including financial deficits as a result of the modern economy, time consumption, and a lack of sophisticated knowledge and experience. The complexity of evaluating components has prompted the researcher to create a model to assist decision makers and maintenance managers. The specific goal of this study model is to assist decision makers in dealing with the challenges that arise from component criticality maintenance. The company's strategy decision is to be implemented efficiently in order to boost water production capacity and overall safety. The choice of the most important component among the available options is a significant one. As component selection decisions are critical to a company's quality success or failure.

The decision maker must examine significant criteria and have unique understanding of the component properties in order to determine the most critical component among the different choices. However, those parameters should be taken into account in order to enhance water production capacity. The component will be thoroughly identified, as well as the criteria that together represent the production aim. These components will be analyse base on thesecriteria. Criticality is based on how the components perform under the criteria and the most critical component would be a choice of immediate maintenance. The evaluation criteria for determining component criticality decision were chosen through studies and interactions with firm workers in various departments for this study. Different methods have been widely used in the literature to assess component criticality: Some of these methods are the Simple Additive Weighting Method (SAW), the Simple Multi-Attribute Rating Technique (SMART), the Elimination and Choice Translation Reality (ELECTRE), and the Analytical Hierarchy Process (AHP). The company's plant layout is shown below.

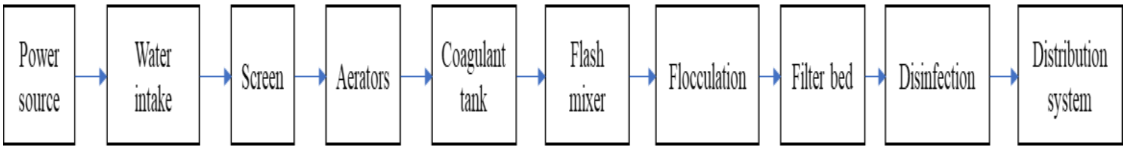


Figure 1-1: A generic layout of municipal water works (Municipal Water Works, Minna).

Power source means the process of generating power to the company. Source means the process of collecting the water together at a particular place before any other process take place. Water intake means the process transferring water to the water treatment chamber for the treatment process. Screen chamber prevent large or heavier object from entering the water system process. Aerator is a chamber where the taste and odour are removed (dissolve iron and manganese) by means of spraying water in to air through stacks of perforated trays. Coagulant tank is a chamber where chemicals are added to water. Flash mixer is a chamber or tank where pump impeller uses to mix coagulant with water for further processes. Flocculation is the process of bringing no settling particles to large, heavier masses solids objects. Filter bed is a chamber where the no settling particles or impurities that did not removed during coagulation and flocculation process is removed. Disinfection is a process where the bacteria and water borne dieses should be removing and the water will be ready for drinking after this process.

In this study, a prototype framework based on the TOPSIS approach was used to assess component criticality in order to predict water production capacity.

The frame work of the TOPSIS Algorithm method is given below

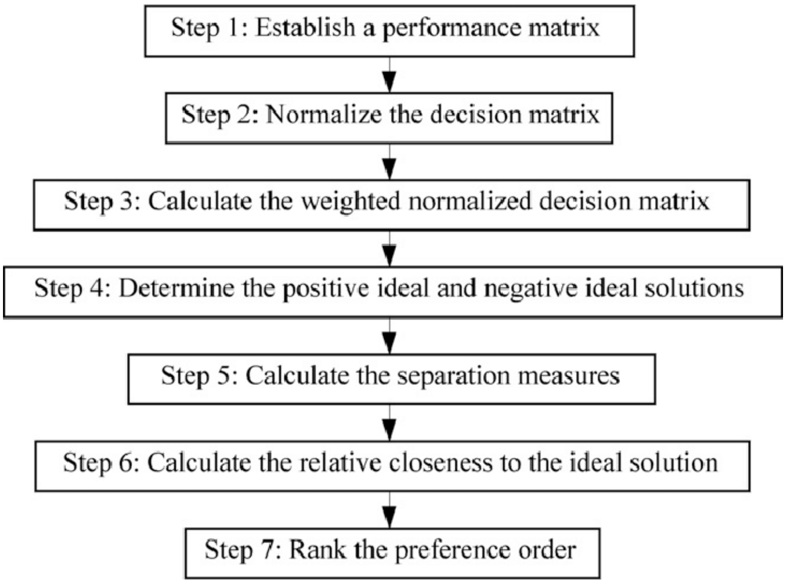


Figure 1-2: **TOPSIS framework of the research work (Hwang and Yoon, 1981)**

1.2 Statement of the Research Problem

Municipal water works (and other Manufacturing industries) regularly are confronted by the challenge of budget deficits orchestrated by business uncertainties and are looking for a way to cut on the production cost. The key players in such scenarios are the Maintenance engineers who are often required to make the most of what is available to drive optimum productivity. This often requires that a choice be made of "which maintenance location to address urgently and which to be delayed." Sadly, such decision is often left to the subjective opinion of the maintenance personnel which is not only discretional, but also lacking in repeatability and is unsustainable.

1.3 Justification for the Study

Most national Governments in sub–Saharan Africa (like Nigeria) has been battling with inadequate supply of pure water to her teaming populations. From the technical point of view, the expertise required for the management of the sophisticated working required of a water work is lacking amongst most of the local employees. This has challenged effective management of water works facilities and rise in waterborne diseases in most affected areas. This study develops and demonstrate a framework suitable for management of water works plants in a manner that saves cost and improves productivity. Maintenance and production manager of industrial plants stands to gain a lot from this project as it provides them with useful resources to aid maintenance decisions bothering choice of location and resources allocation.

1.4 Scope of the Research Work

The water supply system involves complex networks of infrastructural components used for water intake, treatment and distribution. This study only covered the identification of and prioritisation of components involved in intake and distribution.

1.5 Aim and Objectives of the Study

The aim of this study is to develop a decision aid based on TOPSIS algorithm to support prioritizing of maintenance activities. The aim will be achieved through the following specifics objectives;

i. The identification and functional analysis of major components of the municipal water works.
ii. Determination of preference criteria for major components evaluation.
iii. Development of prioritization model based on TOPSIS
iv. Component’s prioritization.

CHAPTER TWO

2.0 LITERATURE REVIEW

The overall perspective on the general population towards support is one of exquisite straightforwardness. Their contact is frequently restricted to car or apparatus fix studios. From this experience, upkeep gives off an impression of being an unavoidable movement that costs cash and requires some investment. The view held in the board rooms of industry seems to coordinate with this discernment. Uplifting news is for the most part not news by any stretch of the imagination, so individuals possibly will more often than not consider upkeep when things turn out badly.

The second there is a significant security or natural occurrence, the media wake up with information on the support reductions, genuine or fanciful, that has supposedly added to the episode (Jahanshahloo et al., 2006 a). Consider what you saw on TV or read in the papers after any of the aircraft, ship or modern calamities, and you will promptly perceive this image. What do we really do when we deal with a business? In our view, we deal with the danger of wellbeing and ecological occurrences, antagonistic exposure, loss of effectiveness or usefulness, and loss of piece of the pie. It is an outright need for a business endeavour to create the benefit needed to cover its future dangers, to empower it to remain in business and to keep up with unblemished its abundance delivering limit.

This is as legitimate today as it was then, at that point. In the upkeep the board setting, the dangers that are of worry to us identify with wellbeing or ecological occurrences, unfriendly exposure, and of loss of benefit or resource esteem. In this exploration, the job of support in limiting these dangers will be thought of. The level and sort of dangers change over the existence of the business. Some danger decreases strategies work better compared to other people. The administrator should know which ones to use, as the expense viability of the procedure’s contrasts. Here, a portion of the danger decrease instruments and strategies accessible to the maintainer will be inspected, and their materialness and viability will be examined. Dangers can be quantitative or subjective. Generally, an answer can be fined when managing evaluated hazards, which identify with the likelihood and result of occasions. Subjective dangers are very perplexing and harder to determine, as they manage human insights. These identify with people groups' feelings and sentiments and are hard to foresee or once in a while even comprehend (Jahanshahloo et al., 2006b). Dynamic requires hazards should be assessed and the two viewpoints are significant. The general significance of the subjective and quantitative parts of hazard changes from one case to another and individual to individual. Indeed, even a similar individual might utilize distinctive technique each time. It isn't ideal to classify individuals or organizations as hazard chasing or hazard opposed. It isn't only an outlook; the circumstance they face decides their disposition to chance. This large number of variables makes the investigation of hazard both fascinating and testing (Narayan et al., 2007).

In most cases, goods and services are usually needed for our existence and comfort, therefore, the focus of our efforts is to change raw materials into products that are more useful. For example, furniture from wood or process data to obtain useful information is the best examples of the process. By doing so, value is added to the raw materials, thereby creating products that others need. Value can also be added without any physical material being used. Thus, when a nurse takes a patient’s temperature, this information helps in the diagnosis of the illness, or in monitoring the line of treatment. What do we actually achieve when we carry out maintenance? Capital investments create production capacity. This capacity will decrease with use and time, unless we take the right actions which we call maintenance. Equipment deteriorates with time for a variety of reasons. It can become internally contaminated by particles or residues from the manufacturing process or from construction materials. When utilized, it may deteriorate owing to wear, corrosion, erosion, fatigue, or creep. These mechanisms will lead to component and equipment failure, resulting in equipment unavailability, and maintenance costs at large. Since unavailability can affect safety or production, so there is need to keep that as low as economically possible. Planned downtime has lower consequences than unplanned downtime, so there is a way to minimize it. What do we mean by the term maintenance? The British Standard BS 4778-3.1:1991 defines it as "…actions intended to retain an item in, or restore it to, a state in which it can perform its intended functions." In simple terms, equipment is needed to do something for us, i.e., to have a function.

To retain that function over its life, maintenance needs to be carried out. Instead of relying on sound engineering concepts and other controls, workers and managers can increasingly rely on how things were done previously. People can lose sight of their fear." Maintenance is central to process plant performance, as it affects both profitability and safety. How well it done depends on our ability to answer the questions, what work to do, when to do it, and the process steps to use. Doing so efficiently means the minimum volume of work will be done at the right time in the right way. When an item of equipment fails prematurely, the additional maintenance costs will be incurred and a loss of production and/or safety. As a result, the utilization of the full capability of the equipment cannot be achieved. This can be avoided with timely and proper maintenance. Increased production and lower expenses are the results of good maintenance. By preventing premature failures, maintenance extends the life of the plant (Narayan et al., 2007).

2.1 Maintenance at the Activity Level (an explanation of terminology)

2.1.1 Types of maintenance

Terminology and rationale for use when the consequences of a service failure are minor the maintenance manager can afford to restore the item after it has failed. On-failure or breakdown maintenance is the name for this method. Unfortunately, many failures have unacceptably severe consequences; therefore, a breakdown approach cannot always be used. It is possible to forecast the time of failure if deterioration can be measured and the period of incipiency can be noted. In this situation, the work can be scheduled to cause the least amount of disruption to production. This capacity to schedule tasks allows for a rapid and effective turnaround time. On-condition (or condition-based) maintenance is an approach for detecting and correcting deteriorating conditions before they lead to functional breakdown.

If there are any concealed faults, the equipment must be tested on a regular basis. This will reveal whether or not it is in functioning order. Failure-finding or detective tasks are carried out after the exam is completed. If an object is found to be in a failed state, it can be repaired by performing breakdown maintenance. Even if the item is still in working order, it may need to be repaired or replaced on a regular basis under specific circumstances. Testing for hidden problems; condition monitoring of incipient breakdowns; and pre-emptive repair or replacement action based on time are all examples of planned maintenance (running hours, number of starts, number of cycles in operation, or other equivalents of time). The following is a list of maintenance jargon:

Breakdown maintenance: Repairs are carried out only after the equipment has failed to function, therefore they cannot be planned ahead of time. On-failure maintenance is another term for it.

Corrective maintenance: Repair is carried out after the breakdown has begun, resulting in a reduction in performance. Such degradation is usually discovered by condition monitoring or inspections. The actual repair may be performed before or after functional failure, depending on the severity of the failure, but the important difference from breakdown maintenance is that the functional failure is visible before it occurs, allowing for the scheduling of the repair.

Scheduled overhaul replacement (hard-time maintenance*)*: Repairs are made dependent on the age of the vehicle (calendar time, number of cycles, and number of starts or similar measures of age as appropriate). When the age at failure is predictable, i.e. when the failure distribution curve is peaky, this technique can be used. Such distributions are common in fouling, corrosion, fatigue, and wear-related failures.

On-condition (or Condition-Based) maintenance; Inspections or condition-monitoring operations, which are themselves scheduled on calendar time to detect if breakdowns have already begun, provide the basis for repair. On-stream inspections and vibration monitoring are two examples of on-condition duties. With the use of specific instrumentation, continuous monitoring of particular parameters may be possible. The nature of on-condition maintenance is remedial. Testing or failure-finding (detective) tasks aimed at determining whether or not an item can work when called upon. Testing is relevant to concealed failures and non-repairable objects, i.e., if we know an item has failed, it must be removed from service. If the item fails after that, we fix or replace it (Narayan, 1998).

Predictive maintenance: Repairs are dependent on extrapolating from the results of on-condition activities or continuously monitored condition readings to forecast the timing of functional breakdown. It's the same as "on-condition maintenance."

Preventive maintenance: Prior to a functional failure, a duty of repair or inspection is completed. It is carried out based on the age of the equipment and the expected time of breakdown. As a result, even if the equipment is in perfect working order, a pessimistic estimate can be made. Preventive maintenance includes scheduled overhauls or replacements, time-based failure detection, and on-condition operations.

Planned maintenance: is any work that has been thought through in advance. It includes all of the preventive maintenance (Narayan, 1998).

Trips and breakdowns that occurred without one being aware of them are unplanned. When the machine stops by it, the work that will be carry out is reactive maintenance. If it is plan to stop the machine and do work on a predictive or preventive basis, it is call proactive maintenance. If the incipiency period is too small to schedule the work, there is no opportunity to minimize production losses. In this case, one cannot control the timing of the work and the corrective maintenance is reactive. If the work is schedule condition-based corrective maintenance work in a suitable time window to minimize losses, such work is proactive.

There are numerous failure modes that have little or no impact on the overall system or plant. In such circumstances, it is more cost-effective to wait for failures to occur before taking action. After World War II, when mass manufacturing sectors experienced significant growth, preventive maintenance became increasingly popular. Preventive maintenance tactics became fashionable as a matter of policy, even in cases when they were not economically warranted. As a result, even though the equipment was in fine working order, it became 'due' for maintenance. There are times when each of the tactics is suitable, and the decision must be made based on the best strategy to reduce risks. When the risks are low and the repercussions are minor, reactive techniques are appropriate. Proactive tactics are useful when there is a hazard to safety, production, or the environment.

2.2 The Raison d’ etre of Maintenance

Minor faults when left unattained, could escalate into serious incidents. If a serious occurrence, such as an explosion, has occurred, it is critical to minimize the damage. When the escalation and damage limitation models are combined, a composite image of how minor occurrences can lead to substantial environmental harm, fatalities, major property damage, or serious loss of manufacturing capacity emerges. This model is depicted in Figure 2.1 (Narayan, 1998).

Figure 2-1 Risk limitation model (Narayan,1998)

One can now describe the primary role of maintenance as follows:

Maintenance's raison d'être is to reduce the calculated risk of major safety, environmental, negative PR, asset, or production loss accidents that might reduce an organization's viability and profitability in the short and long term, while doing so at the lowest overall cost possible.

This is a positive job that involves keeping the revenue stream going at full capacity, not only detecting and resolving problems. Trips, malfunctions, and predicted failures that harm safety and output must be avoided or minimized. If this happens, additional care must be taken to remedy the situation in order to reduce the severity of safety and production losses. This contributes to the plant's safety and profitability. Maintaining the plant's integrity throughout time ensures that safety and environmental problems are kept to a minimum. A company's good safety and environmental performance boosts employee morale and reduces negative publicity. It also improves the organization's reputation and helps it keep its license to operate. This ensures the plant's long-term survival. Maintenance will minimize quantitative hazards, but it may also reduce qualitative risks in the process. Compare this perspective on maintenance to the traditional one, in which it is viewed as a disruption to normal operations and an unavoidable expense burden.

Maintenance managers understand that every business is vulnerable to serious incidents that might result in significant losses. Only a handful of the little occurrences will evolve into major incidents, so it's impossible to say when they'll happen. It is possible to believe that such events cannot be predicted, but is this true? Often, it is clear that the situation is primed for a major crisis. Hence, the escalation of minor accidents can be summarised as follows;

i. Reduce process variability to lower demand rates.

ii. Increase barrier availability.

iii. Perform all of these at low cost.

How can the dependability of the People or Procedures obstacles be determined? There is no clear statistic to utilize, and even if there were, there would be no consistent and repeatable technique. When it comes to the People barrier, knowledge, competence, and motivation are all essential aspects that influence the barrier's availability. Motivation fluctuates throughout time and is easily swayed by unrelated external circumstances. Because of the corporate culture, working environment, and amount of interest and participation, there would be some motivational overlap. There is no problem as long as the average value is high and the variations are modest. Redundancy can also help boost barrier availability if there are at least two persons available to do a job in an emergency.

An individual's knowledge and competency can be tested from time to time, either through formal tests or by observing their performance under stressful settings. People barrier availability might be quite high in a setting where people support one another. Salary and reward schemes that favour individual performance over team performance might be counterproductive in this situation. Procedures that are used on a daily basis will generate a lot of feedback. These suggestions will trigger modifications, ensuring that they are current.

Those that aren't used too often will collect dust and become obsolete. If they have an impact on vital functions, they should be reviewed more frequently. Procedures for damage limitation can be tested on a regular basis to ensure that they are working properly (such as building evacuation drills). Because the People and Procedures obstacles are dominated by soft issues, determining their dependability is a matter of judgment. In the case of the People barrier, redundancy helps, at least to a point. Illustrations, floor plans, and memory-jogger cards are all excellent tools for increasing the Procedures barrier's availability. It's a good idea to keep certain designs and procedures on hand at all times at the job site. As a result, wiring schematics may always be found on the inside panel of control cabinet doors. Similarly, help screens can be accessed by pressing a mouse button or by looking for fire-escape instructions on hotel room doors. Obviously, they must be replaced on a regular basis to keep them current (Narayan, 1998).

2.3 The Continuous Improvement Cycle

The plant's performance could be tracked once it's up and running. As a result, the effectiveness of maintenance can be improved. A model depicting this process is given in Figure 2.2. The concept divides the maintenance procedure into four stages. The first is the planning phase, during which the work's implementation is thoroughly considered. Alternative maintenance solutions are assessed in terms of their likelihood of success, as well as their costs and advantages, in this phase. We'll schedule the work in the next step. We allocate resources and finalize the timeline at this point. In the third step, we carry out the work while also collecting data. Some of this information will come in handy in the next phase, which is analysis. The findings of the analysis can be used to improve future work planning. The cycle of constant development is now complete.

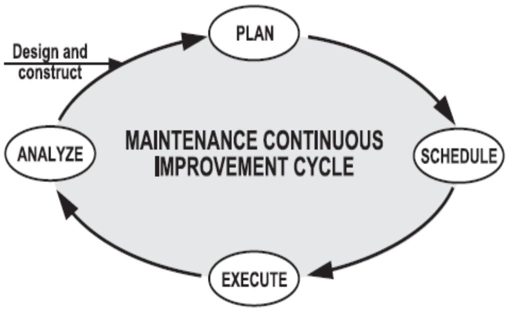


Figure 2-2 Phases of maintenance (Narayan, 1998)

2.4 Failure Modes and Effects Analysis (FMEA)

The performance requirements incorporated in the function specification enable for the identification of any systems or subsystem's success or failure. If the goal is not met, it is possible to pinpoint why this is the case. To do so, one must first determine the mode of failure. Each failure can have a number of different failure modes. Consider emergency generators that are powered by an engine. They must start if the main power supply fails, which is a crucial function. They serve other purposes as well, but for now, let's concentrate on this one. What causes it to fail to start, and how does this happen? To start the engine, one must first create a fuel supply and combustion air supply, as well as crank it up. Several factors could thwart the cranking operation's success. Weak batteries, as well as issues with the starter motor or the starting-clutch system, are examples. The engine will be unable to start if any of these faults occur. These are referred to as failure modes. One can also take this type of analysis down to a lower level. For example, the clutch itself may have failed due to a broken spring. At what level should one stop the analysis? This depends on someone maintenance policy. The following options may be considered for the cause: replace the clutch assembly or77 of the clutch assembly at site and replace the main element damaged, for example, the 7 broken springs (Knotts, 1997).

The FMEA can also be carry out at a sub-system functional level, for example, fails to start or stopped while running, as discussed above. It is also feasible to do an FMEA at a level of the smallest replaceable element, such as that of the clutch spring. When designing process plants, a functional approach is generally used. When designing individual equipment, the manufacturers usually carry out FMEAs at the level of the non-repairable component parts. This enables the manufacturer to identify potential component reliability problems and eliminate them at the design stage. In a functional analysis, maintenance significant items can be identified, failures of which can cause loss of system or sub-system function can also be identify. In this case, the analysis will be stop at assembly level because there is a need to replace it as a unit, and not by replacing, for example, its broken spring.

Unlike the manufacturers, one cannot usually justify analysis at the lower level, because the cost of analysis will exceed the benefit. The volume of work in a component level FMEA is much higher than in a functional FMEA. For each failure mode, there will be some identifiable local effect. For example, an alarm light may come on, or the vibration or noise level may rise. In addition there may be some effects at the overall system level. If the batteries are weak, the cranking speed will be slow, and there will be a whining noise, this is the local effect. The engine will not start, and emergency power will not be available. This may impair safety in the installation, leading to asset damage, injury or loss of life; this is the system effect. One can also identify how significant each failure mode is by examining the system effects. In this case, failure to start can eventually cause loss of life.

However, if we have another power source, say a bank of batteries, the failure to start of the engine will not really matter. There may be some inconvenience, but there is no safety implication. The failure is the same, that is, the engine does not start, but the consequences are different. The purpose of maintenance is to ensure that the system continues to function. How one maintains each sub-system will depend on the consequences, as described by the system effects. For example, if the failure of an item does not cause immediate loss of function, one can limit the maintenance to repairing it after failure. In each situation, the outcome is dependent on the configuration of the facility. The operating context may differ in seemingly identical facilities (Knotts, 1997).

2.4.1 Prevention of failures or mitigation of consequences

Once the functional failures have been identified, the question arises as to how best to minimize their impact. Two solutions are possible:

i. To eliminate or minimize the frequency of failures
ii. Take action to mitigate the consequences.

If one can determine the root cause of the failure, then one may be able to address the issue of frequency of events. Usually, this will mean elimination of the root cause. Historically, human failures have accounted for nearly three quarters of the total. Hence, merely designing stronger widgets will not always do the trick. Not doing the correct maintenance on time to the right quality standards can be the root cause and this is best rectified by re-training or addressing a drop in employee motivation. Similarly, changes in work practices and procedures may eliminate the root cause. All of these steps, including physical design changes, are considered a form of redesign. In using these

Methods, one needs to attempting to improve the intrinsic or operational reliability of the equipment, sub-system, or system. As a result, we expect to see a reduction in the failure rate or frequency of occurrence. An alternative approach is to accept the failure rates as they are, and devise a method to reduce their consequences. The aim is to do the applicable and effective maintenance tasks at the right time, so that the consequences are minimal. Once the tasks has been identify, the tasks will be schedule, arranging the required resources, materials, and support services.

Thereafter, execute the work to the correct quality standards. Last, record and analyse the performance data, to learn how to plan and execute the work more effectively and efficiently in the future. When there are safety consequences, the first effort must be to reduce the exposure, by limiting the number of people at risk. Only those people who need to be there to carry out the work safely and to the right quality standards should be present. Maintaining protective devices so that they operate when required is also important. Should a major incident take place in spite of all efforts, we must have damage limitation procedures, equipment designed to cope with such incidents, and people trained in emergency response (Davidson, 1994).

2.5 Availability

The time equipment is able to function to stated criteria in relation to the period it is in service is referred to as availability. The item will be unable to perform when it is down for planned or unplanned maintenance, or when it has tripped. Note that it is only required that the equipment is able to operate, and not that it is actually running. If the operator chooses not to operate it, this does not reduce its availability. Some items are only required to operate when another item fails, or a specific event takes place. If the first item itself is ina failed state, the operator will not be aware of its condition because it is not required to work till another event takes place. Such failures are called hidden failures. Items subject to hidden failures can be in a failed state any time after installation, but one will not be aware of this situation. The only way to know if the item is working is to place a demand on it. For example, if one wants to know whether a fire pump will start, it must be actually started; this can be by a test or if there is a real fire. At any point in its life, it will be very difficult to know whether it is in working condition or has failed. If it has failed, it will not start. The survival probability gives us the expected value of its up-state, and hence its availability on demand at this time. Thus, the availability on demand is the same as the probability of survival at any point in time. This will vary with time, as the survival probability will keep decreasing, and with it’s the availability. This brings us to the concept of mean availability (Resnikoff, 1978).

2.5.1: **Mean availability**

It is very important to know the shape of the PDF curve; one can estimate the item’s survival probability. If the item has not failed till time t, the reliability function R (t) gives us the probability of survival up to that point. As discussed above, this is the same as the instantaneous availability. In the case of hidden failures, one will never know the exact time of failure. One needs to collect data on failures by testing the item under consideration periodically. It is unlikely that a single item will fail often enough in a test situation to be able to evaluate its failure distribution. So we collect data from several similar items operating in a similar way and failing in a similar manner, to obtain a larger set (strictly speaking, all the failures must be independent and identical, so using similar failures is an approximation). Further assumption can also be made, that the hazard rate is constant. When the hazard rate is constant, it is call the failure rate. The Mean Time To Failure, or MTTF, is the inverse of the failure rate. The MTTF for non-repairable goods is calculated by dividing the total time in service (hours, cycles, miles, or other comparable units) by the total number of failures. Items that must be replaced in their entirety, such as light bulbs, ball bearings, or printed circuit boards, are considered non-repairable.

A similar measure of average operational performance is employed in the case of repairable products, called Mean Operating Time Between Failures (MTBF). This is calculated by dividing the total number of failures by the total duration in service (hours, cycles, miles, or other comparable quantities). If the item is as good as new (AGAN) after each repair, it has the same value as MTTF. In practice the item may not be AGAN in every case. We will use the term MTBF to represent both terms. Another term used in a related context is Mean Time to Restore (MTTR). This is a measure of average maintenance performance that is calculated by dividing the total time for a series of successive repairs on a specific repairable item (hours) by the total number of failures of the item. The term "restores" refers to the period of time between when the equipment was turned off and when it was resumed and successfully operated (Resnikoff, 1978).

2.6 Failure

The inability of a piece of equipment, a sub-system, or a system to satisfy a set of specified performance standards is referred to as failure. As a result, some expectations can be expressed numerically. A centrifugal pump's discharge pressure, for example, should be 10 bar gauge at 1000 litres per minute. In some circumstances, our expectations can be defined within a range of acceptable performance. For example, at 10 bar gauge; the output rate of this pump should be 950–1000 litres per minute. The performance standard in question could be for a system, subsystem, piece of equipment, or component. These requirements relate to what we need to accomplish as well as our assessment of the item's design capacity and inherent reliability (Lorenzo, 2001).

2.6.1 Critical and degraded failures

Because of a disappointment, the framework might be completely debilitated to such an extent that there is a total loss of capacity. For instance, if a fire siphon neglects to begin, it will bring about the inaccessibility of water to battle fires. On the off chance that there had been a genuine fire and just one fire siphon introduced, this disappointment could bring about the annihilation of the office. For this situation, the inability to-beginning of the siphon brings about complete loss of capacity. As a subsequent model, expecting there are sets of three smoke alarms in encased hardware lodging. The rationale is with the end goal that an alert will come on in the control room if any of the three finders detects smoke.

In the event that any two locators sense smoke, the rationale will initiate the storm framework. It is conceivable that one, two, or every one of the three indicators is faulty, and can't identify smoke. When there is smoke, there is no impact if by some stroke of good luck one locator is inadequate, as the other two will enact the storm. In the event that two of them are in a bombed state simultaneously, the inception of the downpour framework won't happen when there is smoke in the lodging. Last, with the deficiency of each of the three, even the caution won't start. The deficiency of every one of the three units will bring about complete loss of capacity, so this is a basic disappointment. On the off chance that two of the three come up short, the third can in any case start the alert on request. The administrator then, at that point, can react to the alert and start the downpour framework physically. The framework can in any case be useful in raising the caution, so it has incomplete or corrupted usefulness.

2.6.2 Evident failures

At the point when the impeller of a siphon wears out, the administrator can see the adjustment of stream or pressure and subsequently know about the weakening in its presentation. It calls an apparent disappointment as the administrator knows its condition. Also, an expansion in the differential tension across a channel or exchanger demonstrates an increment in fouling. At the point when the bearing vibration readings is thinking about and plot the changes, it is feasible to foresee when it needs substitution. For each situation, the administrators know the state of the hardware, utilizing their own faculties or instruments. In this unique situation, the administrator is the individual who is liable for beginning, running, and halting the hardware. For instance, the driver of a car is its administrator (Lorenzo, 2001).

2.6.3 Hidden failures

During regular operation, however, the operators are unaware of these faults. Do you know if the brake lights on your car work? Similarly, there is no way of knowing whether a smoke detector or a pressure relief valve is operational at any one time. If the smoke detector is in good working order, a second event, such as a fire (which produces smoke), will set it off. If the vessel pressure reaches the specified pressure of the relief valve, it should lift. When there is a power outage, the standby power generator must start. Will the standby generator or the pressure relief valve be activated? Protective instruments can also detect hidden failures. As the complexity of the equipment grows, the designer adds various protection mechanisms to alert the user, such as alarms, or bring it to a safe state, such as trips. These safety mechanisms are rarely used, and the operator has no way of knowing if they are operating. These are vulnerable to unnoticed failures. Is it an obvious or concealed failure if the operator is not physically present when the event occurs? A pump seal, for example, could leak in an otherwise unattended unit. A pool of process liquid on the pump bed, for example, is usually indicative of a leak. It does not convert the event from an obvious to a hidden failure just because the operator was not present and did not notice it. The leak would have been visible if the operator had been present, and a second occurrence would not have been necessary. The key is not whether there was a witness present, but if the consequence occurred concurrently with the failure. A second event must occur in order to detect a concealed failure, and unless this condition occurs, it is an obvious failure. As a result, the moment the operator notices the problem is unimportant. To return to the prior point about the brake lights, you know that the car was roadworthy and the lights were working when you inspected it. You'll know the answer quickly if you ask a friend to stand behind the car while you push the brake pedal. This is an example of a test on a product that has concealed flaws (Lorenzo, 2001).

2.6.4 Incipient failures

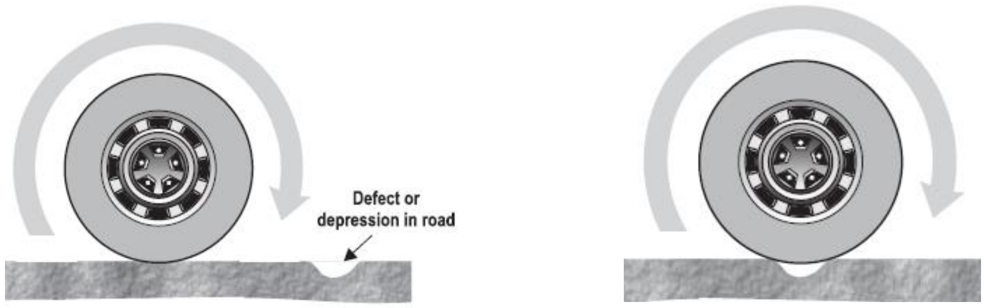
If the degradation is slow and occurs over time, there is a point at which the beginning of the deterioration can be detected. The point at which the onset of failure becomes detectable is known as incipiency. There comes a time when the performance is no longer acceptable as the decline continues. This is the point at which the system stops working. The time between the commencement of incipiency and functional failure is known as the incipiency interval. It is possible to predict the timing of functional failures when the failures are visible and show incipiency (Lorenzo, 2001).

2.6.5 Life without failure

Isn't it lovely to live a life free of failure? The lower the failure rate, the higher the level of reliability. Within certain economic and technical limits, a competent designer strives to make the product or service as trustworthy as feasible. A marble rolling along a smooth glass surface may continue to roll for an extended period of time. Controlling its movement, on the other hand, can be challenging. Similarly, an astronaut performing a spacewalk has a disadvantage. It is extremely difficult to navigate in the absence of friction or gravity, because the only method to do so is to use reaction forces and apply the concept of conservation of momentum. As a result, while a lack of resistance or opposition may save energy, control is more difficult. This approach could be used to explain why democracies are preferable to dictatorships. Failures can be beneficial since they reveal deviations from expected performance and, as a result, opportunities for development. Failures are measurable deviations that provide the means to control a process. When Resnikoff (1978) presented his well-known paradox, he recognized the importance of failures. This is due to the fact that information concerning critical failures is frequently required in order to identify the proper maintenance work, the goal of which is to avoid repeat failures. As a result, with faultless maintenance, such significant failures will never occur, and we will never be able to gather the necessary data. Failure to collect the data required for this purpose can cause any business striving to follow the road of continuous improvement to fail (Lorenzo, 2001).

2.6.6 Incipiency

Items like light bulbs, ball bearings, and structural welds will be examined for these purposes at the level of the lowest replaceable component. Fatigue or deformation produced by thermal or mechanical stress, or chemical attack, are the most common causes of failure. The rate of failure mechanism advancement varies, being fast in some circumstances and gradual in others. Examining one or two common circumstances in which the progress of the failure can be observed, the first instance is the road with a minor surface flaw or unevenness produced by inadequate finishing. The tyres enter the dip when cars travel over the unevenness and then climb back up to the original level. This puts a strain on both the road and the vehicle's suspension. The road is further damaged as a result of this impact, resulting in a deeper depression. The second truck hits the road considerably harder, causing even more damage. If the repairs are not made, the depression will soon turn into a pothole, making driving on this portion of the road dangerous. The sequence of events is depicted in Figures 2.7, 2.8, and 2.9 (Lorenzo, 2001).


A: Damage of road surfaces

B: Tires “drop” into defect and climb out

Figure 2-3 Demonstration of incipiency (Lorenzo, 2001)

The time one notices the start of imperfection is the beginning of the early failures, meant by point x at time t_i in Figure 2.11. The drop of the bend shows the pace of development of the pothole. Sooner or later on schedule, this condition becomes unsatisfactory, as the street is as of now not protected to utilize. The standard used to decide its worthiness is reliant upon the working setting. The higher the speed of the vehicles and the more prominent their stacking, the stricter are the acknowledgment principles. The spotted lines show the overall degrees of worthiness, which are subject to street paces and stacking. At the mark of convergence with the bend, shown by the point y at time t$_f$, it isn't protected to drive out and about any more extended. As such, it has fizzled. The time taken for the condition to fall apart from x to y, that is $t_f - t_i$, is the incipiency stretch.

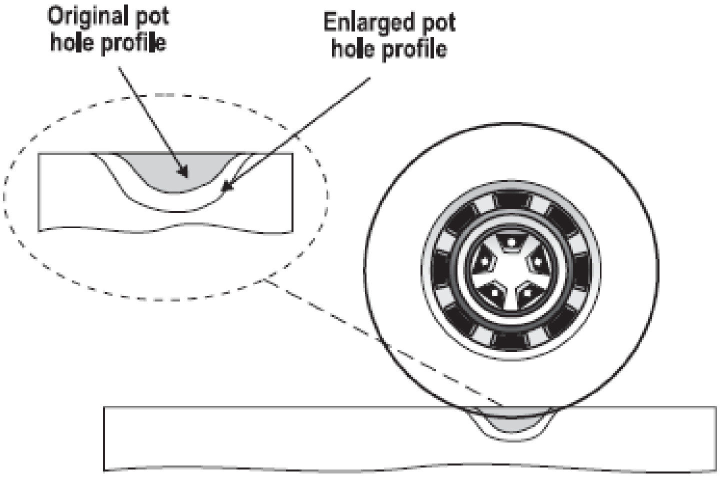


Figure 2-4The 'drop' energy damages the road further (Lorenzo, 2001)

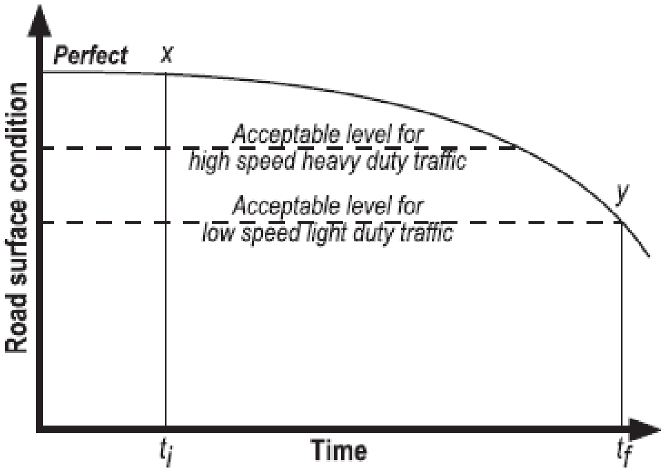


Figure 2-5 Incipiency intervals (t_f− t_i). (Lorenzo, 2001)

2.6.7 Limits to the application of condition monitoring

When the incipiency is short, the amount of time available to plan or carry out maintenance is equally limited. In such instances, monitoring the component's state makes it impossible to plan replacement before it fails. Condition monitoring is a good technique to plan component replacement when incipiency intervals are measured in weeks, months, or years. Condition monitoring is achievable when the change in performance can be measured using human senses or devices. As a result, faults that are hidden or unseen cannot be monitored. When proponents of condition-based maintenance emphasize their capacity to forecast breakdowns, they are correct. Any ability to predict improves the decision-making process. They do, however, offer the appearance that condition monitoring systems will cure all of our issues. It has been recognized that not all failures lend themselves to condition monitoring. The failure must have incipiency, be measurable, and have a realistic time interval. It is imperative that providers of condition monitoring services demonstrate how they achieve these requirements on a regular basis (Lorenzo, 2001).

2.6.8 Human failures

Human activity (or inaction) is responsible for over three-quarters of all accidents. It is impossible to wish it away since it is far too significant a component to ignore. Humans are intricate systems with hundreds of possible failure scenarios. The phrases "human error" and "human failure" will be used interchangeably in the following discussion. Human error can have a wide range of reasons. Lorenzo divides them into three categories: random, systematic, and sporadic. Better training and supervision can help to correct random errors. Systematic variability is indicated by a shift in performance in one direction. This can also be decreased if regular performance feedback is provided. The most difficult to foresee or control are sporadic errors. In this situation, the individual's performance is generally satisfactory. A sporadic error is caused by a sudden distraction or loss of concentration.

Humans operate best when they are under a certain amount of stress. To keep us aware, active, and expecting, we need a certain amount of tension. This is referred to as "facilitative stress." Physical or psychological factors can cause an excessive amount of stress. This might lead to exhaustion and a lack of concentration. Work that is monotonous, cognitively undemanding, or generally boring can cause too little stress. Submarine lookouts proved ineffectual after around 30 minutes, according to the British Royal Navy, since they couldn't stay attentive. Motivation was not an issue for the lookouts because they knew their own lives depended on their attentiveness. The following are some examples of psychological stress.

i. Sudden onset,
ii. Stress duration,
iii. Task speed,

Each individual is unique and thrives at varying amounts of stress. However, a number of the stressors have a comparable effect on many people. It is necessary to address the elements that contribute to stress in order to reduce human failures. This allows one to create the ideal environment for each individual. While it is unlikely that one will be able to influence stress generated by domestic issues, focusing on those at work is critical. Job enrichment aims to eliminate boredom and unacceptably low stress levels in the workplace. High levels of stress at work are to blame for the remaining issues. Operators in the control room undertake crucial tasks. Their abilities are in high demand during plant upsets, start-ups, and shutdowns. When things go wrong, it's critical to use alarms to get their attention. Control room designers must take care to keep the number of alarms installed to a minimum. During a plant outage, if too many alarms go out at once, operators may lose concentration and react improperly, exacerbating the problem (Lorenzo, 2001).

2.7 Design Quality

A well-designed plant will have some distinct features. The plant should be able to produce products of the desired quality consistently and at a rate of production considered satisfactory. In most cases, a satisfactory rate of production also implies that the production process is efficient. Some criteria require that the plant be reliable, easy to operate and maintain. The first three points describe functionality of the plant. In other words, the plant is capable of producing the required output, with the designed inputs of materials, energy, and human effort. However, it will be safe and profitable only if it meets the remaining three conditions. The exposure to safety or environmental incidents is higher in plants that are difficult to operate. With poor operability, employees will find workaround solutions to their problems. Their make-shift efforts can lead to unwanted incidents as they do not have training or experience in design. Similarly, repair times will be excessive in plants that are difficult to maintain. As a result, protective devices and industrial equipment are in short supply, posing a risk to workers' safety and profitability. Frequent excursions or breakdowns occur in unreliable plants, resulting in production losses and increased work for operators and maintainers. It is reasonable to expect designers to make every effort to achieve these six standards, but they will not always succeed. Therefore, examine why the design quality is less than optimal. These fall in one or more of the following categories:

i. Insufficient information is available to the designer in respect of the required functionality.

ii. The design team is under severe resource and time pressure

iii. The design team lacks the required knowledge, experience, and skillsThe customer requirements have changed since the time the plant was conceived.

A plant with a poor design will be a problem for the rest of its existence. The maintenance manager will try to discover answers once the facility is up and running, but these will usually be temporary and low-cost repairs. This problem can only be solved with a long-term solution that tackles the underlying reasons. It's critical to get the design right the first time, because the alternative is a possibly dangerous or undersized plant that would be perpetually in difficulty. From the start of the project, it is a good idea to involve the relevant people in the organization. The relevant inputs can be provided by the marketing, operations, and maintenance teams (Knezevic, 1997).

2.8 Operability

Operations staff can provide information based on their past experience in running the plant. Using this information, the designer can design plants that are easy to commission, operate, and shut down. Operators can help check these features while it is still in its early stages of design. In order to shut down plants safely, the operators’ feedback can help identify special design features. Ergonomic considerations can play an important role in safe operations. An operational review of the three-dimensional model of the plant will take this into account. The costs and impact on the schedules of the resulting design changes can be quite low. Operational staff that is exposed to the design at an early stage becomes familiar with the plant long before the date of commissioning. This helps identify the gaps in their training and skills, which can be filled while the operators are still in their current jobs. Operator involvement can be a very motivating and satisfying experience. It will improve their pride and ownership of the plant.

2.8.1 Maintainability

The ability to quickly recover a damaged plant is a measure of its maintainability. There are three issues to consider at the design stage to ensure good maintainability. The ease with which the fault and cause are located and identify is very important. In addition, accessibility to the defective equipment or parts should be easy, just as the lifting gear, transport, and lay-down facilities are required to be available.

Modern photo copiers illustrate the use of improved diagnostic aids, including self-diagnosis. These machines tell us how to trace and rectify the fault when it occurs. Access to most parts is by operating simple clamps, levers, or hand wheels. Older generation machines did not boast such features, and the improved maintainability will be evident to those who have used both varieties. The (former) Procurement Executive of the Ministry of Defence in the United Kingdom has produced an excellent video called ‘Maintenance Matters’ on defence equipment maintainability. One example in this video compares two designs of fighter aircraft. There is a black box for recording the relevant flight information in both designs. A technician removes the unit after each flight to download the data. The black box is in a compartment accessible from the outside, as illustrated in Figures 2.12 and 2.13. In one design, the cover of the compartment is secured with about seventy fasteners. These fasteners have different types and sizes of heads, including cross-head and high-torque screw heads as well as more conventional types. As a result, the technician needs seven different tools to open the cover. Then he has to lift it out bodily and place it on the tarmac, before pulling out the black box. In the other design, the black box compartment cover is hinged along the top edge. It is secured by three toggle-clamps along the bottom edge. The technician cansopen the cover easily and quickly by operating the clamps.

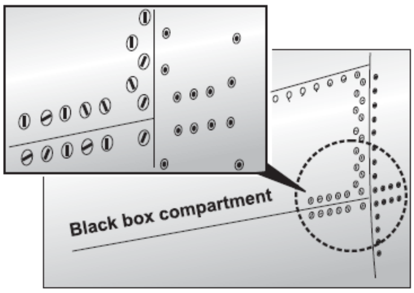


Figure 2-6: Multiple screws fastening system (Knezevic, 1997)

In the open position, the cover doubles as a rain protection. The difference in maintainability in the designs will be evident from these two figures. The second design enables rapid retrieval of the black box, and the time required to do the work is only a small fraction of that required earlier. Through the lifetime of the aircraft, the maintainers will enjoy the benefits of the additional thought and attention given to the maintainability aspects (Knezevic,1997).

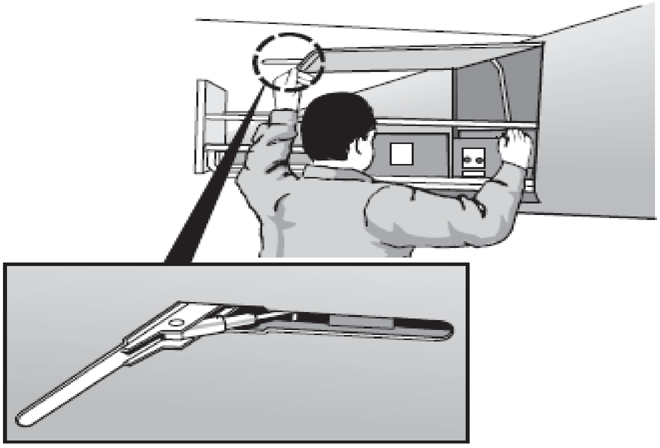


Figure 2-7: Hinged toggle-clamp system (Knezevic, 1997)

Figures 2.6 and 2.7 are reproduced from the video ‘Maintenance Matters,’ courtesy of the Ministry of Defence, United Kingdom. The same video illustrates poor maintainability in another aircraft design. The example is about emergency batteries that need periodic servicing. In order to reach the batteries, the technician has to remove the ejection seat and the top of the instrument panel. Then he has to move the circuit breaker panel to one side, and remove a part of the rudder panel before reaching the batteries. Thereafter, the items have to be reinstalled in the reverse order. He does this work once in six weeks, so one can imagine his frustration and possible safety implications. In an offshore oil platform, the author inspected a diesel-engine driven hydraulic pump. This provided motive power to a hydraulic turbine that was used to start up a gas turbine. The hydraulic pump and engine were on a compact skid, so tightly packed that it was very difficult to reach the instruments or critical engine parts. This remained a problem unit through its life. In contrast to the previous figures, the photograph in Figure 2.14 shows a control panel in a modern offshore Floating Production, Storage, and Offloading unit (FPSO). Note the compact fold-away design of the computer keyboard, which allows easy access to the printed circuit boards (Knezevic, 1997).

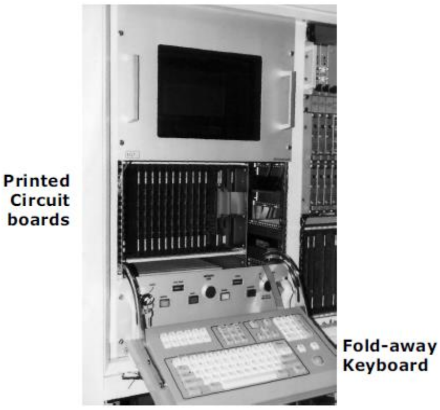


Figure 2-8: Control panel door (Knezevic, 1997)

The designer has to consider the range and volume of the anticipated maintenance work. We require adequate workshop facilities and lay-down areas with cranes and other lifting gear. The anticipated workload and availability of third-party facilities will help specify the requirement of machine tools. The main criterion in defining the size and location of the warehouse is the ease and speed of retrieval of spare parts. Contractors and vendors may own and operate the workshop and warehouse, if that meets economic and strategic criteria. We can identify maintainability issues by reviewing the three-dimensional model of the plant. Maintainers are the best people to do this work, and they can suggest solutions as well.

Software packages are available to simulate maintenance actions of male and female human models, if the three-dimensional model of the plant is available in electronic format. Using such packages, one can easily identify access and handling problems. This type of study will help reduce unnecessary downtime and maintenance cost over the life time of the plant. By solving the problems before commencing fabrication work and avoiding needless change requests, one can save money and time. At the same time one can minimize the risks associated with their implementation (Knezevic, 1997).

2.9 Reliability

We want reliable industrial equipment, and expect the vendor to build it into the design. As users, we do not generally give the vendor feedback on how well their equipment performs. Often there is no contact with a vendor and we make the first phone-call only when planning a major overhaul or after a catastrophic failure of the equipment. Vendors do not have access to operational history, but we expect them to know everything about the reliability of their equipment. Not having a crystal-ball they have to make intelligent guesses based on the demand for spare parts and requests for service-engineer support.

The limited exposure during major overhauls or serious breakdowns is not enough to judge operational performance adequately. Without proper failure histories, it is difficult for equipment vendors to improve their products. Much of the fault lies with the user, but there is a lot more that vendors can do to gather failure data. Some vendors do manage to overcome these situations, but these cases are few and far between. Another problem is that buyers of capital goods often do not specify reliability parameters in their requisitions. There aremany reasons why this occurs. First, the measurement of reliability performance has to stand up to contractual and legal scrutiny. Second, buyers have preferred suppliers, for sound business reasons. These reasons include the standardization of spare parts, and satisfaction with previous support and service.

Competitive prices or quality considerations do not govern whom one buy from any more because the overall economics depend on such preferences. A vendor who has made great strides in improving the reliability of the equipment may still lose out to the established vendor. Hence, reliability performance is an important selling point the first time we purchase an item, but thereafter other criteria become significant. Third, the actual buyer is often the design and construction contractor, not the ultimate customer who owns the plant. If the owner does not specify a detailed list of preferred vendors, contractors will choose the vendor based on their own experience with different vendors. Once the customer and the vendor have to deal through a contractor, the importance of the views of the customer diminishes. Contrast this situation with that of sellers of consumer goods and services. A manufacturer of a consumer durable such as a washing machine or an automobile sells the product directly to an end user, as do service providers such as airline companies. Even though there may be agents and intermediaries who handle the actual transaction, the deal is clearly between the manufacturer and the final customer.

The marketing effort focuses on the end user. The two parties at the ends of the chain settle warranty or liability claims between them. Reliability now becomes important, because the customer wants it and can influence the supplier. If the customers are unhappy with the product or service, they can take their business elsewhere. Thus, in the case of consumer goods, the manufacturer makes every effort to keep the customer happy by providing reliable goods and services. One phone call gets you an agent to log your complaint. It offers a repaired unit to replace your machine or to repair it, if that is your preference. Then it transfers your call to a courier service that arranges to collect and deliver the units. The company retains customer loyalty, and should get excellent failure data from its service departments. Industrial equipment buyers can use simple measures of reliability, for example, by specifying minimum run lengths between overhauls. In this regard, the ANSI/API Standard 682 (3rd Edition, September 2004), ISO 21049: 2004, (Identical): Pumps—Shaft Sealing Systems for Centrifugal and Rotary Pumps, has taken the lead. It specifies a design criterion of three years of continuous service while meeting emission standards. This means that we can build warranties into the contract, with penalties for poor reliability performance. Once the general population of buyers starts specifying such requirements in their purchase orders, the suppliers will find a way to gather failure data.

A plant consists of many systems, sub-systems, and equipment items. From a reliability point of view, these may be in series, parallel, or some combination. In a series system, illustrated in Figure 2.15, failure of any one component will result in a system failure. For the system to work, all three components A, B, and C must work. In Boolean notation, we represent this by using gates to link the components. Let us use the example of an automobile to represent a complete plant. In order to function properly, its engine, transmission, steering, suspension, and safety systems must all be in good shape. These systems can be show with the blocks in series, similar to that in Figure 2.15. If we assume that each system failure can be represented by an exponential distribution, the overall plant reliability is the product of the individual system reliability. Note that as the number of components in series rises, the system reliability falls. Figure 2.15 illustrates a system consisting of 20 components. For simplicity, we assume that each component has the same high level of reliability, ranging from 0.999 to 0.98.

The corresponding system reliability is 0.98 in the case with component reliability of 0.999 and 0.667 in the case when component reliability is 0.98. This is one reason why complex systems are sometimes unreliable. Even when the component parts are very reliable, the overall system reliability can become quite low. This is an important lesson for designers of protective systems, which they use, for example, to safeguard critical equipment. However, some designers make these systems very complex. This can be non-productive and, in extreme cases, positively dangerous.

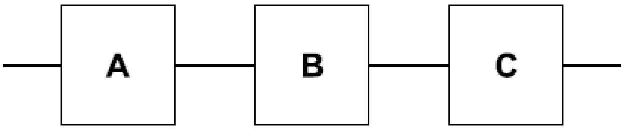


Figure 2-9: Reliability Block Diagram of a series system (Knezevic, 1997)

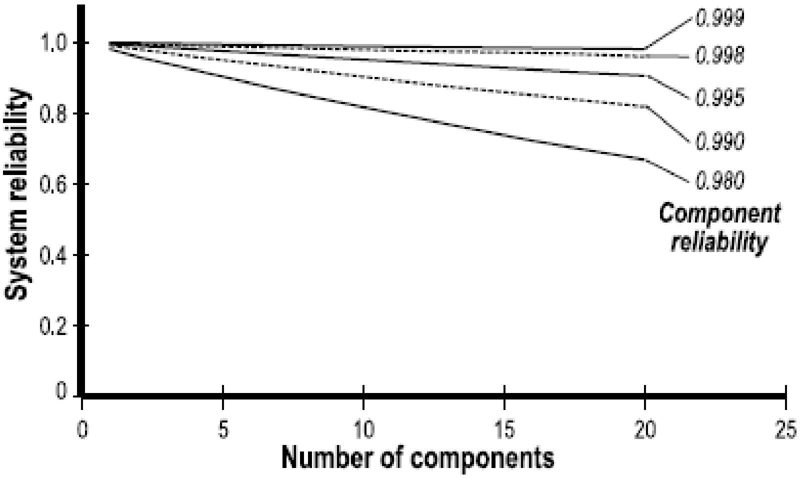


Figure 2-10: Effect of component reliability on system reliability (Knezevic, 1997)

When there are many series elements (in terms of the reliability block diagram), there is a steep fall in the system reliability. We cannot ignore the so-called KISS principle (Keep it simple, stupid!). Figure 2.11 shows a reliability block diagram with parallel elements. In this case, we need only one of the components to work for the system to be effective. As long as A or B or C works, the system will work. Fire detection systems with voting logic, as well as backup equipment in a one out of two (1002) or two out of three (2003) or similar configuration, are examples of such a setup. This arrangement is represented in Boolean notation as elements joined by OR gates. The level of redundancy has a quick effect on system reliability. We can accept very low component dependability levels with a large level of redundancy.

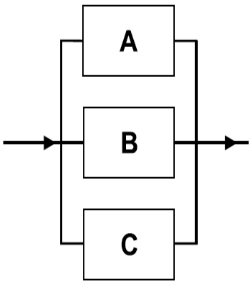


Figure 2-11: Reliability Block Diagram of parallel elements (Knezevic, 1997)

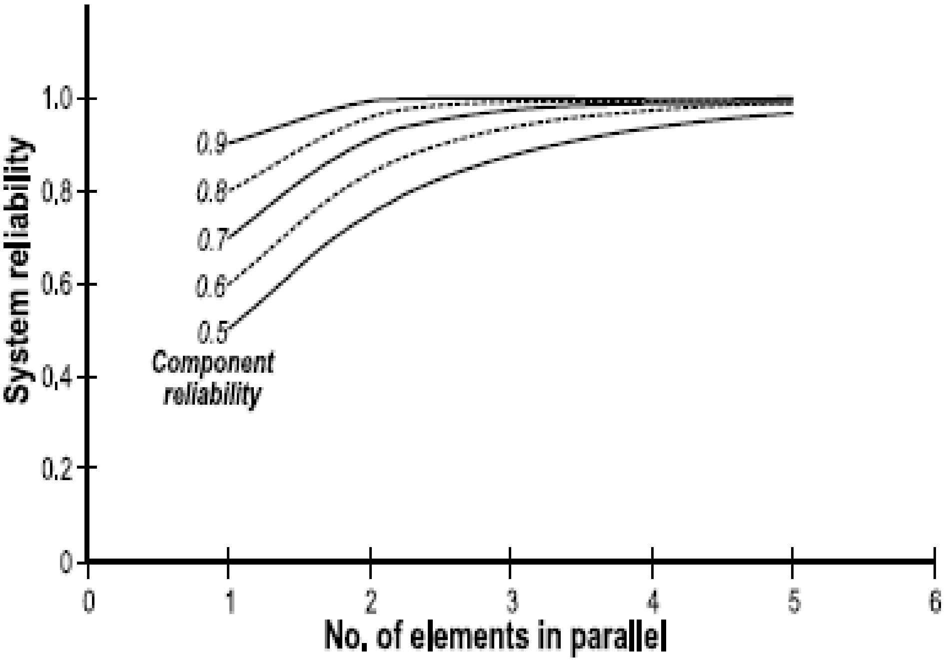


Figure 2.12: Effect of redundancy on system reliability (Knezevic, 1997)

2.10 Risk reduction

Hazards that can be expected during the lifetime of a process plant will be considered. The first step in managing them is to identify and evaluate the risks. One can measure quantified risks using their component parameters, namely, the frequency and severity of the events. If the risk is qualitative, we identify the factors affecting the perceptions and their impact. There is an element of simplification here, since quantitative risks can affect qualitative risks and vice-versa. Recall our observation that one cannot eliminate risks altogether, but can reduce to a level termed As Low As Reasonably Practicable (ALARP). Risk reduction below this level can be disproportionately costly. Ideally, the best time to do this is while the plant is being designed. This does not always happen for reasons such as a lack of awareness, time, tools, resources, or skills. Often, the project team may get a performance bonus if they complete the project in time and within budget.

The main risk they worry about can be that of the size of their bonus. Thus, their personal agenda may conflict with that of life cycle risks facing the plant. We will discuss a selection of tools that are applicable in managing risks during the design and operational phases of the plant. Of these, Reliability Centred Maintenance (RCM) has a wide range of applicability. It is used when dealing with complex machinery with many moving parts. Most reciprocating and rotating machinery falls in this category. Static equipment such as pressure vessels, pipelines and structure shave a relatively small number of failure mechanisms. The main consequences that they may face are loss of containment and structural failure. Risk Based Maintenance (RBM) is the most appropriate process to analyze risks in these items. Once we take care of these two classes of equipment, we are left with those that protect other equipment against process safety hazards. The Instrumented Protective Functions (IPF) process is use to analyze such protective equipment. These three techniques can help us manage the risks faced during the life of the process plants (Davidson, 1994)

2.11 Information for decision making

Throughout the life cycle of a business process, the operating context will evolve and change. This is because external factors such as market conditions and technological advancements have an impact on the business process. Fashion and changing customer preference influence the demand for products. Within the business, conditions may also change, with changes in ownership interests, new product lines, and occasionally, geographical relocation. There are two objectives common to businesses, namely, to remain in business and to make a profit. In order to do that, businesses must be able to predict the market for their products. The greater this ability, the more successful they will be in adapting to the changing needs of the customers. While a feel for the market or instinct is a useful gift, it is only available to a few lucky entrepreneurs. The rest have to rely on their ability together the appropriate data and analyze it to obtain the required information. The lucky few also work hard at it, and one might argue that their success is due to this effort, though others may attribute it to their instincts. Analysis by itself has no value. It must help achieve business objectives. For this purpose the data must be appropriate, analysis technique suitable, and the errors recognized and compensated. The resulting information is useful for making good decisions.

In any decision-making process, time is crucial. It slows down the data collection and analysis process. Even when the knowledge is incomplete or inaccurate, one must make decisions. We are more likely to make poor decisions when we have insufficient or erroneous information. Due to the constant strains of time, data quality and timeliness are always at a premium. The analyst must identify these risks when presenting recommendations (www.oreda.com/Accessed, April, 2020).

2.11.1 Work and the generation of data

Whenever work is done, it is natural that some data are generated as the work proceeds. These may include (amongst other sources):

Data about inputs, e.g., Materials, Labour, and Energy consumption, Output volumes; Process speed data, e.g., start and finish times, cycle time, Process quality data, e.g., rejection levels, frequency of corrections, rework v. Energy efficiency records; Process slowdowns, upsets or trips, direct and indirect delays; Data on soft issues, e.g., morale, attitudes, team spirit, customer satisfaction.

In addition, some relevant external data is being generated continuously by competitors, trade unions, customers, and government. It is better to analyze the two data sets separately, and use both sets of information in making decisions.

2.11.2 The collection of quantitative data

Data may be numerical, in coded format, and in free text. Work history records are often in free text, but most other quantitative data is invariably in numerical or coded form. Process history is often in free text, but both work history and process data additionally contain a fair amount of numerical data. The accountants and tax collectors were the first to recognize the importance of data collection. As a result, accountants designed data collection systems for their own use. These systems fulfil their original function, which is to record past performance and to ensure that an audit trail is available. The double-entry book-keeping system they designed was able to account forever cent. To collect this data, they needed time, and some delays were acceptable in the interests of accuracy. Most people are reluctant to design new data collection systems when there are existing systems in place.

These are not always appropriate for their new decision-making roles, so they make attempts to bend the systems to suit. However the problem is more fundamental as the two have different functional requirements. The architecture for recording money transactions is not always suitable for analyzing failure history satisfactorily. In the latter case, the records must centre on the equipment tag number. The equipment constructional details, operating context, performance, downtime, resources used and cost data are all important, and must relate to the tag. One always needs the start-stop timing of events when we calculate equipment reliability parameters. From the maintenance engineers' point of view, a better approach would be to start by defining the function that they want performed. This top-down approach will help identify the type and timing of information required. They can then identify the data required for obtaining this information. By examining the existing data collection systems, they can check if they provide the required data at the right time. If so, there is no problem, otherwise they have to fill the gaps between desired function and that available with existing systems. If this is not possible, they have to design and install new systems. Open architecture data bases can provide a solution that meets the requirements of both types of users. Systems that can talk to each other are superior to stand-alone systems. With suitable links, one can relate cost, history, equipment tag, and plant groups or other data collection nodes. This effort will help prevent the proliferation of systems and wasteful effort in recording the same data two or three times, along with the possibility of inconsistencies between systems.

Quantitative data for use in reliability calculations may be collected within one plant, several plants in one company, or as a joint industry project (JIP) by several companies. An example of such a JIP is one in the offshore oil and gas industry called OREDA, which has been very successful. The reliability data from OREDA is used, for example, in risk assessments, mathematical modelling, IPF, and RCM studies. The data collection methodology has now been captured in an International Standard, ISO 14 224, 1999 (www.oreda.com/Accessed, April, 2020).

2.11.3 The collection of maintenance data

The failures have been discussed at the component, equipment, sub-system, and system levels. We know that maintenance can restore performance to the design capability, but any enhancement beyond this level requires some redesign. There are two ways of enhancing equipment performance, first by reducing failure rates, and second by reducing the consequence of failures. Although both methods are possible, each has an associated cost. This additional dimension means that there is a cost-effective optimum solution awaiting discovery. We can state these requirements as a set of functional requirements, as follows:

1. To identify design improvements to reduce failure rates.
2. To plan and execute maintenance in such a way that the consequences of failures are acceptably low
3. To do the above at as low a long-term life-cycle cost as possible (www.oreda.com/ Accessed, April, 2020).

2.11.4 Failure reduction

This function requires an analysis of all significant failures to establish their root causes. Failure can be analysed by using some or all of the following;

i. Comprehensive and good quality incident investigation reports.
ii. Knowledge of the process; flow schemes, production rates, and other related data.
iii. Procedures used to operate the equipment; including start-up or shut down sequences.
iv. Records of the actual operating history, including process charts and readings

v. History records showing failure and repair data

vi. Spare parts consumption history.

Using root cause analysis (RCA), solutions follow fairly easily once the study is completed. The analysis must be thorough, and should not stop at proximate causes. It is easy to fall into this trap, often the RCA work stops at an early proximate cause.

Eliminating proximate causes is like treating a sick person's symptoms instead of the disease itself. The analysts need patience and persistence to reach the underlying root causes. The solutions may relate to the process, people, procedures, or plant. Often, the solution will involve training people, adjusting or revising procedures, or making the process steady. The solutions often require us to address management styles, company cultures, or conflicting goals (www.oreda.com/Accessed, April, 2020).

2.11.5 Reducing the consequence of failures

A suitable set of maintenance strategies to minimize the consequence of credible failures must be available. One can break this need down into the following sub-functions:

1. To identify credible failure modes and their consequences
2. To find applicable and effective strategies that can prevent or mitigate these consequences
3. To create maintenance routines that integrates these strategies into practical and executable steps
4. To measure and confirm that the routines are carried out to the required quality standards and at the right time.
5. One can use analysis tools such as RCM to achieve these objectives.

What do we need to carry out these tasks? The data requirements include the following:

i. Configuration of the equipment, e.g., series or parallel, voting systems (1002 and 2003), bridge, or nested.
ii. Equipment performance data
iii. Equipment layout drawings.
iv. Expected performance standards.
v. Operating mode, e.g., duty/standby loading levels, continuous or intermittent Operation.
vi. Knowledge of consequence of failures6.An appropriate analysis tool.

A competent maintenance planner equipped with suitable tools can do this work effectively. In order to check that the routines are in line with the strategies, we require an audit trail. The documents providing this trail constitute the relevant data. Item 4 above requires us to measure the quality and time lines of execution. We can achieve this if data about the following are available:

i. Compliance records, to verify that the planned work is done in time
ii. Staff training and test records to confirm competence
iii. Service level records with respect to supporting logistics
iv. The operating performance of equipment, as recorded after maintenance
v. Housekeeping and walk-about records, noting leaks and unsafe conditions
vi. Results of physical audits carried out on maintenance work (www.oreda.com/Accessed, April, 2020).

2.11.6 Collection of the qualitative data

The word qualitative in its descriptive sense, Qualitative factors affect feelings and emotions of the people involved. They are responsible for morale and may help or hinder motivation. People do not always make decisions on sound rational judgment and analysis. Quantitative analysis can only go so far, and perceptions and emotions can easily swing the balance. This is why morale and motivation are important. There is few quantitative indicators of morale such as trends of sickness and absenteeism. Organizations experiencing high absenteeism among the workforce often find a similar trend among the supervisors and middle managers. This is often indicative of low morale. Other indicators include participation levels in suggestion schemes and voluntary community projects. A well-recognized but hard to measure indicator is the number of happy faces around the facility. In an article entitled 'It's the manager, stupid,' The Economist reports on the results of a very large survey on employee satisfaction carried out by Mays (2006), the opinion-polling company. This covered over 100, 000 employees in 24 large organizations over a 25-year period. They report that the best performing units were those where the employees were the happiest. The worst performers were also full of dissatisfy workers. The study also found that individual manager's matter, by correlating employee satisfaction with things within their managers' control Good morale is necessary for a motivated workforce. However, there are other factors as well, so it is not sufficient to have just high morale. These include the physical and psychological needs of people, as well as their domestic and social stability. Such factors are not easy to measure even the persons directly affected may not be recognized.

These needs are also changing over time, and not in a linear or predictable way. You can recognize motivated people when you meet them. They are usually go-getters with a can-do attitude. They have ideas and are willing to share them. Often they are quite passionate about their ideas. Some of them sing or whistle at work. In spite of all these indicators, motivation is hard to measure, and we usually need expert professional help. People with a logical frame of mind tend to shy away from such soft issues. Their zone of comfort is in rational thinking, preferably with numbers to support their decisions. Their contribution is in countering those who decide by hunch and gut feelings. Morale and motivation are hard to measure, and the results may make us feel uneasy. These are some of the reasons why we do not always address them satisfactorily. The point however is this; if you do not know what makes people tick, you are not always able to make the right decisions. One should monitor sickness and absenteeism regularly. These records are easy to collect and are useful in judging morale. We should measure motivation periodically with the help of professional experts. The trends will help decide if one needs corrective action (www.oreda.com/Accessed, April, 2020).

2.11.7 Errors in data collection

The quality of any analysis is dependent on the correctness of the source data. However good the analysis technique, if serious errors exist in the raw data, the results will not be of much use. One can categorize maintenance records into two main types: Static data, including tag numbers (which identify the items of equipment by location), make, model and type descriptors, service details, and cost codes;

Dynamic data, including vibration levels, operating performance, time of stoppage and restart, as-found condition, repair history, spare parts, and resources used. Errors in static data are usually reconcilable as it is possible to spot them through audits. If the tag number entry is incorrect, for example, if pump P4120A is recorded as P4210A, one can use the service or duty to validate it. If on the other hand, we record P4120A as P4120B, we can use the operating log to reconcile this error. Similarly, we can identify an error in the cost code by identifying the tag number and hence the location and service.

The relative ease with which we can verify static data makes them less critical, as long as a logical numbering system has been used. This does not reduce the need to record static data correctly in the first instance. If the error rate is high, the validation task can become very difficult. Dynamic data is more difficult to validate or reconcile. Some dynamic data such as vibration or alignment readings are volatile. You cannot come back a few days or weeks later and obtain the same results because they will have changed. In other cases, the record exists only in one place. For example, the technician records the as-found condition or repair history only in the job card. Similarly, if there is some confusion between the active repair time and the downtime, it may be impossible to validate. Some dynamic data entries are duplicated. In these cases, one can trace the errors easily. For example, spare part consumption details may also be available in warehouse or purchase records. Human eyes can easily pick up text data errors. These include errors such as spelling mistakes, keystroke errors, transposition of letters or words, use of hyphens, backslashes, or colons between words block of data. The main data fields are as follows:

1. Defect reported, e.g., running hot, stuck open, high vibration, spurious alarm or trip, external (or internal)leak, fail to start (or stop, open, close).
2. As found condition, e.g., worn, corroded, broken, bent, dirty, plugged, jammed.
3. Probable cause, e.g., process condition (pH, flow, temperature, pressure, plant upsets, foaming), procedures not followed, wrong installation, drift, misalignment, loss of calibration, quality of utilities.
4. Repair description, e.g., part(s) replaced, cleaned, realigned, recalibrated, surface finish corrected, lubricated, resealed.

2.11.8 Obtaining information from data

In the context of maintenance management, the information we require relates to one of the following areas:

i. Output of maintenance work, namely, system effectiveness, plant availability, reliability and efficiency
ii. Inputs such as labour hours, materials, and energy
iii. Information to improve operational reliability by, e.g., identifying the root causes of failures
iv. Information to demonstrate timely completion of maintenance work. Information to assist in the planning of maintenance work in future. In each instance, we have to analyze the appropriate set of data suitably. We will consider each of them in turn
v. We measure system effectiveness in volumetric terms namely, how much we produce versus how much we require and what it is possible to produce. Usually we can apply this metric at the plant level or at system level, but applying it at the equipment tag level is difficult. Because of this difficulty, we use the time-availability, or the proportion of time the equipment is able to produce to the total period in operation. The latter metric requires the start and end dates, and the duration of downtime for planned and unplanned maintenance work. If a good maintenance management system is in place and the records are available, this data is easy to obtain. Otherwise we may need to trawl through the operating log and the maintenance supervisor’s note book.
vi. A simple metric to use to judge the plant and equipment reliability is the mean time to failures or MTTF. To do this, we simply divide the time in operation by

> the number of failure events. Often, so we make a further simplification and use calendar time instead. At the plant or system level, we can measure the number of trips and unplanned shutdowns. The time in operation will be the calendar time less the duration of any planned shutdowns. Although the absolute values are of interest, trends are even more important.

A rising trend in MTTF is a sure indication of the success of the improvement program. Sometimes, even these measurements are not possible, but maintenance work orders (or job cards) may be available. We can calculate the mean time between non-routine work orders as a measure of reliability. Here non-routine means work orders for corrective and breakdown maintenance work. Each of these approximations decreases the quality of the metric. However, in the absence of other data, these may be the best available data. The operators will normally monitor plant efficiency continuously. The metrics include flows, energy consumption, pressure or temperature drops, conversion efficiency, and consumption of chemicals and utilities. Efficiency is one of the parameters where the deterioration in performance shows an incipiency curve that operators can plot quite easily. Because the loss of efficiency is strong justification for a planned shutdown, it is a good practice to monitor this parameter.

i. Records of inputs such as human resources, energy, and materials are normally available. It should be possible to identify the inputs at the equipment, system, and plant levels. viii. It is a good practice to record all near-misses and incidents. We should analyze high-risk potential operational and integrity-related events. Because the RCA work may start several weeks after an event, the quality of incident reports is important.

ii. Technicians should record the start and completion of preventive and corrective maintenance work in the maintenance management system. We define compliances the ratio of completed planned work to that originally scheduled. The monitoring of compliance is important, and can normally be produced with data from the maintenance management system.Learning is a continuous process. On each occasion that we do work, new learning points arise. If we capture and incorporate these learning points in the next plan, we complete the continuous improvement loop. A mechanism for capturing these learning points is therefore necessary. One can use the maintenance management system itself for this purpose or build a separate database (www.oreda.com/Accessed, April, 2020).

2.11.9 Decision support

One has to manage the planning and execution of maintenance work properly. Maintenance professionals must recognize the importance of data in the continuous improvement process. Improvements in maintenance performance depend on course corrections based on proper analysis of data.

2.11.10Multi criteria decision analysis (MCDA) OR multi criteria decision making (MCDM)

Designing, prioritizing, ranking, or selecting a group of options under usually independent, incommensurate, or conflicting qualities is particularly important to MCDM since they play a significant role in the decision-making process. MCDM refers to selecting the best decision option from a finite collection of decision options based on several, often conflicting criteria. The following are the main steps in multi-criteria decision making (Hwang and Yoon, 1981).

Establish a system evaluation criterion that relates system capabilities to goals. Develop alternative systems for attaining the goals (generating alternative), Compare and contrast alternatives based on a set of criteria. One of the normative multiple criteria analysis methods should be used. Accept one option as the "best" option (preferred), If the final solution isn't acceptable, acquire additional data and move on to the next multi-criteria optimization iteration.

2.11.11Multi criteria decision making techniques

In the case of discrete situations, there are important tools to assist decision makers in selecting solutions. Because those procedures have gotten easier for users with the use of computers, they have gained widespread adoption in many areas of economic and management decision-making processes. The following MCDM techniques were discovered:

i. Simple Additive weighting method (SAW)
ii. Analytical Hierarchy Process (AHP)
iii. Simple Multi-Attribute Rating Technique (SMART)
iv. Elimination and choice translation and Reality technique (ELECTRE) are the most frequently used methods (Chen, 2000).

The nature of those methodologies' recommendations is determined by the problems being addressed: selecting, ranking, or sorting. Models/techniques can also be chosen depending on evaluation criteria such as:

i. Internal consistency and logical soundness.
ii. Transparency
iii. Ease of use
iv. Data requirements are consistent with the importance of the issue being considered
v. Realistic time and manpower resource requirements for the analytical process.
vi. Ability to provide and audit trail, software availability, where needed.

The categorization methods can be classified based on the decision maker's information (no information, information on qualities, or information on alternatives) and data type.

There is a need to evolve a decision system based on these factors which can help identifying components equipment that are significant in the point of view of maintenance so as to enable the maintenance managers to decide upon relevant maintenance strategies. This paper presents a multi-attribute approach for evaluation of maintenance criticality of components of the system based on the TOPSIS technique.

These are made from organic and inorganic compounds, devoid of petroleum substances. Synthetic fluids are used for light weight machining operations (Xavior & Adithan, 2009). The disadvantages of synthetic fluids are they form a lot of fine mist during machining which are hazardous therefore causing nasal health related issues and dermatitis to the machinist, however when mixed with hard water it leaves sticky remains on the machine system . The advantage of the synthetic fluids is they do not undergo most of the problems related with oil based fluids. (Xavior & Adithan, 2009).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Materials

The following components of the production plant at Chanchaga Municipal Water Works Components are the materials for the study. Valves, Pumping machines, Pipes lines, Reservoir, Power source, Fire Hydrants, Water tanker.

3.1.1 Pumping machine

Pumps are utilized in a water distribution system to improve the energy output (Mays, 2006). Pumps come in a variety of shapes and sizes. Positive displacement pumps, kinetic pumps, turbine pumps, horizontal centrifugal pumps, and vertical centrifugal pumps are examples of these pumps. Centrifugal pumps, on the other hand, are the most widely utilized type of pump in water distribution systems. This is due to their inexpensive cost, simplicity, and dependability across a wide range of flows and head (Mays, 2006) defined a centrifugal pump as "any pump in which fluid is energized by a rotating impeller," regardless of whether the flow is radial, axial, or a combination of the two. The fluid in radial flow pumps is displaced axially in the pump, whereas the fluid in mixed-flow pumps is displaced both radially and axially in the pump (Punmia *et al*., 2001) pointed out that small-capacity pumps can be run in tandem to provide maximum variable discharge at maximum efficiency. It is extremely possible to operate each pump near optimum efficiency with a parallel setup. The same discharge flows through each pump in series operation, increasing the pressure (or head) in the process. Pumps in series, unlike parallel pumps, work at the same time. The following strategies were outlined by (Feldman, 2009) on how pump stations and other controlled facilities are usually operated.

1. Variations in section pressure trigger the commencement of pressure control pumps. Increased demand would lower network pressure and make pump start-up more difficult. When pressure rises owing to a drop in demand, a pump is turned off.

2. Pumps for level control are initiated and stopped in response to changes in reservoir water levels.

3. Pumps that are controlled by time are started and stopped at specific times throughout the day.

In pumped supply, pumps are used to develop the necessary pressure head to distribute water to the consumers and storage reservoirs (Punmia*et al*., 2001) believe that such a system is undesirable since it necessitates pumping raw water from the source to the treatment plant, followed by pumping purified water directly into the distribution mains. Depending on the changes in consumption, the pumps must be run at different speeds. Whereas, if there is power failure the entire water distribution system is disturbed. Also, the system requires constant attendance.

Table 3-1Pumping stations

Pump Station	Pump	Design Flow (Q) $M^{3/h}$	Design Head H(m)	Attributes of each pump				
				Type	Speed (n)	Power (Kw)	Manu	Date installed
	1	350	150.3	Centifugal	1490	230	KSB	2010
	2	558	150	Centifugal	1490	335	KSB	2000
	3	558	150	Centifugal	1490	355	KSB	2000
	4	350	150.3	Centifugal	1490	230	KSB	2010
	5	350	160	Centifugal	2900	230	Overman	2010
	6	350	150.3	Centifugal	1490	230	KSB	2010
	1	490	190	Centifugal	1470	300	Weir pump	2012
	2	475	160	Centifugal	2900	315	Mass Daft	2010
	3	608	180	Centifugal	1490	315	Overman	2010
	4	475	160	Centifugal	2900	315	Weir pump	2010

(Municipal Water Works, Minna).

Plate I: Centrifugal pump with a capacity of 355kW (Municipal Water Works, Minna)

3.1.2 Pipe lines

The transmission system, which consists of raising mains, and the distribution system, which consists of distribution mains, make up the water system piping. The transmission system is made up of components that are designed to transport huge amounts of water across long distances from water treatment plants to service reservoirs. The transmission system's pipes range in diameter from 300 to 900 mm and have a total length of 43,125meters.Water is subsequently transferred from the service reservoirs and transmission pipe to the users via the distribution pipe. The distribution system is made up of pipelines with diameters ranging from 100 to 400 mm and a total length of 94,625 meters. Ductile iron, galvanized iron, asbestos cement, and polyvinyl chloride (PVC) pipes are used to construct the pipelines. The diameter, length and materials of the pipes in the transmission and distribution systems are shown in Tables 3.2(a) and 3.2(b), respectively.

Table 3-2: **Transmission system piping**

Diameter (mm)	Length (m)	Material
900	5500	DI
700	3125	DI
600	1875	DI
500	6625	DI
450	18125	DI
300	7875	DI

(Municipal Water Works, Minna).

Table 3-3: A distribution system piping

Diameter (mm)	Length (m)	Material
400	1500	DI
400	2875	AC
350	2062.5	DI
300	25125	AC
250	1937.5	AC
250	2250	PVC
225	1875	AC
200	2000	PVC
200	850	AC
150	36725	AC
150	4875	PVC
100	6287.5	AC
100	4700	PVC
100	1000	GI

(Municipal Water Works, Minna)

Plate II:: A Transmission system piping (Municipal Water Works, Minna)

3.1.3 Valves

Valves are used in water distribution systems for a variety of purposes, including isolation, air release, drainage, checking, and pressure reduction. A total of 102 valves were inventoried. The valves were air release valves, sluice valve and butterfly valves. The sizes of the valves ranged from 300 to 900mm on the transmission pipelines and 100 to 400mm on the distribution pipe lines.

Sluice and gate valves are widely employed in the distribution system to turn off supply as needed. They also divide the water mains into suitable sections. The air valves were used to discharge air when the mains are being filled and to admit air when it is being emptied. The admission of air on empting the main is of great importance on steel mains which may flatten if the pressure falls below that of atmosphere. As such bad and inoperable valves result in loss of considerable quantity of water. Valves are said to be reliable if they can be found and identified under all-weather condition and can be operated and works properly. The valves in the transmission and distribution system with their diameters are shown in the table below:

Table 3-4: A transmission main valves

Valve type	Diameter (mm)
Air release	900
Air release	700
Air release	500
Butterfly	450
Butterfly	900
Butterfly	700
Butterfly	500
Butterfly	450
Butterfly	300

(Municipal Water Works, Minna).

Table 3-5: A distribution main valves

Valve Type	Diameter (mm)
Sluice	400
Sluice	350
Sluice	300
Sluice	250
Sluice	225
Sluice	200
Sluice	150
Sluice	100
Gate	200

(Municipal Water Works, Minna).

Plate III: A transmission main valve (Municipal Water Works, Minna)

3.1.4 Storage and distribution reservoirs

Storage and distribution reservoirs are crucial units in a contemporary distribution system, according to (Punmia *et al.*, 2001). Filtered water must be stored in clear water storage until it is pumped into service reservoirs or distribution reservoirs. The roles and economic benefits of service reservoir were listed by (Bhargava and Gupta 2004) as follows:

i. The service reservoirs absorb the hourly variations in flow and allow the pumps to run at a constant speed. This increases efficiency while lowering operating costs.
ii. The pumping of the water in shifts and in tune with power supply hour is made possible through the reservoirs without effecting the supply, 8 to 16 hours of pumping may easily pump the supply of the whole day;
iii. The reservoir help maintain a constant pressure in the distribution mains, otherwise the pressure would drop with increasing demand;
iv. The reservoir make economy by reducing the size of the pump; and
v. Reservoir could also serve as storage for emergencies such as outbreak of fire, failure of pumps or bursting of mains a started by (Punmia *et al.*, 2001).

Storage reservoirs can be above, on, or below the ground surface, depending on terrain and local environmental circumstances. Small ground-level reservoirs are normally earth-lined with granite, asphalt, or some synthetic membrane. Underground reservoirs are usually made of reinforced concrete. Concrete is used to line large surface reservoirs.

Water towers and elevated reservoirs are frequently employed to obtain the requisite head inside the distribution system. The ground-level water tower can be made of either prestressed concrete or steel. Steel is commonly used to create elevated water-storage reservoirs. According to (Otun and Abubaka, 2009), the capacity of a storage reservoir is the required volume to store excess when supply exceeds demand, as well as to provide a deficiency when demand exceeds supply. There should also be space set for requirements and dismantling storage. They estimated the reservoir's equalizing volume to be between 1/6 and 1/3 of the entire demand.

Table 3-6: Minna Municipal service reservoir

Reservoir name	Material	Shape	Vol(m^3)	Year of Construction	Areas Served
Biwater tank	Bolted steel	Rectangular	4,500	1984	Shango,Barkin-sale,ArmyBarrack,new secretariat
Shiroro Tank	Reinforced Concrete	Rectangular	2000	1995	Tunga, Tungalowcost,shiroro
Tunga East Tank	Reinforced Concrete	Rectangular	2000	1995	Tunga, David Mark ro Tunga market, Top Medi road.
INEC Tank	Reinforced Concrete	Trapezoidal	1000	1964	Police barracks, Bay cli road, school of midwife Tunga dan boyi rail-v quarters
Uphill tank	Reinforced Concrete	Circular	7000	2000	Minna central, Old airp Maitumbi, Bosso road, quarters, commissione quarters
Paida hill Tank	Reinforced Concrete	Circular	4000	1995	UngwanDaji, Unguwansarki, F-layout, Zarumai,Abayi
Dutsekura tank	Reinforced Concrete	Circular	10000	1995	Dutsenkurahausa,dutsenkuragwari, bossolowcost,bossoEstate,police secondary school, shanu village, London street

(Municipal Water Works, Minna).

Plate IV: A clear water storage surface reservoir (Municipal Water Works, Minna)

3.1.5 Hydrant

Throughout the distribution system, there is only one operational hydrant. A fire hydrant is an active fire-fighting measure and a source of water given in most urban, suburban, and rural areas with municipal water service to allow fire-fighters to tap into the municipal water supply to aid in the extinguishment of a fire. Given the importance of fire hydrants, the Water Board should build more fire hydrants in strategic locations across the water distribution system.

Plate V: A fire Hydrant (Municipal Water Works, Minna)

3.1.6 Power source

Power source is one of the main components because the equipment cannot operate themselves without power supply. The power is supply to Chanchaga water works from Shiroro to its sub-station with about 5MVA capacity which is also step down with the help of step down transformer to 33kVA and further step down to a voltage of 11kVA and finally to 415V which is the design voltage for most of the equipment can operate depending the type of duty they assign to do. Some equipment use only single phase, some are double phase while some are 3-phase for them to be function perfectly. In case of power failure, two standby generators are available with capacities of 1000kVA and 2000KVA respectively. These generators supply the entire units when they experience power failure in the water works.

Plate VI: A step down Transformer deck (Municipal Water Works, Minna)

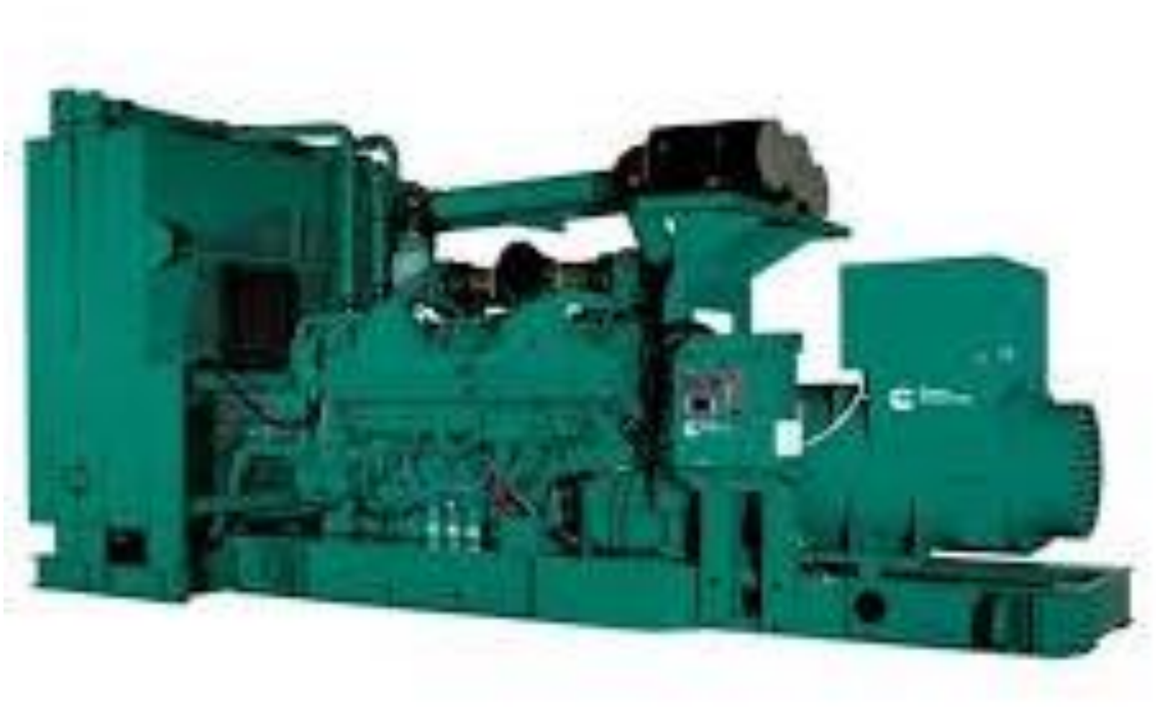


Plate VII: A DC generator with a capacity of 2000kva (Municipal Water Works, Minna)

3.1.7 Water tanker

During the earliest stages of an emergency, a water tanker (also known as water trucking) can be a quick way to supply water to communities in need. Tanker operations, on the other hand, are costly and time-consuming to manage. This technical note looks at some of the most important aspects surrounding the effective and efficient deployment of tankers in an emergency.

Water can be transported in a variety of containers, some of which are expressly built for the job and others which are fabricated to meet an immediate demand; if at all possible, utilize specially designed water tankers. They'll be more dependable and safer. If the tank is not securely fastened, temporary tankers manufactured from flatbed trucks with portable storage tanks attached can be hazardous.

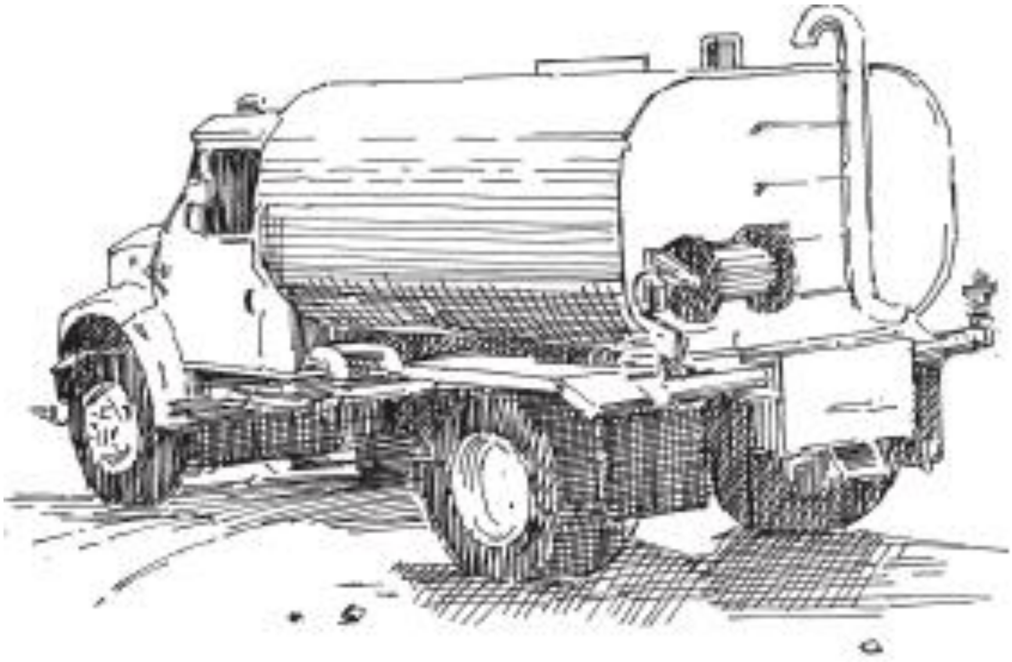


Plate VIII: A purpose- built tanker.(Municipal Water Works, Minna)

3.2 The Existing Criteria for this Research Work

3.2.1 Scoring Scheme for Maintenance Significant Factors;

The failure of an item, its repair, and continued use raise a number of concerns. The occurrence of failure, severity, and reliability of an item are all factors associated to item failure. The issue of repair can be linked to service time and the ability to organize resources for repair, both of which are classed as maintainability and lead time to procure parts. When the device is used, a measure of safety and financial loss may be necessary. Measures such as the economic safety factor help alleviate this fear. As a result, the seven parameters to be evaluated in this study are: likelihood of failure (occurrence), chance of non-detection, reliability importance measure, maintainability, spare component lead time, economic safety factor, and Taguchi loss function (Camacross and Feachem, 1988).

Each attribute is evaluated in a variety of ways by defining a rational approach for quantifying the single criterion for each cause of failure, which is based on a set of tables. To accommodate for the various criticality levels, each factor is separated into many classes, each of which is assigned a distinct score (ranging from 1 to 9).

After then, the scores were determined based on the maintenance personnel's experiences. Below is a quick overview of the process and technical data used to assign the various scores?

3.2.2 Chance of failure (O)

It is concerned with how frequently a failure mode happens; a greater score suggests that the item is more vital. The likelihood of failure was calculated as a function of the Mean Time Between Failures (MTBF). Data on component MTBF was gathered from past historical records and maintenance logbooks, and then combined with maintenance personnel's experience. For example, if a component's MTBF is between 2 and 4 months, the probability of failure is between 7 and 8. Table 3.7 shows the likelihood of failure, as well as the MTBF and scores associated with it.

Table 3-7: Chance of failure (O)

Occurrence	MTBF	Scores
Almost never	>2 years	1
Rare	2-3 years	2
Very few	1-2 years	3
Few	3/4- 1 years	4
Medium	6-9 months	5
Moderately high	4-6 months	6
High	2-4 months	7
Very high	1-2 months	8
Extremely high	< 30 days	9

(Marivappan, 2004)

The **Chance of failure** can be estimated based on the MEAN TIME BETWEEN FAILURE (MTBF), defined as the mean value of the length of time which elapses between failures. However, this measure is applicable only to reparable items. Computation of MTBF of repairable components can be further classified into two main methods vis; replacement and non–replacement methods.

Base on replaceable, MTBF

$$\boldsymbol{MTBF} = \frac{\boldsymbol{t_n - t_o}}{\boldsymbol{n}} \tag{3.1}$$

Where; t_o is the reference starting time, n is the number of failures, t_n is the time to n^{th} failure.

3.2.3 Non-detection of failures (D)

The likelihood of detecting a failure cause or mechanism is dependent on a number of factors, including the operator's or maintenance personnel's ability to detect failure with the naked eye, through periodic inspection, or with the assistance of machine diagnostic aids such as automatic controls, alarms, and sensors (Table 3.8).

Table 3-8: Non-detection of failure (D)

Likelihood of non- detection (%)	Criteria for non-detection of failures	Score
<10	Extremely low	1
10-20	very low	2
21-30	Low	3
31-40	Fair	4
41-50	Medium	5
51-60	moderately high	6
61-70	High	7
71-80	very high	8
>80	Extremely high	9

(Marivappan, 2004)

Therefore, the number of failure dictated (D) by the operator, or by the periodical inspection or by machine diagnostic aids/total number of failure occurred can be expressed as;

$$\boldsymbol{D} = \frac{\boldsymbol{Nf}}{\boldsymbol{N}} \tag{3.2}$$

3.2.4 Reliability importance measure (RI)

The change in top event occurrence for a given change in the probability of occurrence of input event is assessed using Biranbaum's Reliability Importance (RI) measure. The chance that a system will be in a critical condition due to the breakdown of a component at time t is represented by Birnbaum's component measure. The Birnbaum’s is estimated as follows;

Let $(t) = \left(r_{1(t)}, r_{2(t)}, \dots, r_{n(t)}\right)$, be the vector of individual component reliabilities at time t, and $RS(r(t))$ be the system reliability. The i^{th} component's importance is measured by the Birnbaum expression as follows:

$$\boldsymbol{I_i^B(t)} = \frac{\partial \boldsymbol{RS}(\boldsymbol{r}(\boldsymbol{t}))}{\partial \boldsymbol{r}_i(\boldsymbol{t})} = \boldsymbol{RS}\,[\boldsymbol{r}_i = \mathbf{1}, \boldsymbol{r}(\boldsymbol{t})] - \quad [\boldsymbol{r_I} = \mathbf{0}, \boldsymbol{r}(\boldsymbol{t})] \tag{3.3}$$

…where $[1,(t)]S_iR\, r = r\,(t)$ and $[0,(t)]S_i\, R\, r = r(\,t)$ represent the reliability of the system with component i in functioning and failed states, respectively. From the inspection data collected for the pump, pipe and the valve (see appendix B, E,& F) the chance of failure, non- detectability of failure and reliability importance measure can be calculated. Table 3.9 shows the parameters for assigning a dependability important score to a component.

Table 3-9: Reliability importance measure (RI)

Criteria %	Criteria for Reliability importance	Score
Less than 10	Negligible	1
10 to20	Slight	2
20 to 30	Little	3
30 to 40	Minor	4
40 to 50	Moderate	5
50 to 60	Significant	6
60 to 70	High	7
70 to 80	Very high	8
More than 80	Extremely high	9

(Marivappan, 2004)

3.2.5 Maintainability (M)

Maintainability is defined as the likelihood that an item, component, or system can be returned to its original/desired state within a given time frame. A low score suggests a decreased likelihood of returning the equipment to its original/desired state. As a result, a lower maintainability score is connected with a higher maintenance criticality index. Table 3.10 shows the scores allocated to the various levels of the maintainability index.

Table 3-10: Maintainability (M) Score

Criteria	Maintainability	Score
$M_t > 0.8$	Almost certain	1
$0.7 < M_t \leq 0.8$	Very high	2
$0.6 < M_t \leq 0.7$	High	3
$0.5 < M_t \leq 0.6$	Moderately high	4
$0.4 < M_t \leq 0.5$	Medium	5
$0.3 < M_t \leq 0.4$	Low	6
$0.2 < M_t \leq 0.3$	Very Low	7
$0.1 < M_t \leq 0.2$	Slight	8
$M_t < 0.1$	Extremely Low	9

(Marivappan, 2004)

3.2.6 Spare parts (sp)

Maintenance necessitates a huge number of spare components. Their likelihood of availability and importance to the equipment's operation have a significant impact on the equipment's maintenance criticality. Because spare parts are so important, this aspect must also be considered when determining the maintenance criticality of a component. The likelihood of spare parts availability is graded on three levels: easy, difficult, and scarce, and their relevance is graded on three levels: crucial, essential, and desirable. Table 3.9 below shows the score scheme for their combinations.

Table 3-11: Spare parts Score (SP)

Criticality	Availability		
	Easy	Difficult	Scarce
Desirable	1	4	7
Essential	2	5	8
Vital	3	6	9

(Marivappan, 2004)

3.2.7 Economic safety loss (ES)

When determining the maintenance criticality of a component, the economics of safety must also be considered. With a larger number of moving parts, the repercussions of failure (particularly in terms of safety) are greater. Table 3.10 shows the grading scheme for assigning scores with the Economic Safety Loss (ES).

Table 3-12: Economic safety loss (ES) Score

Status of the equipment/ sub system	Score
With no moving parts	3
With one moving part/critical category	6
With more than one moving parts/critical category	9

(Marivappan, 2004)

3.2.8 Taguchi loss function (TL)

When a product/service does not perform/delivered optimally, the organization and the society suffer a loss as a whole. This loss is known as Taguchi loss. Though Taguchi loss is basically a quality loss, but quality of a product is directly affected by maintenance of any equipment. Higher the level of maintenance better will be the quality. The average loss is expressed as follows: Where A is the loss when quality characteristics assume the value of its specification limits and Δ is the difference between specifications limit and target value. The loss obtained with this equation is used for assigning the scores to this function are shown in the Table 3.13.

Table 3-13: Taguchi loss function (TL) Score

Criteria	Average Loss	Score
$L(X) \leq 0.01$	Negligible	1
$0.01A < L(X) \leq 0.02A$	Marginal	2
$0.02A < L(X) \leq 0.06A$	Very Low	3
$0.06A < L(X) \leq 0.15A$	Low	4
$0.15A < \ L\ (X)\ )\ \leq\ 0.30A$	Medium	5
$0.30A < L(X) \leq 0.60A$	Moderately high	6
$0.60A < L(X) \leq 1.0A$	High	7
$1.0A < L(X) \leq 4.0A$	Very high	8
$L(X) > 4.0A$	Severe Loss	9

(Marivappan, 2004)

3.3 TOPSIS Analysis

In the analysis of TOPSIS technique of multiple – criteria decision method, the ranking of the existing alternatives involves in the problem will be comparing with each other through the individual alternative criteria by which at the end, best alternative will have the closest distance to the ideal solution and farthest distance from the negative ideal solution.

i. Collection of the data
ii. Formation of the decision matrix
iii. Determination of normalized decision matrix
iv. Determination of weighted normalized decision matrix
v. Determination of ideal and negative ideal solution
vi. Determination of separation from positive and negative ideal solution
vii. Determination of relative closeness to the ideal solution
viii. Prioritization of the alternatives based on their maintenance significance.

3.3.1 Procedure for TOPSIS Implementation

The origin of the TOPSIS was from the work of (Hwang and Yoon,1981). The decision problem involving selecting from n alternative maintenance location based on m criteria can be represented as a matrix, $Q_{m,n}$as shown in equation (3.1) (Jahanshaloo *et al.,* 2006).

$$\boldsymbol{Q_{m,n}} = \begin{bmatrix} \boldsymbol{Q_{1,1}} & \boldsymbol{Q_{1,2}} & \cdots & \boldsymbol{Q_{1,n}} \\ \boldsymbol{Q_{2,1}} & \boldsymbol{Q_{2,2}} & \cdots & \boldsymbol{Q_{2,n}} \\ \vdots & \vdots & \ddots & \boldsymbol{Q_{1,1}} \\ \boldsymbol{Q_{m,1}} & \boldsymbol{Q_{m,1}} & \dots & \boldsymbol{Q_{m,n}} \end{bmatrix} \tag{3.4}$$

The determination of normalized decision matrix will be calculated using the formula

$$\boldsymbol{n_{i,j}} = \frac{\boldsymbol{Q_{i,j}}}{\sqrt{\sum_{i=1}^{m} \boldsymbol{Q_{i,j}^2}}} \tag{3.5}$$

The benefit criterion can be deduced from the above normalized decision matrix to have

$$\boldsymbol{n_{i,j}} = \frac{\boldsymbol{Q_{i,j}}}{\boldsymbol{Q_{max}}} \tag{3.6}$$

While the cost criterion is giving by the formulae

$$\boldsymbol{n_i} = \frac{\boldsymbol{Q_{min}}}{\boldsymbol{Q_{ij}}} \tag{3.7}$$

The weighted normalized formulae was determined from the equations (3.3) and (3.4) which yield

$$\boldsymbol{v_{i,j}} = \boldsymbol{w_j n_{i,j}} \tag{3.8}$$

The positive ideal solution formulae is giving by

$$\boldsymbol{V^+} = \{\boldsymbol{v_1^+}, \boldsymbol{v_2^+}, \dots, \boldsymbol{v_n^+}\} \tag{3.9}$$

While the negative ideal solution formulae is giving by

$$\boldsymbol{V^-} = \{\boldsymbol{v_1^-}, \boldsymbol{v_2^-}, \dots, \boldsymbol{v_n^-}\} \tag{3.10}$$

The relative closeness to the ideal solution formulae is giving by

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{i,j} - v_j^+\right)^2} \tag{3.11}$$

While the relative closeness to the negative ideal solution formulae is giving by

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{i,j} - v_j^-\right)^2} \tag{3.12}$$

The ranking coefficient of the alternatives formulae is giving by

$$R_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{3.13}$$

The procedure ends with the establishment of the alternatives ranking in the decreasing order of the R_i value rating.

3.4 Important of Weighting Criteria

Considering that the weights of criteria might have a major impact on the outcome of the decision-making process. As a result, it's critical to pay close attention to the criteria weights. The usage of weighting methods is taken into account when deciding the criteria preference of each criterion in order to achieve desirable features and to establish and satisfy a multiple measure of performance across all the criteria chosen by selecting the best alternative feasible. In multi-criteria evaluation, weights allocated to criterion have qualitative and quantitative data to ensure that the weight is taken into account for better and more accurate decision making. However, giving weights to criteria using qualitative data might be impacted by decision maker preference, hence (Saaty, 1977) established a numerical scale of "1– 9" to convert qualitative data into quantitative data, with "1" denoting equal relevance and "9" denoting great importance. Subjective, objective, and integrated or combined weighting approaches are the three types of weighting approaches (Ginevicius and Podvezko, 2005).

Expert opinion is used to determine subjective weight, and in order to obtain subjective judgements, analysts typically ask decision makers a series of questions. Subjective criteria weight determination, on the other hand, might take a long time, especially when there is no agreement among the problem's decision makers. Analytical Hierarchy analysis is an example of a subjective weighting method (AHP).Criteria weights are derived from information obtained in each criterion by mathematical models in objective weighting procedures, with no consideration of the decision maker's influence (Aldian and Taylor, 2005). The integrated weighing approach is a form of weighting that combines subjective and objective weighting techniques. It relies on the notion of merging subjective weights based on an expert's opinion based on his or her expertise and experience in the relevant sector, as well as data acquired from the criteria data in a quantitative form (objective weighting method).

3.5 Entropy Method

The entropy approach is used to determine the weight in an issue since the decision matrix for a set of candidate materials has a specific amount of information when using this method. The entropy is based on a decision matrix that is predefined. In information theory, entropy is a criterion for the amount of uncertainty represented by a discrete probability distribution, with consensus that a broad distribution indicates more uncertainty than a tightly packed one (Deng *et al.*, 2005). For each criterion, the entropy of the set of normalized outcomes of the j^{th} criterion is determined using material data, and the entropy of the set of normalized outcomes of the j^{th} criterion is given by

$$\boldsymbol{E_i = -\left[\sum_{i=1}^{m} p_{ij}\ln\left(p_{ij}\right)\right]/\ln(m);\ \mathrm{j} = 1, 2 \ldots} \tag{3.14}$$

The p_{ij} form the normalized decision matrix and is given by

$$\boldsymbol{p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}}; i \ = 1, 2, \ldots., and \ ; j = 1, 2, \ldots} \tag{3.15}$$

Where r_{ij} are the elements of the decision matrix; k is aconstant of the entropy equation and j E as the information entropy value for j^{th} criteria. Hence, the criteria weights, w_j is obtained using the following expression.

$$\boldsymbol{w_{ij} = \frac{1 - E_j}{\sum_{j=1}^{n}(1 - E_j)}} \tag{3.16}$$

Where (1-E) is the outcome of the information drive from the criterion "J".

Table 3-14: The collected criteria data

Components	**Criteria**						
Alternative	Chance of failure (O)	Non-detection of failure (D)	Reliability importance Measure (RI)	Maintain ability (M)	Spare Part (SP)	Economy safety loss (ES)	Taguchi Loss Function (TL)
Pump	5	2	5	5	6	6	2
Pipe	3	1	4	5	6	3	1
Valve	4	1	3	5	6	3	1
Reservoir	2	1	1	5	3	3	1
Fire hydrant	1	1	1	5	5	3	1
Power	5	1	5	5	6	9	6
Water Tanker	5	2	5	5	5	9	5

The characteristics of seven distinct components data acquired from Niger State Water Board Minna are described in Table 3.12. Pump, pipe, valve, reservoir, and fire are the components. The options include hydrant, power source, and water tanker, which are represented as $A_1, A_2, A_3, A_4, A_5, A_6,$ and A_7, respectively, while the criteria are chance of failure, non-detection of failure, and cost of failure. Measure of the importance of reliability, $C_1, C_2, C_3, C_4, C_5, C_6,$ and C_7 indicate maintainability, spare parts, economic loss functions, and Taguchi loss functions, respectively.

3.6 Indicative Case Study

To expose the workability of the model, an indicative case study will be used that considers only three alternatives and three criteria namely: pump designated as A_1, pipe (A_2) and valve (A_3) and chance of failure designated as (C_1) Non detection of failure (C_2) and Reliability importance measure (C_3) respectively.

The MTBF representing the chance of failure of the pump is then computed using equation 3.1 From the operation of the component, it can be deduced that $t_0 = 0$, $t_1 = 7$,$t_2 = 5$, $t_3 = 3$, $t_4 = 1$:

Whence the MTBF can be calculated as; $MTBF\ pump\ = \frac{t_n - t_o}{n}$

$$= \frac{16 - 0}{4} = 4$$

Similarly, the MTBF for the periods $t_0 = 0$, $t_1 = 5$ is;

$$= \frac{5 - 0}{1} = 5$$

MTBF Pump;$= \frac{5+9}{2} = 4.5$

For the valves, $t_0 = 0$, $t_1 = 3$, $t_2 = 3,\ t_3 = 3$; $MTBF\ pipe\ = (t\_n - t\_o)/n$ implies that

$$= \frac{11 - 0}{3} = 3.6$$

For $t_0 = 0$, $t_1 = 4$, $t_2 = 4$,and $t_3 = 4$.

Whence, MTBF pipe is

$$\frac{12-0}{3}=4$$

Considering the valve under similar condition; t_0 =0, $t_1 = 7$, $t_2 = 3$, t_3 = 1

$$\frac{11-0}{3}=3.6$$

For the period; $t_0 = 0$, $t_1 = 4$, $t_2 = 4$, $t_3 = 4$

$$\frac{12-0}{3}=4$$

Whence *MBTF valve* $= \frac{3.6+4}{2} = 3.8$.

The same procedure can be carried out for Non-dictation of failure calculated as $\frac{N_f}{N}$

$$D_{(pump)} = \frac{20+20+18+20+30+18+10+21+24+20+30+10}{12} = 20.08\%$$

$$D_{pipe} = \frac{15+10+10+10+11+7+6+6+8+9+8+6+7}{12} = 8.9166\%$$

$$D_{valve} = \frac{11+11+10+10+8+9+8+10+15+10+8}{12} = 9.1666\%$$

Considering the reliability importance measure$\left(\frac{\partial RS(r(t))}{\partial r_i(t)}\right)$, the following procedure can be observed;

$$I_i^B(t)\,pump = \frac{60+60+48+45+45+50+53+50+55+40+46+48}{12} = 50.00\%$$

$$I_i^B(t)\,pipe = \frac{34+30+41+39+43+30+31+40+33+31+30+30}{12} = 34.33\%$$

$$I_i^B(t)valve = \frac{24+20+29+30+31+35+22+24+20+28+24+23}{12} = 25.83\%$$

The formula below was used to derive the decision matrix of equation 3.4 as follows;

	C_1	C_2	C_3
A_1	5	2	5
A_2	3	1	4
A_3	4	1	3

The determination of normalized decision matrix is calculated using the equation below.

$$n_{i,j} = \frac{Q_{i,j}}{\sqrt{\sum_{i=1}^{m} Q_{i,j}^2}}$$

	C_1	C_2	C_3
A_1	0.7071	0.8165	0.7071
A_2	0.4243	0.4083	0.5657
A_3	0.5657	0.4082	0.4243

The determination of Entropy value is calculated using the equation below

$$E_i = -\frac{\left[\sum_{i=1}^{m} p_{ij} \ln\left(p_{ij}\right)\right]}{\ln(m)}; \mathrm{j} = 1,2 \ldots$$

Whence the Entropy Value E_j is

	C_1	C_2	C_3
E_j	0.5354	0.3013	0.5354

The determination of weighted criteria value is calculated using the equation below

$$w_{ij} = \frac{1 - E_j}{\sum_{j=1}^{n} (1 - E_j)}$$

Wight Criteria Values W_j

	C1	C2	C3	TOTAL
W_j	0.2854	0.4292	0.2854	1

The determination of weighted normalized decision matrix is calculated using equation

$$v_{i,j} = w_j n_{i,j}$$

Weighted Normalized Decision Matrix

	C_1	C_2	C_3
A_1	0.2018	0.3504	0.2018
A_2	0.1211	0.1752	0.1615
A_3	0.1615	0.1752	0.1211

The ideal positive and negative solution determines using the formulae

$$V^+ = \{v_1^+, v_2^+, \dots, v_n^+\}$$

$$V^- = \{v_1^-, v_2^-, \dots, v_n^-\}$$

A+	0.2018	0.3504	0.2018
A-	0.1211	0.1752	0.1211

The relative closeness to the positive and negative ideal solution are determined using the formulas below.

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{i,j} - v_j^+\right)^2}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{i,j} - v_j^-\right)^2}$$

Separation from Positive and Negative Ideal Solution

	S^+	S^-
A_1	0.0000	0.2091
A_2	0.1971	0.0404
A_3	0.1971	0.0404

The ranking coefficients of the Alternatives are determined by using equation

$$R_i = \frac{d_i^-}{d_i^- + d_i^+}$$

	C_i	RANK
A_1	0.0000	2
A_2	0.8300	1
A_3	0.8300	1

Following the steps undertaken in the indicative case study, the main work considers seven criteria and seven alternatives. The decision matrix is obtained as presented in equation 3.1.The steps of TOPSIS was repeated based on the decision matrix of Table 3.13. Finally, the result shows that the alternative A_2 and A_3which are pipe and valve are having the same magnitude of relative closeness coefficient of 0.830012 and that indicate that the two components suffers highest criticality. The alternative A_1 which is pump is having the relative closeness coefficient of 0 and that shows that it has a less criticality in maintenance. Therefore, the alternatives A_2 and A_3 need to be address urgently while that of A_1which is pump can be delayed.

Table 3-15: Decision matrix

	Criteria						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	5	2	5	5	6	6	2
A_2	3	1	4	5	6	3	1
A_3	4	1	3	5	6	3	1
A_4	2	1	1	5	3	3	1
A_5	1	1	1	5	5	3	1
A_6	5	1	5	5	6	9	6
A_7	5	2	5	5	5	9	5

Table 3-16: Normalized decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.4880	0.5547	0.4951	0.3780	0.4211	0.3922	0.2408
A_2	0.2928	0.2774	0.3961	0.3780	0.4211	0.1961	0.1204
A_3	0.3904	0.2774	0.2970	0.3780	0.4211	0.1961	0.1204
A_4	0.1952	0.2774	0.0990	0.3780	0.2106	0.1961	0.1204
A_5	0.0976	0.2774	0.0990	0.3780	0.3509	0.1961	0.1204
A_6	0.48805	0.2774	0.4951	0.3780	0.4211	0.5884	0.7223
A_7	0.4880	0.5547	0.4951	0.3780	0.3509	0.5884	0.6019

Table 3-17: Entropy values E_j

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
E_j	0.9000	0.7560	0.8586	1.3230	1.1542	1.1320	1.4980

Table 3-18: Weights criteria values W_j

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Total
W_j	-0.1617	-0.3932	-0.2279	0.5202	0.2484	0.2125	0.8017	1

Table 3-19**:** Weighted normalized decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	-0.0789	-0.2181	-0.11282	0.19662	0.1046	0.08335	0.19302
A_2	-0.04734	-0.10905	-0.09025	0.19662	0.1046	0.04167	0.09651
A_3	-0.06312	-0.10905	-0.06769	0.19662	0.1046	0.04167	0.09651
A_4	-0.03156	-0.10905	-0.02256	0.19662	0.0523	0.04167	0.09651
A_5	-0.01578	-0.10905	-0.02256	0.19662	0.08717	0.04167	0.09651
A_6	-0.0789	-0.10905	-0.11282	0.19662	0.1046	0.12502	0.57905
A_7	-0.0789	-0.2181	-0.11282	0.19662	0.08717	0.12502	0.48254

Table 3-20: Positive and negative ideal solution

A^+	-0.0789	-0.2181	-0.11282	0.19662	0.0523	0.04167	0.09651
A^-	-0.01578	-0.10905	-0.02256	0.19662	0.1046	0.12502	0.57905

Table 3-21: Separation from positive and negative ideal solution

	S^+	S^-
A_1	0.3178	0.4181
A_2	0.1270	0.4954
A_3	0.1301	0.4940
A_4	0.1493	0.4927
A_5	0.1589	0.4900
A_6	0.7100	0.1101
A_7	0.6279	0.1834

Table 3-22: Relative closeness for ideal solution

	C_l	Rank
A_1	0.5682	5
A_2	0.7960	1
A_3	0.7916	2
A_4	0.7675	3
A_5	0.7552	4
A_6	0.1343	7
A_7	0.2261	6

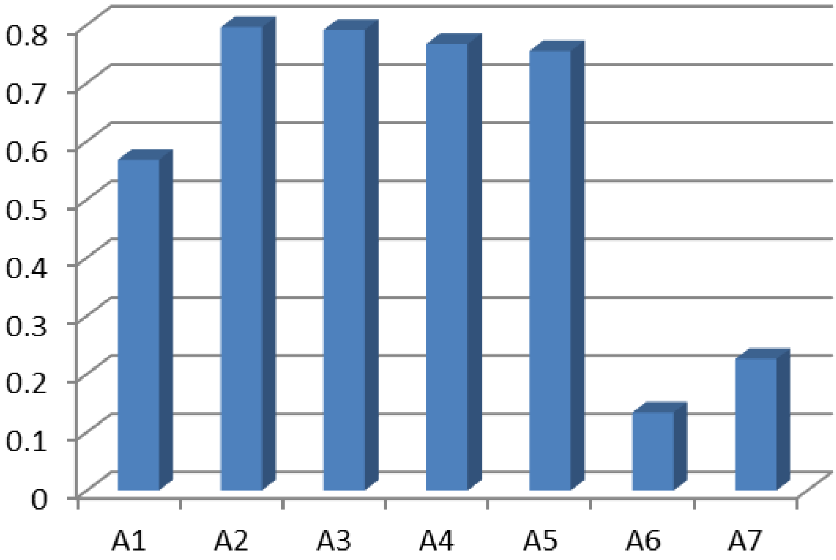


Figure 3-1: Final ranking of components based on their maintenance significance

The bar chart above shows the final results of the components considered in this research work based on their relative closeness coefficient's magnitude of which A_1 is the pump, A_2 is pipe, A_3 is valve, A_4 is the reservoir, A_5 is fire hydrant, A_6 is power and A_7 is water tanker respectively.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results of the Research

The table below shows the final results of the research work.

Table 4-1: The final ranking of the results

	C_1	Rank
A_1	0.56815	5
A_2	0.79592	1
A_3	0.79162	2
A_4	0.7675	3
A_5	0.75517	4
A_6	0.13429	7
A_7	0.22608	6

4.2 Discussion of the Results

This research work is a case study of Chinchaga water works, Minna. As a result of budget shortage the company is facing, there is a need for the management to prioritize the existing components in terms of their criticality that will be of help to the management to know the component that needs urgent attention and which to be delay. This paper presents the application of the proposed MCDM method (TOPSIS) with Entropy method of determining the weighted criteria values to the problem of prioritizing the component's criticality. The seven existing components are considered in this research work to check their criticality. The result was obtained from the Table3.20. The alternative A_2 which is pipe has relative closeness coefficient of 0.79592 which shows its highest criticality. This is attributed to age of the pipes, high pressure in the system during the period of low water consumption, environmental and soil condition among others.

The Alternative A_3 which is valve has the second value of relative closeness coefficient of 0.7916 which is very close to that of pipe. This is attributed to the responsibility of the component during the normal operating processes.

The alternative A_4 which is the reservoir becomes the third component that suffers criticality with relative closeness coefficient of 0.7675.This is attributed to the age of the component. Though the Alternative A_5 which is fire Hydrant with relative closeness of 0.75517 is very close to that of reservoir in value of which they are almost the same value range of criticality. This is attributed to the scarcity of the component within Minna metropolis. Therefore, these components need to be treated simultaneously since there relative closeness coefficient are almost the same.

The Alternative A_1 which is the pump has the relative closeness coefficient of 0.56815 which shows that the pump has less criticality when compare with the above mentioned components. Therefore, the maintenance work on this component can be delay due to budget deficient which will pave way for the management to pay much attention to those components with high criticality. This occurs as a result of paying regular attention to the component, since it consider the most important component among the existing components.

The Alternative A_6 which is power source has the relative closeness coefficient of 0.13429 which make it to have the lowest value criticality. This is occurs as result of paying much attention to the component, simply because of the company's tradition that "NO POWER NOSUPPLY OF WATER". Though, the Alternative A_7 which is water tanker has relative closeness coefficient of 0.22608 which is higher than that of power source.

Therefore, the Alternatives: A_2, A_3, follow by A4 and A_5 which are pipe and valve follow by reservoir and fire Hydrant are suffering highest criticality which need urgent attention before these Alternatives: A_1,A_7 and A_6 which are pump, water tanker and power source with less criticality should be delay.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research examines the role of maintenance as a support function and its impact on production efficiency in terms of equipment life and performance, which is critical for achieving production profitability. Maintenance, as a function in a production system/organization, can improve production efficiency, reduce downtime or undesirable stoppages, improve product quality, and, as a result, plant profitability, which is one of the most compelling reasons for a company's investment.

Physical assets are maintained to ensure that they continue to function at the capacity for which they were designed. A well-maintained plant has a decreased rate of failures and downtime, as well as improved cost efficiency and productivity. Due to maintenance budget fluctuations and constraints, scheduled maintenances are rarely fully completed.Budget constraints have a negative impact on maintenance plans, resulting in unfavourable deterioration of manufacturing plant components, as well as an increased chance of accidents and downtime. , this study has proposed a prototype framework that uses the TOPSIS algorithm as an effective tool for integrating scores to arrive at a priority measure as an alternative to standard Failure Mode and Effect Analysis' Risk Priority Number (FMEA). Microsoft Excel is used to calculate the outcome.

5.2 Recommendations for Further Work

Because of its adaptability, implementing this strategy for dealing with a variety of multi-criteria decision-making challenges in the future is not an option but a need. The proposed strategy is also successful in a group decision context where reaching a moot point independently is challenging. It will also be useful in future studies. Other variations of TOPSIS procedures, such as the interval version of TOPSIS and the fuzzy version of TOPSIS, can be utilized as well.

Other MCDM methods, such as ELECTRE, AHP, SMART, and SAW, can be utilized in a fuzzy environment and the results compared in addition to the methods given in this work.

5.3 Contributions to Knowledge

The processes of rebranding of the raw materials into new products that is more useful. For example, process data to obtain useful information in order to improve production capacity through maintenance work, which is has relative closeness coefficient of 0.79592 that is the highest criticality. Also the relative closeness coefficient of 0.79162 attributed to the responsibility of the component during the normal operating processes. And, any component that suffers criticality with relative closeness coefficient of 0.7675 will be attributed to the age of the component. Hence, fire hydrant with relative closeness of 0.75517 is very close to that of reservoir in value of which they are almost the same value range of criticality.

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APPENDIX A

Table A1: Failure Mode and Effect Analysis of the considered components of the Municipal water:

S/N	Component/ Sub System	Component Function	Failure Mode	Failure Consequence	What to Monitor/ Process control
1	(a):Power source D.C GENERATOR - cylinder block - piston & ring - connecting rod - crankshaft - flywheel	to generate electricity power	-opening or shorting of circuit winding -abnormal connection of stator windings -rotor dynamic eccentricity -broken rotor bars -cracked end rings -higher losses and reduced efficiency	-no conversion -reduced efficiency of conversion -intermittent conversion	-Roller bearing and winding temperature -Displacement monitoring -Roller bearing, gearbox, vibration, shaft vibration. -Stator and rotor current
	(b): STEP DOWN TRANSFORMER -core -winding -tank -Solid insulation -bushings		-Short circuits -malfunction of the oil circulation -Insulation failure -Improper maintenance -Oil contamination	-low voltage -no conversion -increase in transformer temperature which result to explosion -Total collapse of the transformer	-Daily internal/external inspection -Regular inspection of oil level and the temperature readings
2	Pumping machine - impeller - stator - O - rings - bearing - fan	To move water at the design flow rate	- cavitation's - fouling - corrosion - wear	- causes pitting and fractures in the impeller, weakening the metal -reducing pump efficiency	- cavitation's is most easily avoided during the design stage, ensuring the chosen pump will have sufficient NPSHa a so that the liquid remains above vapour pressure

3	Valve - hand wheel - body - seat ring - Bonnet - gland packing	To isolate water or release air in the pipe	- leakage of water - over tighten of bolts - environmental temperature - seat tear - chemical reaction	- over pressure - vibration - erosion and lead to fracture - drop efficiency and cavitation’s resulted	- use pressure regulator - use torque wrench - blasting and painting - polish and replace
4	Pipeline - joint - pipe support -pipe pad - fitting	To convey water	- corrosion - wear -fatigue	- causes pipe erosion due to corrosion, wear and fatigue	- these may be reduced or eliminated through the use of pipe pads
5	Reservoir - foundation - top	To store clear water	- overtopping - crack - foundation defect	-It may result to internal erosion in foundation - it also result to total collapse of the reservoir downstream slope failure	-Implementing computer programme technology such as SLOPE/W or and UTEXAS3 to study the any critical failure - daily inspection
6	Fire hydrant - stem/operating unit - stem sleeve - hydrant value	To provide fire fighters water in case of emergency	- corrosion of stem/operating Nut - crack of stem sleeve - corrosion of hydrant valve	- The hydrant can become totally locked and completely inoperative - leakages of the hydrant causes locked in seat ring resulted to the hydrant valve inoperative	- regular in lubrication - daily inspection

7	Water tanker - floor tank - roof tank	To supply water during consumer's emergency	- corrosion - violent weather changes - excessive pressure due to overfilling of tank - failure of pressure vacuum relief valve	- result to leakages - affect the coating both internally and external - result to tank failure - result to tank explosion	-Proper metallurgy of the used compatible material to reduced corrosion -Tanks should be protected by the emergency vent system -Tanks should be inspected periodically

APPENDIX B

Table B1: Monthly Reliability of the major components in Minna Water Works for the year 2020

S/N	Components	Monthly Reliability of the Components (%)												
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	AV Total
1	Power source													
	DC Generator	45	50	48	49	50	50	47	48	45	50	50	49	5
	Step down Transformer	52	50	51	47	48	51	53	50	45	48	50	51	5
2	Pumping Machine	60	60	48	45	45	50	53	50	55	40	46	48	5
3	Valve	24	20	29	30	31	35	22	24	20	28	24	23	3
4	Pipe line	34	30	41	39	43	30	31	40	33	31	30	30	4
5	Fire Hydrant	8	9	10	12	10	9	11	10	12	9	8	9	1
6	Reservoir	9	10	11	8	9	7	9	10	10	7	8	8	1
7	Water Tanker	53	50	45	46	50	50	51	55	45	48	49	51	5

KEY:		SCORE	
1	8-10%	6	51-60%

2	11-20%	7	61-70%
3	21-30%	8	71-80%
4	31- 40%	9	81-90%
5	41-50%		

APPENDIX C

Table C1: Monthly component performance of year 2020 measure in A (is the difference between the specification values and target value of loss function)

S/N	Components	Monthly component performance												
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	AV Total
1	Power source													
	DC generator	0.30	0.30	0.45	0.35	0.40	0.45	0.40	0.30	0.40	0.40	0.45	0.45	6
	Step down transformer	0.35	0.50	0.40	0.50	0.40	0.50	0.45	0.40	0.30	0.40	0.50	0.50	6
2	Pumping Machine	0.030	0.03	0.02	0.03	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.02	2
3	Valve	0.003	0.002	0.01	0.001	0.01	0.001	0.003	0.004	0.01	0.03	0.01	0.001	1
4	Pipe line	0.003	0.004	0.01	0.003	0.005	0.006	0.003	0.01	0.002	0.004	0.006	0.005	1
5	Fire Hydrant	0.003	0.002	0.001	0.004	0.001	0.01	0.004	0.005	0.004	0.006	0.005	0.005	1
6	Reservoir	0.004	0.007	0.01	0.005	0.006	0.008	0.004	0.002	0.005	0.007	0.006	0.006	1
7	Water Tanker	0.25	0.30	0.15	0.10	0.30	0.20	0.16	0.18	0.20	0.25	0.25	0.15	5

KEY	SCORE
0.01 below	1
0.01-0.02	2
0.021-0.06	3
0.061-0.15	4
0.151-0.30	5
0.31-0.60	6
0.61-1.0	7
1.1-4.0	8
4.1 above	9

APPENDIX D

Table D1: Monthly maintainability of the major components for the year 2020

S/N	Components	Monthly component performance												
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	AV Total
1	Power source													
	DC generator	0.45	0.50	0.55	0.48	0.50	0.47	0.60	0.50	0.48	0.40	0.40	0.50	5
	Step down transformer	0.50	0.60	0.50	0.48	0.50	0.48	0.45	0.60	0.50	0.50	0.50	0.35	5
2	Pumping Machine	0.55	0.45	0.50	0.45	0.35	0.50	0.55	0.40	0.50	0.50	0.50	0.60	5
3	Valve	0.45	0.50	0.30	0.40	0.40	0.50	0.65	0.35	0.60	0.35	0.45	0.45	5
4	Pipe line	0.50	0.50	0.50	0.45	0.50	0.45	0.45	0.60	0.50	0.45	0.50	0.45	5
5	Fire Hydrant	0.45	0.50	0.50	0.45	0.50	0.35	0.55	0.50	0.40	0.50	0.45	0.50	5
6	Reservoir	0.30	0.60	0.45	0.65	0.50	0.50	0.45	0.35	0.50	0.45	0.50	0.45	5
7	Water Tanker	0.35	0.45	0.65	0.55	0.50	0.50	0.35	0.45	0.55	0.45	0.40	0.55	5

KEY	SCORE		
0.8 above	1	0.31-0.4	6
0.71-0.8	2	0.21-0.3	7
0.61-0.7	3	0.11-0.2	8
0.51-0.6	4	0.001-0.1	9
0.41- 0.5	5		

APPENDIX E

Table E: Monthly likelihood of Non- dictation of failure of the major components for the year 2020

S/N	Components	Monthly likelihood of Non- dictation of failure (%)												
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	AV Total
1	Power source													
	DC Generator	11	10	12	9	8	9	8	9	10	12	10	9	1
	Step down Transformer	8	9	7	10	10	15	10	7	15	11	10	8	1
2	Pumping Machine	20	20	18	20	30	18	10	21	24	20	30	10	2
3	Valve	11	11	10	10	8	9	8	10	15	10	10	8	1
4	Pipe line	15	10	10	10	11	7	6	8	9	8	6	7	1
5	Fire Hydrant	9	10	11	8	9	8	9	10	12	10	9	11	1
6	Reservoir	10	10	7	8	8	9	11	8	9	7	9	10	1
7	Water Tanker	15	10	13	18	25	20	30	15	18	24	18	18	2

KEY	SCORE		
		31- 40%	4

81-90%	9	21-30%	3
71-80%	8	11-20%	2
61-70%	7	8-10%	1
51-60%	6		
41-50%	5		

APPENDIX F

Table F: 2020 monthly maintenance (Repair and Replacement of the major and sub component of the Municipal Water Works) ,Minna

S/N	Comp/sub comp	Repair	replacement	Lubr	Monthly maintenance of the major components												
					J	F	M	A	M	Jun	July	Aug	Sep	Oct	Nov	Dec	Total
1	POWER SOURCE																
	DC generator			•				•				•				•	5
	Cylinder block	•															
	Piston & ring		•								•						
	Connecting rod		•								•						
	Crankshaft										•						
	Fly wheel																
	Step down transformer			•				•				•				•	
	Core																
	Winding																
	Tank	•									•						5
	Solid insulation																
	Bushings		•								•						

2	PUMPING MACHINE									
	Impeller									
	Stator									5
	O-rings		•							
	Bearings		•	•	•	•		•	•	
	Fan									
3	VALVE			•	•			•	•	
	Hand wheel	•					•			4
	Body									
	Seat ring	•					•			
	Bonnet	•					•			
	Gland packing									
4	PIPE LINE									
	Joint	•	•					•		
	Pipe support		•					•		3
	Fitting	•						•		
	Pipe pad									
5	FIRE HYDRANT									
	System/opera									

	ting Nut							
	Stem sleeve							
	Hydrant valve		•				•	1
6	RESERVOIR							
	Foundation	•				•		2
	Top	•				•		
7	WATER TANKER							
	Floor/roof tank	•		•	•			5

KEY	SCORE
Jan	9
Feb-Mar	8
Apr	7
May- Jun	6
July	5
Aug	4
Sept	3
Oct	2
Nov-Dec	1