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Strategic Maintenance Management of Equipment/ Machinery to Promote Resilient Infrastructure

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Abstract:
All equipment/machinery are designed to carry out specific function and to last for a period of time called the design life span, but in real sense, they are unreliable as they degrade with age and fails when it no longer has the capacity to deliver required service or product. Failure of equipment/ machinery result not only in productivity loss but also delay of services, cause loss of life and environmental problems. The cautiousness of resilient equipment/machinery maintenance is continuously increasing since they are the fundamental component in the operation of critical infrastructure, but the constraints are in adequate strategic maintenance management and policies, untrained personnel, lack of spare-parts, substandard maintenance workshops, etc. This paper, therefore, examines strategies for effective maintenance management of machineries to promote resilient infrastructures. To achieve this objective, the paper takes a look at the components of engineering infrastructure, the available maintenance strategies and policies, the benefit of strategic maintenance management, the factors affecting equipment/machinery performance and service life and the strategies that promote resilient equipment/machinery life and performance. It also identifies the usual maintenance problems and proffers strategies to tackle them. The study finds that, selecting a successful maintenance strategy requires a good knowledge of equipment failure, behavior and management practice.

Keywords: *Maintenance, equipment/machinery, management, infrastructure, strategy*

1. Introduction

There is an absolute need to maintain our properties. We need to maintain our properties until we considered that its useful life has ended. For this purpose maintenance has become very important. But there are many challenges associated with. In our country although there is no scarcity of human capital but limited financial capital is present. Maintenance has many benefits. It is extreme beneficial for capacity utilization. It helps to improve the quality of additional capacities such that the ever increasing demand can be managed properly. But it is extremely unfortunate that in most of the countries, maintenance function is given a low status and considered to be a third rate job. But considering the benefits as well as importance, huge importance needs to be placed behind maintenance.

1.1. Literature Review

Over time, the need to maintain assets and tools became more narrowly focused and trades such as blacksmithing emerged. The industrial revolution made our tools more mechanized and increased the specialization of the trades. Maintenance trades emerged to keep the equipment running or repairing it when it broke down. This was effectively the start of the first generation of maintenance, where owners ran their equipment until it failed and downtime was a fact of life.The approach to maintenance of equipment/machinery has changed due to affluence and changing technology over the last decade with series of activities to keep infrastructure in operation. Up until 1940, maintenance activities were not planned; they were only performed when a failure occurred (Murthy, Atrens, &Eccleston, 2002). Between 1950 and1960, the first scientific approach to maintenance management emerged, moving from the corrective maintenance paradigm to the preventive maintenance paradigm, reducing unplanned downtime in production (Dekker, 1996). The emerging perspective was that maintenance should not be viewed only at a narrow operational and technical level representing an unavoidable cost; but it could be viewed in a long-term strategic view. This strategic role of maintenance can therefore be viewed from the overall business viewpoint, and assessing effectiveness as a main maintenance goal. Today, maintenance is clearly seen as a source of added-value, with the key role for driving performance improvement. Strategic planning can

be described as the process of specifying objectives, generating strategies, evaluating strategies and monitoring results (Armstrong 1982). According to the European regulation EN 13306, maintenance is defined as 'the combination of all technical, administrative and managerial actions during the life cycle of equipment, intended to retain or restore it to a state in which it can perform its required function'. In simple term, Maintenance is the upkeep of facilities and equipment. Upkeep means the restoration to, or keeping in, a specified operating condition.

Technically, maintenance is a risk management activities/practice used to maximize output and minimize loss and waste through functional checks/inspection, commissioning, measuring, substitution, regulation, repair, failure detection, parts replacement, setup, lubrication, cleaning etc. to retain or restore a functional unit in or to a specified state in which the unit can perform its required function. Thus Maintenance may be considered a set of activities which help keep plant, machinery and other facilities in good working condition. The current trend is not so much the need for a general increase of interventions as for more rational planning and management. The concept of maintenance has undergone a dramatic evolution whose reasons are related to organizational and technological development, and to the revolution of information and communications technology. Originally, service was almost exclusively focused on the mere preservation of equipment/machinery, but with the advent of the computer revolution, a new concept of productive organization has emerged. Maintenance is becoming a new form of science, which tends to counteract the causes of obsolescence and degradation resulting from use and aging. Maintenance activities can significantly contribute to the productivity of a system; however, their cost in terms of both technical and economic resources can become quite relevant. According to Amrine and Ritchey, maintenance is a function of management concerned with the day to day problem of keeping the good operating condition of physical equipment. There are many reasons why facilities and equipment must be maintained. The major objectives of maintenance include the following:

- To extend the useful life of the system. This is particularly important in developing countries where there is a scarcity of capital funds for replacement.
- To assure the optimum availability of the system for service or production and obtain maximum possible return on investment.
- To ensure the safety of personnel using the facility or equipment.

1.2. Strategic Maintenance Management

Maintenance management is the process of maintaining a company's assets and resources while controlling time and costs to ensure maximum efficiency. Maintenance management is one of those aspects of managing a company that is usually not explored in depth. Basically, the concept of strategic maintenance management of equipment/machinery deals with the principles and techniques of maintenance, and shows how the complexity of maintenance strategic plans can be resolved by a systematic approach integrated into the infrastructural plans of the equipment for the least amount of disruption and cost. The planis used to formulate a maintenance schedule for the equipment as a whole, along with a maintenance organization and a budget to ensure that maintenance work can be resourced. Strategic maintenance management requires effective utilization of maintenance resources. The resources needed for equipment maintenance are human, financial, material and time which have to be provided in the right mix.

- Human Resource (Personnel): The special nature of equipment maintenance requires personnel that have some relevant technical/engineering training. The maintenance personnel are made up of engineers, technicians and craftsmen. They need regular capacity-building through self-study, on the-job and external training and re-training.
- Financial Resource (Money): Effective equipment maintenance is expensive. However, it is more cost-effective than non-maintenance. Funds are needed to recruit and maintain the personnel, purchase the necessary maintenance tools and set up a workshop, buy the needed spare parts and maintenance consumables such as solvents and lubricants.
- Material Resource (Equipment): For a typical business organization with a production plant, where many equipment haveto be maintained, a Maintenance Department (with a standard Workshop) is the ideal. Such a workshop needs a full complement of test (or diagnostic) and repair tools. The maintenance department may also need supportive equipment such as vehicles to reach locations and/or to move personnel and maintenance tools around.
- Time Resource: Time is needed to inspect equipment, source spare parts, disassemble, replace/repair, reassemble, and test equipment. Time is the basic unit to convert failure consequence into cost. Detection time, fixing time, delay time and loss time are the four fundamental time penalties.

Strategic maintenance management is a documented explanation of how several cause and effects, process/methods and innovation relationships anticipate the impact of a changing world of infrastructure equipment to increase availability, reliability, safety, productivity and profitability. The cause and effect has a timing dynamics to it, to set management expectations. The strategy shall define the framework and directions for maintenance activities. The basis of any organization's journey towards maintenance excellence is the establishment of an effective maintenance strategy. It provides the necessary roadmap to achieve short and long-term goals. Equipment maintenance management as evolved to the extent that managers have to operate at two levels; strategic-tactical and operational. In the former, the equipment manager must be strategic in relating to the end users of the potential impact of maintenance decision. In the later case, the equipment manager ensures corporate and regulatory compliance plus the proper operation of all aspects of the equipment necessary to create an optimal, safe and cost effective infrastructure. Data capturing enables good decisions,

planning and continuous improvements. A typical Equipment strategic Maintenance management Document should contain:

- Maintenance Policy: stating the need for equipment maintenance, who does it, how it will be done, what is expected from it etc.
- Performance analysis and monitoring: stating the requirement for maximum output, what equipment process reliability, availability, quality is needed, how much to be spend on maintenance etc.
- Risk assessment of equipment: stating the failure mode and effects analysis, what can cause failure, what will it cost, how often it happens and safety needs.
- Records management: stating maintenance history of equipment and parts usage.
- Maintenance resources required.

One of the major managerial responsibilities is the design and implementation of policies for the achievement of the short-term and long-term goals of the enterprises. Previous performances must be studied so as to generate or forecast future maintenance activities. Given a projection of the pattern and the level of future activities, the desirability of alternative actions can then be investigated. Once a strategy has been selected, control procedures must be incorporated to enable the firm to reassess its validity. The quality of the forecast or projection the management can make is strongly related to the information that can be extracted and used from the equipment manual and past event.

1.3. Resilience Machinery Infrastructure

Resilience is the capacity of machinery to adapt to changing conditions, to reduce the magnitude and/or duration of disruptive events and to maintain or regain functionality and vitality of its core purpose in the face of stress or disturbance. That is, the capacity to bounce back after a disturbance or interruption. This helps to minimize negative effects of projects on communities and environment. Building or incorporating resilience from the beginning of a project gives many sustainability options than when the infrastructure is already constructed. Infrastructure ranges from agriculture and food systems, health care facilities, national monuments and commercial facilities, to energy and water supply systems, chemical facilities, road infrastructures, emergency services, nuclear power plants, telecommunications and information technology systems, transportation systems, and a wide variety of other public and private facilities. The effectiveness of a resilience equipment/machinery infrastructure depends upon its ability to anticipate, absorb, adapt, and/or rapidly recover from a potential disruptive event. Resilient expectations are articulated in equipment to ensure continuity of its critical services and functions. The range of issues considered in articulating resiliency equipment's for infrastructure systems includes prioritizing, triage and sequencing as well as the ability to make emergency supplement investment. The framework for the protection and enhancement of the resilience level must be defined by:

- Developing a foundational understanding of critical infrastructure system and system dynamic.
- Developing an integrated scalable risk assessment and management approaches.
- Developing an integrated proactive capabilities, technologies and methods to support and secure resilient infrastructure.

2. Equipment/Machinery Maintenance Model

A maintenance model is a mixture of the various types of maintenance in certain proportions, and its appropriate responds to the needs of a particular equipment/machinery. There is no one maintenance strategy for all situations and all companies.(a) Planned maintenance is also known as scheduled maintenance or productive maintenance. Maintenance occurs in a planned manner (b) Unplanned Maintenance: It is an operation/activity carried out without any prior planning.

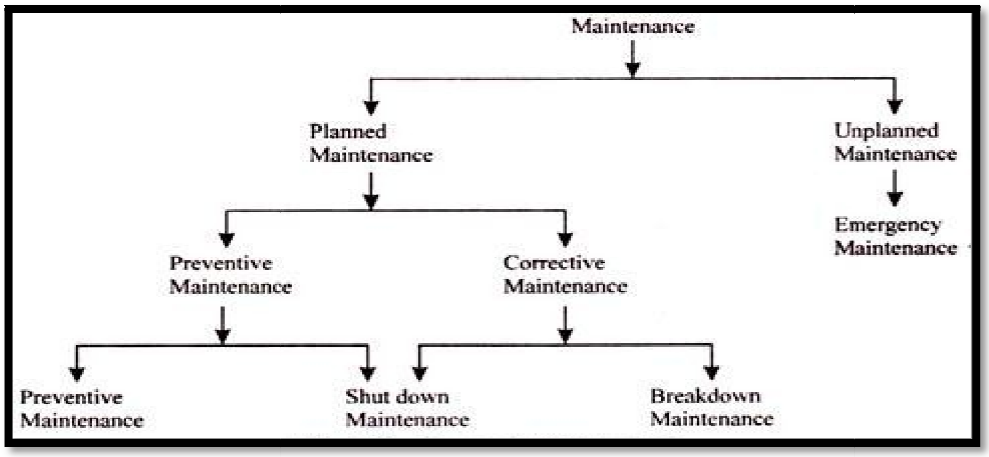

Figure 1: Types of Maintenance

2.1. Quantitative Model

Maintenance is a service which has economic value to the production process. When this value is calculated and expressed in quantitative terms, only then the comparison of cost effectiveness of various maintenance policies is possible. A simple and very important efficiency index may be expressed by:

E = K/mT + nt + CW. (Anthony Kelly 2006).
E = maintenance efficiency index.
K = a constant such that value of the expression is100 for the base year.
m = total cost of maintenance in the base year.
n = total cost of lost time due to maintenance in the base year.
C = total cost of waste material (scrap) in the base year.
T = Total cost of maintenance.
t = down time to maintenance. W = material wastage due to maintenance operations.

2.2. Failure Mode Effects Analysis (FMEA)

FMEA is a quantitative approach proposed to clear up equipment failure modes in equipment or development products to support decisions.A process analysis tool, it depends on identifying:

- Failure mode: One of the ways in which a product can fail; one of its possible deficiencies or defects
- Effect of failure: The consequences of a particular mode of failure
- Cause of failure: One of the possible causes of an observed mode of failure

2.3. Maintenance Costing and Budgeting

Costing and budgeting for the maintenance department embraces the provision of financial information on labour and materials expenditure, its allocation to the various cost centres together with manpower resources and the development of objectives with programmes and budgets for meeting them. The basis for cost control is provided by the use of cost account codes. Typical major code headings might include (a) capital projects, (b) planned preventive maintenance, (c) workshop services. The costs attributable to the cost codes consist broadly of wages and salaries, overhead charges, materials costs, transport costs and sundry items. The overhead charge made upon maintenance is made up of charges occurring within the maintenance department plus the overhead charges reflected from other departments like administration, general management etc. Charges arising within the department include services' rent and rates, transportation and insurance.The overhead charge made upon maintenance is made up of charges occurring within the maintenance department plus the overhead charges reflected from other departments like administration, general management etc. Charges arising within the department include services' rent and rates, transportation and insurance. When producing a departmental business plan, it is necessary to include in the budget a set of objectives and strategies for implementing the planned maintenance programmes, completion of certain capital works and the operation of a planned overhaul programme. One objective for the department ought to be the reduction of resources allocated to corrective and emergency maintenance and an increase in planned preventive work.

Unlike direct production which can be rated in terms of output of any particular machine, no such analytical yardstick is available for rating maintenance. In maintenance you should essentially strive to maximise availability and reliability of the machines/ assets and minimise downtime. Maintenance though a support function, is certainly linked to increase in the productivity of the system in the long run. Chandra, (1976) proposed some indices as below, which might help management, achieve their objectives more effectively and efficiently. Overtime hours worked is indicative of the failure of planning. Emergencies should be reduced to a bare minimum.

i) Maintenance productivity index $= \frac{\text{The output of product}}{\text{The cost of maintenance effort}}$

ii) Maintenance cost index $= \frac{\text{Maintenance cost x 100}}{\text{Capital cost}}$

iii) Downtime index $= \frac{\text{Downtime hours x 100}}{\text{production hours}}$

iv) Waste index $= \frac{\text{Quantity of Waste produced x 100}}{\text{Quantity of total output}}$

(This is somewhat similar to 'wastivity' which, however, gives a more comprehensive conceptualisation of waste rather than just think of output waste. This would be discussed in the unit on Waste Management).

v) Breakdown Maintenance Index $= \frac{\text{Total hours spent on breakdown x 100}}{\text{Total man hours available}}$

vi) Level of Maintenance $= \frac{\text{Total hours spent on scheduled maintenance x 100}}{\text{Total man hours available}}$

vii) Inspection of effectiveness $= \frac{\text{Standard minutes of work saved on improved inspection}}{\text{Total standard minutes of inspection carried out}}$

3.Factors Affecting Equipment/Machinery Performance and Service Life

Strategic maintenance decision making involves selecting the right care and repair methodologies that maximize equipment life and performance for the least cost to the user. But to be able to make successful maintenance management

strategy choices, you must understand how equipment fails. A final incident destroys it because it is not physically able to withstand that incident. In some cases the end of an equipment's life is instantaneous and without warning.

- Over stressed components, resulting from overloading, excessive temperature, fluctuating forces leading to fatigue etc.
- Environmental Attack such as rusting, chemical corrosion, wear, erosion cavitations etc.
- Error or Mistake as a result of wrong choice being made in ignorance, error at the design stage, operator or maintainer making a mistake, incompetent management decision etc.
- Poor Design Choices and-or Poor Manufacturing / Assembly Quality such as selecting undersized equipment, wrongly specified components, poor welding, poor casting, incorrectly positioned holes and out of tolerance machining, assembly errors, under-torque on bolts, poorly fitted electrical connections and short-cut assembly quality etc.
- Lack of Maintenance and Care such as not changing lubricating oil, leaving electrical equipment open to dust and dirt ingress, starting machines under full load, not checking remaining service life, not cleaning equipment etc.

When Equipment fails, it may not yet be broken, but it is no longer able to deliver the needed service. The actual time of failure depends on when the cause of the failure coincides with the item's ability to accommodate the failure mechanism. This means that the failure happens at the time the item can no longer operate as required. This point in time can be controlled by the selection of the right andappropriate maintenance strategies.

3.1. Maintenance Safety Information

Accident mainly caused by failure to observebasic safety rules or precaution. Improper operation can be dangerous and could result in injury or death. Manual is an effective way to find safety precautions and warnings. A good maintenance program is the key to long equipment/machinery (E/M) life. Safety and efficient operation of E/M can be achieved only if it is correctly operated and maintained. An E/M is desired to be safe when used in correct manner. The responsibility for executing safety procedures rest with the personnel who install, use and maintain it, but it is the responsibility of the management to ensure an enabling environment is created and strategic maintenance safety procedures is established and adhere to. Maintenance, adjustment, and repair services should only be carried out by qualified personnel using genuine parts. Records of this work should be kept to aid in developing an efficient maintenance program. Some safety precaution to follow in other to minimize the possibility of accidents includes:

- When an E/M is faulty, disconnect and/or fit a danger notice on it.
- Understand and follow all the instruction, procedures, warnings and safety precautions before operating or performing maintenance operation to reduce the possibility of accident and injuries.
- A walk/look around inspection should be performed on a daily basis and prior to operating an E/M. care must be taken to protect personnel and equipment from other hazards within the working environment.
- Make electrical connections in compliance with relevant electrical codes, standards or other requirements, including that of grounding and ground/earth faults.
- Proper care in handling materials can dramatically limit the risk of fire or explosion; however, fully charged fire extinguishers must be kept handy.
- Do not touch electrically energies part of a machine or interconnecting cables or conductor with any part of the body or with any non-insulated conductive object. Replace any wires were the insulation is cracked, cut, abraded or otherwise degraded.
- Keep all electrical equipment and terminals clean, tight and dry. Replace terminals that are worn, discolored or corroded.
- Fuel, oils, coolants, lubricants and battery electrolyte use for maintenance work can be hazardous to personnel if not treated or handled properly.
- Check all control system safety devices by simulating faults.
- It is important that the work area is kept clean and that the components are protected from dirt's and other debris. Also, before components are assembled during maintenance or repair works, ensure that they are properly cleaned and washed.
- Personal protective equipment /Clothing such as helmets, gloves, goggles, gas masks etc. should be worn for safety. You must preferably include the need for wearing protective clothing in the maintenance request or the work/ job specification.

4. Equipment/Machinery Maintenance Management Strategies and Policies

Strategic maintenance management (SMM) is the latest generation of the age-old need of maintaining our equipment or machinery to determinean enterprise's long-term goals and then identifying the best approach for achieving those goals. It comprises the study of the technical and human causes that lead to failures, in order to prevent them, and all actions aimed at organizing resources to maximize the effectiveness and efficiency of the service life in order to optimize the global economic efficiency of the output or production system.Strategic management is based on the principle that prior planning and preparation will improve the actual performance and execution. Historical and statistical records which are compiled and maintained provide guidelines for future maintenance policy. The maintenance strategy must be well conceived and organized to achieve the basic aim of any equipment. So not only the maintenance functions but the economic aspects should also be taken into consideration. Thus whenever a policy of maintenance is practiced, the planning should also include finance to ensure that sufficient funds are available for providing manpower, machines and

other inputs required (Anthony Kelly (2006).It is difficult to predict the extent of losses and damage resulting from failure, it is therefore essential to draw up a maintenance programme comprising inspection activities and preventive investigations. Strategic maintenance management is best developed by a team consisting of equipment operators, maintenance engineers and finance department working together. Lack of sensibility towards schedule optimization arises basically from scarce awareness of the advantages obtainable from investment in maintenance, and limited research on the overall long-period effects of strategic maintenance choices. However, Standardization of equipment Strategic maintenance management policy is a very complex process that is virtually impossible, and the adoption of Strategic maintenance management is a matter of choice of the strategy manger; therefore, there is a high impact of human factor. Some of the Maintenance Management Strategies and Policies include:

4.1. Education and Training

Proactive Education and Continuous Training improves Knowledge of users to make wise choices and take correct actions. Hence, one of the best maintenance strategies is to teach the engineering design requirements of the equipment to the operators and maintainers who will run and care for it. This will breed new ideas and bring innovations into the equipment maintenance and operation.

4.2. Improved Technologies

It is very important to check a valid maintenance strategy that supports new inventions and innovative designs. A potentially useful technology helps to control and monitor experiment to prove its worth in your situation.

4.3. Root Cause Elimination and Design-Out

A maintenance strategy solves problems and recurrently mends equipment performance. Without it a long-term weakening in equipment can be observed. There are methodologies available that use a systematic approach to trace the real cause of problems to their root cause. The benefits of root cause elimination are immediate with the permanent removal of a failure cause.

4.4. Intentional Over-Design

There are times when it is valuable to select more vigorous apparatus than rapidly appears necessary. This is refers to as Intentional Over-Design Selection. It is a strategic maintenance choice that is intended to produce longer periods of equipment operation between failures.

4.5. Quality Control and Assurance

A Quality Control and Assurance maintenance strategy must be adopted to improve the quality and accuracy of parts and workmanship. It is accumulated into the equipment correctly. This will translates into better running equipment with longer mean times between failures.

4.6. Risk and Exposures Assessment

The risk environment affecting infrastructure is complex and uncertain threats, vulnerabilities and consequences have all evolved over the last decade. Performing a high-level vulnerability assessment can help identify equipment risk and exposures. Once these vulnerabilities are identified, equipment managers should immediately start integrating these into their planning. Incorporating sustainability and resilience into the early planning stages can also save money in the long-run. With the equipment core purpose and key environmental vulnerabilities established, equipment managers should go a step further by anticipating worst-case scenario and how to counter them. By prioritizing likely problems, machinery managers can make sure they are making decisions that will improve machinery resilience or at least avoid making them worse. Waiting until brake down occurs before reacting can be more difficult and expensive than being proactive. Thus, plan early, assess the equipment's risk and take a comprehensive approach to making materials, finance, energy and other resiliency decisions. The purpose of the machinery determines which sustainability or resilience strategies to employ, for example, whether it is on-site renewable energy, battery backup system, or powerless ventilation among others. Risk assessment is inherently related to an estimation of uncertainty at different levels. Often, the single most important feature of risk assessment is considered to be the forecasting of possible future outcomes and the estimation of their likelihood based on past events (www.resolute-eu.org). Proper maintenance is of paramount importance to the proper operation of any machine, it is no coincidence that a machine's risk assessment is significantly influenced by the level of service expected and practiced.

5. Conclusion

When equipment is designed the designer makes the assumption that it will be treated with reasonable care and it will undergo a minimum amount of required maintenance. When care and maintenance is withheld from equipment for an extended period of time, accumulated problems develop which eventually cause failure. Maintenance's mission is to make the equipment available when it is required to run. In the old days we waited until equipment broke and then fixed it. That is no longer acceptable. The underlying objective presented about strategic maintenance management of equipment is that the future can be anticipated, forecasted, manage or even controlled. Finance plays a critical role for all stages of equipment maintenance sustainability life cycle, and its efficiency can be determined quantitatively as shown. Various strategies and policies have been articulated to promote resiliency, improve greater on-demand reliability, longer

equipment life, greater efficiency, control complexity and quality, near zero waste, zero tolerance on safety and environmental issues, greater costs controls and flexibility of operation. Consequently, there will be an increase in returns on investment.

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