IMME **Institute of Maintenance Management Education**

MAINTENANCE ARTICLES

CONTENTS

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(1) Zero Breakdown Maintenance

It's absolutely essential for maintenance departments to aim for maximum uptime, higher plant availability & greater overall equipment effectiveness; work for achieving zero breakdowns; arrest various abnormalities, resource wastage & economic losses; promote efficiency, productivity and control costs; adopt modern maintenance management practices, approaches & techniques; thrust upon plant safety and energy conservation programmes; and so on.

Zero breakdown Maintenance is all about working for the ultimate goal with a winning maintenance strategy. New generation maintenance concepts and techniques, such as Condition-based Predictive Maintenance, Machine Reliability & Maintainability Improvement, Reliability-centred Maintenance, Autonomous Maintenance and Total Productive Maintenance, etc. which came up during the past few decades only tend to produce amazing results.

The very first step towards zero breakdowns undoubtedly begins with effective preventive maintenance. However, since preventive maintenance usually entails ill-effects of both over and under-maintenance, it becomes much desirable to incorporate condition-based predictive maintenance practices also with a view to facilitate better control on untimely breakdowns as well as unnecessary shutdowns. However, these maintenance practices alone cannot always take care of all failures since there are often various other factors besides maintenance. It's also necessary to properly collect and analyze failure data along with downtime, nature of failures, failure modes & causes on account of improper operation, inadequate maintenance, design problems - - low reliability & poor maintainability, unfavorable operating conditions, etc. Failure analysis thus constitutes an important activity to enable establishing root causes and subsequently taking appropriate corrective actions to avoid recurrence of the failure problems. Understandably, no amount of preventive & predictive maintenance can take care of perennial design problems in certain machines. Problems of low machine reliability or poor maintainability would normally require design improvements in individual parts or system as a whole. In order to move further and closer to zero breakdown performance, it would also need reinforcement by way of concepts advocated by total productive maintenance, which lay stress on small group activity & autonomous maintenance through total participation of all employees.

Therefore, to achieve zero breakdowns, it's not only the application of modern maintenance management techniques that are essentially required, but also a maintenance programme driven passionately by skilled people with positive attitude and greater sense of participation, dedication and achievement. Maintenance for zero breakdowns requires total involvement, greater commitment and continuous effort by plant people.

There is now a greater awareness of the potential of maintenance management functions and what it can contribute with utmost productivity and effectiveness in realizing economic goals of a company. It is therefore important of have a maintenance strategy in place, which will improve the maintenance performance in a company in such a way that it supports the company's overall economic goals.

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(2) Evolution of Maintenance Practices

Broadly, the evolution of maintenance practices began from Breakdown Maintenance (1950s) to Planned Preventive Maintenance (1960s) and further to Condition-based Maintenance (1970s), Reliability-centred Maintenance (1980s) and Total Productive Maintenance (1990s).

In the past, maintenance was merely considered as the last front of management; looked upon as a perennial cost incurring department; and, manned by low grade unprofessional staff. As a fire fighting department, its importance was realized only when equipment failed and something went wrong. Production only occupied top position in the minds of the top management. For them, maintenance was meant for gunning for two things only – firstly, why a thing is not working and secondly, how long it will take to put it back to service.

With the emergence of maintenance practices, maintenance engineers could not however keep pace in adopting and implementing them in their working environments. Also, traditionally they did not rely much on planned approach for maintenance function. Although generally they had strong hold of maintenance engineering yet lacked in maintenance management aspects. Rarely, they had much idea to exercise control on their losses, wastage, abnormalities, delays, low productivity, inefficiency, etc. They utilized much of their time as operational hours and too little for development activities. They learnt and got groomed in skills on the job and had little opportunity to attend any professional training in the field of their operations. These are just a few common problems that maintenance function faced in the past. However, it does not mean that today all such problems have vanished from industry. They still exist but with less degree of intensity. And, the true value of maintenance is now recognized more frequently.

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(3) Benefits of Returning Excess Materials to Stores

It's always a good practice to return excess maintenance materials withdrawn from the stores after completion of the job. For this purpose, some companies use a format called as "Material Return Slip", or alike. The primary purpose of such a practice is to keep control on direct maintenance cost through waste reduction. The secondary purpose of such a practice is to provide positive effect on the availability of the concerned machine(s) to a certain extent.

It’s quite well known that availability of a machine in a plant, representing a repairable system, depends both on its reliability and maintainability. If excessive maintenance materials, such as machine spares are returned to the stores, theoretically it will increase stock level and therefore tend to increase assurance or service level of the returned parts in the stores. The assurance or service level of a particular spare part is defined as the probability that the spare part will be available in stores when required. It means that there will be lesser probability for the spare part to go out of stock when requisitioned at a future date and therefore there will be lesser chance that a machine may have extended downtime due to the non-availability of a particular spare part in stores when required at a future date.

In other words, such a practice will help in controlling loss of machine availability due to non-availability of spares because assurance level of spares will get improved due to return to stores. However, it will be quite complicated and difficult to quantify such an effect precisely. In fact, in practical terms, it may not be noticeable if stock levels of spare parts in stores are already on higher side than optimum.

Thus, the practice of returning excess maintenance materials to stores benefits in the following ways:

(i) It leads to reduced wastage and consequently reduced consumption of maintenance materials. It helps in reducing direct maintenance cost.

(ii) Reduced consumption of materials by way of returning excess materials to stores facilitates in rethinking and revising re-order levels, ordering quantities, etc. to help reduce inventory and stock holding cost.

(iii) Timely availability of required spares to carryout necessary maintenance & repair gets ensured to certain extent. Therefore it adds to improving maintainability of the machines and consequently their availability.

Further, whereas the practice of returning excess materials affects maintainability, so also availability of the concerned machines in a positive way due to improved assurance levels of the returned parts, but certainly at the cost of more than optimum inventory, i.e. more capital tied up and higher inventory cost.

Thus, the practice of withdrawing excess maintenance materials from stores should be discouraged in the very first place mainly because of the following reasons:

"Withdrawing more quantities than actually required, if it happens as a regular phenomenon, it can only be regarded as a bad and unproductive working habit. Reason – either it leads to throwing excess materials in junk, or it unnecessarily adds as unproductive time to maintenance man-hours on shop floor by way of frequently returning excess materials to stores which could have been avoided in the very first place. However, if it’s a rare thing, it’s all right."

Therefore, there is always a need to inculcate good working habits amongst all maintenance technicians firstly by avoiding withdrawal of excess materials as well as returning excess materials to stores when happens in order to keep control on company's costs.

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(4) Why Does a Machine Fail?

"When stress exceeds strength", equipment fails. Understandably, that is the basic scientific principle behind any equipment failure.

However, the following can generally be said to represent the four major (broad) causes responsible for equipment failures:

(1) Unreliable equipment design and poor layout
(2) Improper operation
(3) Inadequate maintenance
(4) Hostile environment (where equipment operates)

If equipment design is unreliable, it will certainly lead to increased frequency of failure. So also if machine layout is not proper, the machine will be prone to frequent failures. Improper operation often incorporates human errors that are always responsible for undesirable early failures. Inadequate maintenance means either poor quality of materials and/or bad workmanship in maintenance and/or inadequate planned maintenance work, etc. Further, if the environment where the machine is installed is hot, humid, corrosive or present with similar hostile conditions, it will certainly accelerate the failure process and result in higher failure frequency compared to the ideal conditions.

Further, for each of the above stated broad causes of equipment failures, usually there are specific sub causes varying from case to case. For certain sub causes, there could be sub-sub causes and so on.

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(5) Dealing with Frequently Failing Machines

In order to prescribe correct remedies for frequently failing machines, it's absolutely essential to get to know the root causes of the frequent failures. We need to ask several questions, and find answers to each one of them to arrive at the right causes.

Are the failures occurring due to mal operation?
or, due to improper maintenance?

or, on account of unreliable machine or system design?
or, due to hostile environmental conditions where the machines are installed and operating?

Have the machines reached their wear-out phase?
Frequent failures - is it a recent phenomenon or old one?
Time, since when the frequent failures are occurring regularly?
Which machines in particular, if any, are failing frequently?
What are the failure modes and failure causes?
What is the cost of down time per week or per month?
Did any plant people investigate failure problems in the past?
If yes, what were their findings and recommendations? ……, etc.

In fact, many more similar questions may need to be asked till one finds satisfactory answers required to establish the right causes. One could also use a team approach. For this, a team of relevant people from the plant can be appointed to investigate the whole problem in detail along with the root causes and suggest a corrective action plan.

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(6) Definition and Types of Maintenance

Maintenance academicians have classified maintenance in two broad categories, viz. “Planned Maintenance” and “Unplanned Maintenance”. Any maintenance carried out with forethought, control and records is defined as ‘Planned Maintenance’. However, ‘Planned Maintenance’ is not considered a specific kind of maintenance. On the other hand, ‘Unplanned Maintenance’ does not involve any forethought or planning & control action.

Planned Maintenance is further sub-divided into another two categories, such as “Preventive Maintenance” and “Corrective Maintenance”. However, Unplanned Maintenance is classified as “Emergency Maintenance” only. It goes further to classify Preventive Maintenance as “Running P.M.” and “Shutdown P.M.”, and Corrective Maintenance as “Breakdown C.M.” and “Shutdown C.M.”. It thus represents classification of basic maintenance types.

Today, one may however raise a question – ‘where will you like to place other prominent maintenance techniques, such as CBM, RCM & TPM that came up in the recent times!’ All these maintenance techniques may be placed under ‘Planned Maintenance’ category could be the appropriate answer.

However, there are numerous maintenance techniques or practices that are in vogue amongst various maintenance departments in different industries. In fact, there is a big list of various maintenance techniques which is probably not known completely to everyone. However, to satisfy one’s requirement, few names can be mentioned, such as

Breakdown Maintenance, Reactive Maintenance, Preventive Maintenance, Running Maintenance, Routine Maintenance, Scheduled Maintenance, Shutdown Maintenance, Predictive Maintenance, Condition-based Maintenance, Reliability-centred Maintenance, Proactive Maintenance, Design-out Maintenance, Productive Maintenance, Maintenance Prevention, Autonomous Maintenance, On-line Maintenance, Off-line Maintenance, Area Maintenance, Deferred Maintenance, Fixed Time Maintenance, Mechanical Maintenance, Electrical Maintenance, Instrument Maintenance, Opportunity Maintenance, Consequence Driven Maintenance, Total Productive Maintenance, ……. and so on. However, it represents only a partial list.

Now, coming to the Definition of "Maintenance", probably for the first time, British Standard BS 3811:1964 attempted to standardize 'Glossary of General Terms used in Maintenance Organization' or 'Glossary of Maintenance Terminology'.

British Standard BS 3811:1964 originally defined "Maintenance" as –
"work undertaken in order to keep or restore every facility, i.e. every part of a site, building and contents, to an acceptable standard". However, this definition was felt inadequate and therefore modified later as indicated in the following paragraphs.

This British Standard was re-issued as BS 3811:1974 and subsequently modified as BS 3811:1984 (Glossary of Maintenance Management Terms in Terotechnology) and further amended as BS 3811:1993 (Glossary of Terms in Terotechnology).

British Standard BS 3811:1993 "Glossary of Terms in Terotechnology" finally defined 'Maintenance' as –
"the combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function".

The above definition of 'Maintenance' as provided by the British Standard BS 3811:1993 "Glossary of Terms in Terotechnology" is considered valid even today.

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(7) Basic Purpose of Lubrication

Lubricants are said to be the blood-stream of machinery. It's often said, "if plant lubrication programme is carried out effectively, then half of the maintenance problems get vanished automatically".

The aim of lubrication is to facilitate keeping the mating parts separated from each other by providing a lubricant film and thus help in minimizing friction, heat and abnormal wear & tear.

However, the purposes of using lubricants could both be "Primary" and "Secondary" as indicated below:

- To lubricate moving parts to minimize friction & wear.
- To remove heat from the moving parts by acting as a cooling agent.
- To absorb shocks.
- To provide sealing.
- To act as a cleaning agent.
- To reduce noise & vibration.
- To minimize power consumption.
- To reduce failures and down time.
- To extend service life of parts and machinery.
- To reduce workload of breakdown jobs.
- To reduce maintenance cost.
- To reduce inventory of wear-out parts.
- To protect from rusting / corrosion.
- Etc.

Further, conventionally the separation of the mating surfaces in relative motion is achieved by using various lubricants, viz. solids (e.g. graphite), semi-solids (e.g. greases) and liquids (e.g. oils).

Do you feel that there could be some other suitable materials also, such as a gas that may be used for separating mating surfaces in relative motion to reduce friction!

The answer is - yes, it's possible. Some of you must have heard about the hydrostatic bearings that utilize compressed air in place of a conventional lubricant to keep the mating metal surfaces separated from each other to achieve a frictionless drive.

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(8) Is Root Cause Analysis (RCA) Essential?

'Is Root Cause Analysis (RCA) essential?' Yes, it's absolutely essential because root cause finding is imperative to problem-solving. "Without knowing right causes, nobody can prescribe perfect remedies." No doctor can cure a patient until unless he knows the precise cause of the ailment.

Thus, Root Cause Analysis (RCA) is essentially required to facilitate solving plant problems and bring about improvement in performance on a continual basis.

RCA is likely to get unsuccessful or get futile when our energies are mainly directed towards finding "Who is wrong!" rather than knowing "What is wrong!" Also when plant people are always afraid of accepting the real causes of equipment failures due to the fear of disciplinary action against them, RCA will meet failure. In such cases, fruitful corrective actions can rarely be evolved and adopted.

It's therefore to achieve smooth operation and success in RCA, we need to first identify all practical hurdles and problems and devise appropriate ways and means to neutralize all of them. Often, it would require involvement of plant people and imparting proper training to them to bring about the desired change. Whereas, the change will usually be slow, it would forever require continuous effort in the right direction.

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(9) A Glimpse About the History of Maintenance

A glimpse about the "History of Maintenance" could broadly be gathered as follows:

(1) PRE-WORLD WAR II:

During this period, "Breakdown Maintenance" only was prevalent which involved equipment fixing when it broke.

(2) POST-WORLD WAR II:

During this period:

- Importance of "Preventive Maintenance" was realized.
- Practice of Preventive Maintenance started developing.
- Concept of "Productive Maintenance" was advocated by General Electric Company of USA in 60s.
- Concepts, such as "Terotechnology", "Asset Management", "Life-cycle Costs", etc. were evolved in the early 70s in Britain.
- Etc.

(3) 1980 ONWARD:

During this period, the following aspects increasingly became part of Plant Maintenance Management:

- Importance of reducing costs
- Need for Reliable Equipment
- Increased awareness of –
  - Quality
  - Safety
  - Environment
  - Health
- New concepts and practices in maintenance, such as CBM, RCM, TPM, etc.

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(10) Top 5 KPIs for a Manufacturing Industry

KPIs in a manufacturing industry need to be necessarily evolved on the basis of their company's corporate objectives & goals. However, these KPIs should be able to reflect the overall economic performance of a manufacturing unit over a period of time in the first place. Whereas there will always be a variation in opinion so far as the top 5 KPIs in a manufacturing industry are concerned, however, generally more than 5 KPIs may often be required to track the overall economic performance in a manufacturing industry.

Focusing preference on top 5 KPIs for a manufacturing industry, the following may fall under priority list:

(1) % Increase in Sales Turnover
(2) % Increase in Profit
(3) % Reduction in Manufacturing Cost to Sales Turnover
(4) % Increase in OEE
(5) % Reduction in Customer Complaints

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(11) What is S.M.E.D.?

Basically, the abbreviation S.M.E.D. stands for "Single Minute Exchange of Dies". SMED is all about how to do equipment or product changeover in a record time, often under 10 minutes.

The initial two words, namely "Single Minute" used here mean a single-digit number in minutes, i.e. "up to 9 but less than 10 minutes".

In one of the first applications of SMED tool, Toyota Car Company shortened setup time on a 1000-ton stamping press in their plant from 4 hours to as little as 3 minutes in a record time.

"Are you surprised!" However, one should always remember –"Where there is a will, there is a way". What is actually required is *new thinking* to do the changeover job.

SMED is a simple and universal tool which was initially developed by Dr. Shigeo Shingo, a Japanese expert. Although, SMED was first used in the context of "dies" in manufacturing operations, yet the basic principles of SMED are equally relevant to various other situations that warrant reduction in setup and turnaround time. SMED is all about thinking for changeover in a new and novel way. Fundamentally, it involves method study *(part of work study)* to improve upon the existing method of changeover and reduce changeover time to a single digit minute time.

SMED approach basically involves three stages as briefly discussed below:

(1) Stage-1: Separating Internal and External Setup Tasks
(2) Stage-2: Converting Internal Setup to External Setup
(3) Stage-3: Streamlining all aspects of Setup Operations

Dr. Shigeo Shingo observed that many plant people failed to distinguish between internal and external setup and therefore caused problem in achieving changeover in the shortest possible time.

What is the meaning of internal and external setup tasks? The tasks or work activities which are performed after the stoppage of a machine are called 'internal setup'. However, all those tasks or work activities which can be performed parallel to the machine running are called as 'external setup'.

The following things are thus absolutely necessary to achieve the objective of SMED in different situations:

(1) The internal and external setup tasks should be separated from each other.
(2) Think new ways of working to convert as many internal setup tasks to external setup as possible. In fact, it's here that one should use 'Method Study' and apply his creativity. Ideally, internal setup time should be as little as possible which ultimately results in the actual time of changeover.
(3) Finally, we again need to use the principles of 'Method Study' to evolve new innovative methods in order to assure reduced time both for internal and external setup tasks.

In this manner, the aim of SMED can be fulfilled in various cases.

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(12) Scope of Applying SMED at Home

The basic concept of SMED is advocated to achieve quick set up or change over to facilitate completing various tasks in shortest possible time (conventionally, less than 10 seconds) by eliminating delay, waiting time, or any other unproductive activities. Firstly, it requires shifting internal set up work activities to external set up and secondly, it focuses on minimizing time for internal work activities. Those who are conversant with the subject of 'Method Study' can appreciate and understand the concept of SMED in a much better way.

Many people have already been using the concept of internal & external set up work activities wisely in their day to day lives at home and other places based on common sense without really having any precise knowledge about SMED itself.

Think of the following simple situations at home and decide whether we employ SMED at home or not!

(1) During cold season, for taking bath, would you prefer to go to bathroom when hot water is ready in the geyser, or would you simply like to enter bathroom any time and then put on the geyser switch; wait for the hot water to come out; and then take bath?

(2) Would you be ready with your cut vegetables in advance before lighting up gas stove for cooking, or like to do it the other way round?

(3) Won't you first arrange soup, cooked food, salads, water, crockery, etc. close to the dining table before asking your family members to take dinner, or would you like to do it the other way round?

(4) Before setting off to your office at a scheduled time on each day, won't you like your car, brief case, bag and other necessary items, in fact, everything to be just ready at the right time without any delay?

There are several other examples related to home activities that can be quoted to indicate that many of us have often be using our common sense in converting internal activities of a task to external activities . Similarly, there are many examples related to minimizing time content of the internal activities of a task at home that could also be highlighted.

Thus, based on our common sense, we have already been applying SMED principles in context of our home activities for long and surely we could employ them for more provided we are a bit more knowledgeable and innovative. It needs to be remembered - "where there is a will, there is a way".

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(13) Impact of Unplanned Maintenance on Costs

By failing to plan and schedule maintenance, over a period of time, maintenance departments have to face more number of breakdowns and higher downtime in their plants. Subsequently, in such cases, maintenance staff need to deal with a high percentage of workload in the form of reactive/breakdown maintenance which often proves costly.

Further the impact of breakdowns, occurring at random time, shows significant effect on costs in several ways. Whereas some of these costs can be perceived tangibly, the rest could only be realized in intangible terms, as discussed below:

(1) LOSS OF PROFIT DUE TO DOWNTIME:

Loss of Profit due to downtime on account of production loss, referred as indirect maintenance cost or downtime cost.

(2) COST OF SECONDARY FAILURES:

One small undetected failure may have a cascading effect leading to secondary failures.

(3) COST OF REDUCTION IN USEFUL LIFE:

Frequent breakdowns lead to forced deterioration and hence reduction in useful life of various parts.

(4) COST OF SET UP TIME:

In case of breakdowns, often it requires quite some time for fault finding and arranging necessary tools and spares.

(5) COST OF TEMPORARY WORK:

In the event of critical breakdowns, maintenance is pressurized to finish work fast and often it ends in doing a temporary work.

(6) COST OF STANDBY LABOUR:

In order to correct breakdowns speedily as they come up, it requires labour deployed round the clock. In the event of breakdowns labour is utilized productively, but when there is no breakdown, it simply keeps up as standby labour.

(7) COST OF EMERGENCY PURCHASES:

Certain parts required to correct breakdowns if not available in stores may warrant emergency purchases and could involve additional cost.

(8) COST OF INJURY DUE TO BREAKDOWNS:

Certain breakdowns may be hazardous and cause injury to the workers.

(9) COST OF OVERTIME:

Too many breakdowns may create backlog of work which could possibly be cleared at the cost of overtime only.

(10) COST OF REJECTION OR REPROCESSING:

Breakdowns may lead to rejection of products or necessitate reprocessing at additional cost.

(11) COST OF DELAYED DELIVERY OF GOODS:

Delivery schedules may get disturbed due to breakdowns leading to dissatisfaction amongst customers and result in loss of goodwill.

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(14) DIFFERENCE BETWEEN 'NATURAL' AND 'FORCED' DETERIORATION OF MACHINE

Depending on various factors, deterioration of a machine can occur either as "Natural Deterioration" or as "Forced Deterioration". However, a brief comparison of these two types of deterioration is indicated below:

NATURAL DETERIORATION:

- It occurs due to continuous usage of machine.
- It occurs because of exposure of machine to normal stresses as per design specifications.
- It occurs as a result of normal wear & tear in spite of proper operation, proper maintenance and proper environmental conditions. That means it occurs without presence of any apparent problems.
- The speed or frequency of natural deterioration can be reduced only by way of enhancing inherent reliability of machine.

FORCED DETERIORATION:

- It occurs due to various defects & abnormalities in process and/or machine.
- It occurs because of exposure of machine to abnormal stresses as per design specifications.
- It occurs as a result of abnormal wear & tear due to mal operation and/or bad maintenance and/or harsh environmental conditions.
- Incidences of forced deterioration obviously indicate problems with causes in single or multiple areas. It's absolutely necessary to find root causes of such deterioration; devise suitable corrective measures; implement them; and finally follow them periodically.

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(15) DO SIMPLE "AVERAGES" OF SPARES SERVE USEFULLY IN SPARES INVENTORY CONTROL?

In spares inventory control, if simple “averages” are used to get to know the average consumption of various spares, it may prove quite harmful. Let us take a simple example to explain it further.

Suppose, in a particular case, average consumption of a spare part is found to be 0.5 per month (i.e. 1 part per two months), then if some body uses this “average” metric simply to calculate “annual requirement” of this item as 0.5x12 = 6 parts, it’s likely to be erroneous. In actual practice, the real consumption pattern of this spare part may be found varying widely, e.g. from a “MINIMUM – substantially less than 6 parts (may be even 3 parts or less)” to a “MAXIMUM – substantially more than 6 parts (may be even 12 parts or more)” because statistically consumption of spare parts frequently follows Poisson’s Distribution.

It’s therefore simple “average” consumption of a spare part that follows Poisson’s Distribution cannot be straightaway used to calculate its total consumption/requirement for a future time period, such as a year, or so. Simple “averages” in such cases are likely not to work out trustworthy or friendly.

However, there may be certain regularly used items, such as common maintenance consumables, production raw materials, etc. which may follow Normal Distribution in their consumption patterns. In such cases, simple “averages” may be far more authentic or friendly in calculating total consumption of various items for a future time period, such as a year, or so.

It is thus simple “averages” can either work out useful or no useful, depending from case to case, while establishing consumption patterns of various spares in stores.

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(16) What is the World Class Ratio of ‘Maintenance Labour’ to ‘Maintenance Material’ Cost in Industry?

Basically, the ratio of ‘Maintenance Labour Cost’ to ‘Maintenance Material Cost’ is found varying from job to job, plant to plant and country to country. Further, this ratio will often be seen varying significantly from developed to developing countries.

The nation wide average ratio of ‘Maintenance Labour Cost’ to ‘Maintenance Material Cost’ in a DEVELOPED COUNTRY may be found around 60% : 40% or 65% : 35%, or alike. Whereas the nation wide average ratio of ‘Maintenance Labour Cost’ to ‘Maintenance Material Cost’ in a DEVELOPING COUNTRY will usually be found in the reverse order, i.e. 35% : 65% or 40% : 60% or alike.

Because of different economic conditions, distinctively different cost patterns are shown in developing and developed countries. However, an important conclusion can be drawn that developed countries, on an average, incur more cost on “Maintenance Labour” as compared to that on “Maintenance Materials”. On contrary, developing countries, on an average, incur less cost on “Maintenance Labour” compared to that on “Maintenance Materials”.

The above facts necessitate developed and developing countries to follow different maintenance strategies to be able to perform economically in their respective environments.

It is therefore there can hardly be any world class ratio due to wide variation across industries as well countries that can truly be acceptable as a world class benchmark for all companies round the globe. Even if such a benchmark is suggested for a developed country, the same cannot exactly be adopted for a developing country or vice versa.

Then, what!

Probably, a better way out could be to measure your own ratio and subsequently strategize to improve it the way you wish to improve it to gain higher economic advantage.

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(17) Approach for Reducing Plant Failures and Downtime

The following important suggestions comprising a broad approach were given to a particular plant with a view to reduce failures and downtime:

(1) Work out ‘Pareto Analysis’ of downtime and production loss to establish priority.

(2) Recording of failures along with fault finding and rectification time. Highlighting difficulties encountered while correcting faults.

(3) Analyzing records and work out alternative ways to reduce MTTR of various failures.

(4) Preparation of ‘Trouble Shooting Charts’ for critical equipment based on the past experience to facilitate maintenance gang to avoid excessive time in fault finding.

(5) Introduction of proper training programmes for maintenance workforce with a view to achieve minimum repair time and error free maintenance.

(6) Introduction of effective spare parts management with a view to avoid delay due to want of spare parts & tools.

(7) Simplification of maintenance procedures so that maintenance gang can straightway start repair work without any waiting or delay.

(8) Investigation of failure causes and downtime for each type of failure and comparison to the previous history.

(9) Introduction of effective preventive & predictive maintenance activities, such as lubrication, inspection, condition monitoring and tests.

(10) Procurement of all necessary special tools and instruments as per the requirement of various maintenance jobs.

(11) Issuing proper operating instructions to the operators and maintenance instructions to the maintenance gang.

(12) Introduction of maintenance material & spare parts procurement plans, inspection procedures and proper storage together with efficient methods for issuing spare parts & tools to the maintenance gang.

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(18) Failure of Shaft and Bushes: Case Study

A machine incorporated a shaft made of high carbon high chromium hardened steel housed in a cast iron casing. The shaft operated with reciprocating sliding motion over two phosphor bronze bushes.

The machine faced problem of excessive wear of the bushes together with the shaft. Consequently, the bushes required replacement as early as three weeks whereas the shaft needed replacement quarterly. The machine operated in a dusty environment.

What could be suggested to increase the life of the bushes and the shaft?

As a solution, various alternatives could be evolved to increase the lifespan of the bushes and the shaft. The wear of the bushes could be reduced considerably if bushes made of steel or stellite or linear ball bushes are used in place of phosphor bronze bushes. The linear ball bushes have hardened chrome plated steel balls arranged in helical form and provide easy rotary and axial movements. Thus, one of the best alternatives could be found in using linear ball bushes since they involve little wear & friction and have capacity to take more wear than a conventional bush. Also these bushes provide more effective lubrication due to the spacing between the shaft and the bush. The abrasive dust will also not prove much harmful as it will get trapped in the ball cage of the bush.

The wear of the shaft can be reduced by hard chrome plating. The hard chrome surface improves hardness and ensures reduced friction. The shaft also needs to be provided with seals to check any dust ingression.

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(19) Failure of Coal Crusher Bearings: Case Study

This case was related to a coal crusher with crushing capacity of 50-60 tonnes per hour. The prime mover of the crusher incorporated a 50 H. P. motor and operated at 500 R.P.M.

The crusher was operated through belts and pulleys on both sides and supported by four no. of double row spherical roller bearings A, B, C & D housed in pillow blocks as shown in the sketch below.

A fly wheel on each side of the crusher was also installed at the extreme ends to provide higher moment of inertia as shown in the sketch.

The observations showed that the bearings used to fail once in one or two months after running hot. The bearings B & C were found more prone to failure than A & D.

The leakage of the coal dust from the casing of the crusher along shaft was also observed. Multipurpose grease was used for lubrication of the bearings. The grease container was often found uncovered in close vicinity of the crusher.

Therefore, the reasons for premature failure of the bearings were investigated and appropriate corrective actions to improve life of the bearings were suggested.

Coal dust which is highly abrasive in nature was found leaking from the casing along shaft and found entry into the bearing housings. The bearings B & C were found prone to higher failure due to easy access to leaking dust compared to A & D bearings. The problem was further aggravated due to grease container frequently found lying uncovered near the crusher and thus resulted in the contamination of the grease with coal dust. Undoubtedly, using such contaminated grease obviously led to high abrasive wear of the bearings.

The following corrective measures were suggested to reduce the frequency of bearing failures:

(1) The leakage of coal dust from the casing of the crusher needed control by providing adequate sealing arrangement.
(2) The sealing arrangement of the bearing housings needed regular check for effective maintenance.
(3) Grease container required storing far away from the coal crusher and the dusty environment. It also required to be kept properly covered to avoid any contamination.

The above stated suggestions helped to reduce bearing failures substantially. Subsequently, it was also recommended to check excessive vibrations, poor mounting practices, etc., if any, to ensure increasingly better results.

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(20) What is RCM?

Reliability-centered Maintenance (RCM) is a process to ensure that assets continue to do what their users require in their present operating context. Reliability-centred Maintenance is one technique more within the possibilities to develop a maintenance plan in an industrial plant that it has some advantage over other techniques. Initially, it was developed for the aviation sector, where the high costs involved in the systematic replacement of parts threatened the airlines profitability. Later, this technique was transferred to the industrial area after establishing some excellent results in the aeronautical field.

The reliability-centred maintenance is based on failure analysis, both those that have already happened and being tried to avoid with certain preventive actions, and finally those that have a certain probability of happening and that can have serious consequences. RCM can be used to create a cost-effective maintenance strategy to address dominant causes of equipment failure. It is a systematic approach to defining a "routine maintenance program" composed of cost-effective tasks that are planned and scheduled to preserve important functions of various plant equipments. The important "functions" of various equipments to preserve with routine maintenance are identified, their dominant "failure modes" and "causes" determined and the "consequences" of failures ascertained. Levels of “criticality” are assigned to the consequences of failure. Some functions are not critical and are left to "run to failure" while other functions must be preserved at all cost. Maintenance “tasks” are selected that address the dominant failure “causes”.

The RCM method employs Planned Preventive Maintenance (PPM), Predictive Maintenance (PdM), Breakdown Maintenance (also called reactive maintenance) and Proactive Maintenance techniques in an integrated manner to increase the probability that an equipment will function in the required manner over its design life-cycle. The goal of the method is to provide the required reliability and availability at the lowest cost. RCM requires that maintenance decisions be based on maintenance requirements supported by sound technical and economic justification.

RCM analysis determines the “type of maintenance” appropriate for a given item of an equipment. It results in a decision of whether a particular piece of equipment should be reactively maintained ("Accept the Risk of Failure" and “Repair after Failure”), preventively maintained (“Prevent the Failure” by "Defining PM Task and Schedule") or predictively maintained (“Predict & Correct the Failure” by "Defining PdM Task and Schedule") or proactively maintained.

Successful implementation of RCM leads to improvement in cost effectiveness, machine uptime, and a greater understanding of the level of risk that the organization is managing.

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(21) What is TPM?

Total Productive Maintenance, as a means of introducing a new maintenance regime, is centred on optimum mix of different techniques, approaches and ideologies that lay emphasis on organizing improved and efficient form of productive maintenance through total participation of plant people.

TPM perception is unequivocally farsighted, which advocates that a facility cannot be kept in good working condition through certain fixed procedures, but by way of autonomous action only. It focuses on overall equipment effectiveness in terms of availability, output and quality performance factors. TPM also recommends to disciplining unity in the efforts of key departments, such as operation, maintenance, planning, design, etc. to discover the best results of economy in the usage of plant equipment and facilities throughout their life cycle.

TPM aims at arresting all kinds of equipment losses and wastage as it stands for zero defects, zero breakdowns and zero losses. It’s focused on maximizing “Overall Equipment Effectiveness (OEE)” of various machines. In essence, TPM represents total productivity improvement of various resources to enable maximizing return on investment.

Often, the benefits of TPM are phenomenal. It means working for improved knowledge, skills & culture to be able to realize higher output together with better quality from the existing machine resources at lesser cost. It adds to the overall economics in a big way and sharpens competitiveness of the company.

Based on the past experience, generally 10 to 25% production capacity of different machines is lost in various ways which is often found beyond the normal understanding of many plant people. Evidently, therefore, if such hidden or unnoticed losses are identified and controlled, additional plant capacity for higher production can simply be created from the existing resources of plant equipment and machinery. And, that is one of the prime objectives in following TPM approach and improving machine performance by collecting and analyzing OEE data. The impact of merely 1% loss of capacity in many plants is simply enormous.

As such TPM requires involvement of all plant people from top to the bottom. It stands for improving plant together with plant people and creating a pleasant work environment. In other words, it requires both technical and cultural changes. It relies on autonomous small group activities.

The success of TPM is dependent on how cohesively everybody can be an integral part of the TPM programme. It always requires concerted effort to firmly establish TPM culture in a plant. It requires development of plant people with right attitudes, willingness, enthusiasm and ownership, well equipped with adequate knowledge & skills, together with unmatched team spirit to be successful in achieving the desired results. It often takes quite some time before TPM gets firmly rooted and all plant people really become part of the TPM programme.

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(22) Insight into Overall Equipment Effectiveness (OEE)

Basically, Overall Equipment Effectiveness (OEE) indicates overall performance of an equipment and calculated by multiplying factors, viz. “Availability Performance”, “Speed Performance” and “Quality Performance”. OEE is frequently shown by the following formula:

OEE = Equipment Availability x Performance Efficiency x Rate of Quality Products

Or, OEE = A x P x Q

Broadly, OEE of a machine indicates “Potential” utilized vis-à-vis its “Total Potential”. For example, if OEE of a machine is 70%, it clearly indicates that 70% of the “Total Potential” of the machine is only being utilized presently and the rest 30% is simply wasted in various forms, commonly known as machine losses, i.e. six big losses. In other words, we could also say that 30% of the "Total Potential" of the machine remains untapped or unutilized.

We could go a step further. Suppose, there is a machine having capital investment of 2 crores of rupees and showing 50% OEE only, then it will mean that this machine though has potential to produce "X" quantity, yet it's only producing "0.5 X" acceptable quantity. In other words, whereas half of the capital investment of 1 crore of rupees is producing return, the rest half of the investment is not at all generating anything.

In other words, OEE represents "Net Utilization" of a machine in the form of 'o.k.' production, and <u>not</u> as total production which equals 'o.k.' plus 'reject' production.

Of late, some specialists suggested to modifying the OEE formula as follows:

OEE = Equipment Availability x Performance Efficiency x Rate of Quality Products x Energy Consumption

Or, OEE = A x P x Q x E

In order to critically analyze the usefulness of the above formula, we need to get answers to few questions. Firstly, we need to ask a very basic question – "What is the purpose of including 'E' in OEE?"

"Is it to improve 'E' or 'OEE' or 'Both'?"

If your answer is to bring about improvement in 'Both', will you then say that only by including 'E' in OEE formula, both of them can be improved effectively?

"What is your answer?"

According to us, the reason why 'E' is being suggested for including in OEE formula is to improve 'E' only and not 'OEE'. And that is why we do not favour to include 'E' in OEE formula. Further, any variations in A, P & Q in the traditional OEE formula directly affect 'Volume of Production'. However, any variation in 'E' does not directly correlate to variation in 'Volume of Production'. As such, when 'E' is influenced by OEE and OEE is not influenced by 'E', then including 'E' in OEE formula seems illogical.

It's therefore 'E' factor does not find any compatibility with A, P & Q factors. Further, if 'E' factor is included in OEE formula, it will also become difficult to pinpoint the specific reasons for poor OEE performance.

Therefore, let us keep improving OEE in the traditional way by enhancing A, P & Q. And, also let us keep improving 'E' separately without including it in OEE formula, the way most industries have already been doing it traditionally. Let the reigns of controlling or improving 'E' (Energy Performance) exclusively remain in the expert hands of Energy

Manager or Manager (Electrical) or someone else better considered by the management of the company.

To tell you further, some other specialists speculated it slightly differently that OEE with energy can be termed as OEP. They suggested that the energy intensive units can measure the performance in terms of OEP in stead of OEE as indicated below:

OEP = A x P x Q x E
Where, A x P x Q = OEE
Or, OEP = OEE x E

By looking at the above formula, again it's difficult to get convinced and therefore we need to find answers to some of the questions once more as noted below:

(A) Would you like to recommend only OEP for energy intensive units? *Or*

(B) Would you prefer to recommend both OEE and OEP for energy intensive units?

In case, you select (A) – "Could you please apprise us what & how will you be going to analyze OEP data to arrive at useful conclusions to devise further action for equipment improvement?"

However, if you fall for (B), our next question is – "Will it be better to have OEE & OEP data, or just OEE & 'E' data separately?" Please explain with your reasoning.

After finding answers to the above stated questions, we believe that you will also like to go in for OEE & 'E' data separately for improving both of them effectively. We don't see any necessity of including 'E' in OEE formula irrespective of whether it's energy intensive industry or not.

It seems futile when specialists suggest to change OEE formula by including 'E' factor. In the detailed analysis given above, things have been presented logically and it can be concluded that there is no need to include 'E' in OEE formula because it will not only change the basic concept and content of OEE but also make things unnecessarily complicated without any real benefits.

However, if you wish to integrate OEE and 'E' in a fruitful manner, we would like to suggest a KPI, i.e. [Ratio of 'E (Energy Consumed)' to 'OEE (%)'] for monitoring performance of 'E (Energy Consumed)' for a machine in a periodic manner. Such a KPI will actually show performance of 'E (Energy Consumed)' in achieving '1% OEE' of a machine. Obviously, a decreasing trend of this KPI will represent better performance of 'E (Energy Consumed)'.

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(23) Quiz on Maintenance Management Aspects

Judge your basic understanding of the maintenance management aspects through the following quiz.

To answer, please fill in, tick or explain as per the requirement.

(1) An important statement, such as “achieving maximum plant availability at minimum cost” can be regarded as ………………………………….

(2) The ratio of ‘MTBF’ to ‘MTBF + MTTR + MWT’ is supposed to be representing ………………………………………….

(3) The stages during which 80% of the whole life cycle costs of an asset get decided are described as …………………………………………

(4) A popular methodology of ‘Root Cause Analysis’, used to establish causes for maintenance problems, is based on diagrams and frequently called as ……………………………………

(5) If the failure of a system is given as the sum of the individual failure rates of different elements constituting the system, then the configuration of the system is called as …………………………………….

(6) A fixed time replacement policy is usually suggested for an item with random failure characteristic showing a constant probability of failure at all ages. *True or False?*

(7) Do we need to improve maintenance productivity in industry? Why?

(8) What will happen if MTBF of a machine in your department gets reduced?

(9) The sum of direct maintenance cost and indirect maintenance cost is called as …………………………………………..

(10) The ‘Up Time’ of a machine on four consecutive occasions was noticed as UT1, UT2, UT3 & UT4.

If X = (UT1 + UT2 + UT3 + UT4) / 4
Then, X will represent ……………………………..

(11) The ratio of ‘Capital Investment’ to ‘Profit’ is known as …………………………..

(12) When maintenance is done only because it needs to be done since it has already been planned and scheduled, or because that is an established practice though, in real sense,

there may not be any need of it, then such type of maintenance can be referred as ………………………………………..

(13) In maintenance stores, the inventory of ‘C’ class of items in terms of money value is often found lower than that of ‘A’ or ‘B’ class items in different companies. *True or False?*

(14) The art of directing and inspiring people and the process of getting things done through them is usually referred as ……………………………………

(15) The purpose of planned maintenance is mainly to reduce breakdowns and downtime but not necessarily the total maintenance cost. *True or False?*

(16) Conventionally, in many plants, maintenance activities are devoted to achieving maximum plant availability which is influenced by the down time losses only. However, there are other equipment losses also which are frequently found present in many cases. It’s therefore equipment availability alone cannot formulate the correct parameter for evaluating the overall equipment performance. *True or False?*

(17) Roughly, what (%) may be the ‘Inventory Carrying Cost’ in your company’s stores as per your guesstimate?

(18) Maintenance technique which is usefully employed not only to reduce downtime due to excessive shutdowns but also to reduce downtime due to excessive breakdowns is frequently known as …………………………………………

(19) For many industries operating in a developing country like ours, the ratio of cost of maintenance materials to cost of maintenance labour may be found in the range of about 70% (maintenance materials) to 30% (maintenance labour) or alike. *True or False?*

(20) An accident occurs when an unsafe condition is combined with an unsafe act. Many safety surveys indicate that eighty to ninety percent of the accidents are caused due to “unsafe conditions”. Therefore, “unsafe conditions” constitute the major cause for most of the industrial accidents. *True or False?*

(21) Certain maintenance activities that turn out to be uneconomical in a developed country can very well become economical in a developing country. Why?

(22) What is the characteristic of equipment design that is generally represented by MTBF?

(23) Preventive maintenance carried out on scheduled fixed-time basis is often likely to have elements of both over maintenance as well as under maintenance. In order to control ill effects of both over maintenance and under maintenance, the concept of condition-based Predictive Maintenance was evolved and recommended by the experts. *True or False?*

(24) Statements, such as, "I am working in the maintenance department for the last 20 years. I know my problems best. Nobody else can do the way I have been doing. What more can you expect from me!" are supposed to represent ………………………………..

(25) Once the daily maintenance work is recorded in a log book, there is practically no need to transfer it to the respective history cards, and if somebody is doing so, he is fruitlessly duplicating the work. *True or False?* Why?

(26) The ratio of 'Output' (representing production) to 'Input' (representing '3M' resources) is popularly known as …………………………………….

(27) Knowing in advance "What" and "Where" is going wrong in different machines does not help much because if any breakdown is to occur, it will occur certainly. *True or False?*

(28) A machine, for which both MTTR and MTBF are high, is likely to yield low machine availability. *True or False?* Why?

(29) The technique that is based on infrared radiation to detect hot spots or high temperature conditions in various plant equipment is called as ……………………………………

(30) Readings about vibration amplitude were taken on an equipment at different time intervals. A higher vibration will directly reveal the cause of trouble through such readings. *True or False?*

(31) The 'Down Time' of a machine on four consecutive occasions was noticed as DT1, DT2, DT3 & DT4.

If $Y = (DT1 + DT2 + DT3 + DT4) / 4$
Then, Y will represent ……………………………………..

(32) For effective lubrication programme, the following "5 Right" things are always considered essential:

(i) Right Type
(ii) Right Quantity
(iii) Right Method
(iv) Right ……………
(v) Right …………..

(33) Good maintenance can often result in lower consumption of electrical power. For example, worn out pumps or motors running on loose V-belts, etc. are supposed to consume more electrical power. *True or False?*

(34) A Gantt Chart forever provides better effectiveness in planning & scheduling various activities of a maintenance job compared to PERT/CPM.

(35) The inventory carrying cost in the stores of a company was estimated at 20%. However, the yearly inflation rate was recorded close to 7%. If an item is kept in the stores for a period of 1 year, how much more will it actually cost compared to its original price after 1 year?

(36) The third generation findings prove that failure rate of an item (or in other words, reliability of the item) does not always depend on its operating age. *True or False?*

(37) Bathtub curve describes a particular form of the hazard function and indicates failure rate pattern observed in some products during their lifetime which comprises of three distinctive parts. *True or False?*

(38) If stock-in cost for an item is more than its stock-out cost, then there is no need to stock the item in stores. *True or False?* Why?

(39) RCM technique advocates if the criticality of a failure falls in insignificant category, it can be left to "run to failure" strategy. *True or False?*

(40) If availability of a machine is influenced by its reliability, what is the other machine characteristic that also affects its availability?

(41) Which one of the following statements explains the meaning of 'Preventive Maintenance' in a better way:

(i) Replacing failed parts with new parts when required.
(ii) Finding defects of the machine before breakdowns.
(iii) To anticipate machine defects & failures in advance and take proper proactive action before they get converted into breakdowns.

(42) During 20th Century, improvement in productivity was considered much necessary. However, during 21st Century, improvement in productivity has proved more or less meaningless because profitability is supposed to be of greater value. *True or False?*

(43) The approach which is a combination of management, financial, engineering and other practices applied to physical assets in pursuit of economic life-cycle costs; that is concerned with the specification and design for reliability and maintainability of plant, machinery, equipment, buildings and structures, with their installation, commissioning, maintenance, modification and replacement, and with feedback of information on design, performance and costs is known as ……………………………………………

(44) The more the maintenance workload in a maintenance department, the better will be the management of maintenance function. *True or False? Why?*

(45) At high pressures with impact conditions, the abrasion that involves removal of sizeable particles from a surface by the action of a coarse abrasive material is called as ……………………………………..

(46) The time interval between the point at which the onset of failure can be detected and the point at which functional failure occurs is called as…………………………………

(47) A failure mode describes how equipment can fail and potentially result in a functional failure. *True or False?*

(48) The science and practice of wear, friction and lubrication applied to engineering surfaces in relative motion is called as …………………………………..

(49) Third generation research originally carried out by two Americans, Stanley Nowlan and Howard Heap revealed that not one or two but “Six Failure Patterns” actually occur in practice. *True or False?*

(50) The maintenance practice which suggests that maintenance should ideally be carried out just at that point of time when plant equipment and machinery actually requires maintenance is called as ………………………………………

(51) The wear mechanism that is attributed to the cyclic loading of two surfaces in mutual contact and usually occurs without prior indication of major loss of the surface material is known as ……………………………………………

(52) A failure mode whose failure effects do not become apparent to the operators on its own under normal circumstances is known as ………………………………………

(53) In a system involving a pump, coupling and a motor, the reliability of each component is 90%. In such a case, the reliability of the overall system (pump-coupling-motor together) will be much less than 90%. *True or False?*

(54) In complex systems, as high as 60% cases represent “Bathtub” type of failure pattern. *(Tick):*

(55) The probability of failure - free operation of a machine within a given time and specified working conditions is called as...

(56) A process that is used to determine "What maintenance must be done" to ensure that a physical asset continues to fulfill its intended functions in its present operating context, is called as...

(57) Why should V-belts be avoided to run in loose condition? How Flat belts become preferable over V-belts in certain cases?

(58) In brainstorming, the role of logic should start after the creative process gets over. We should use our logic in separating out the useful ideas from the list of brainstormed ideas and finally in evaluating them for proper selection. *True or False?*

(59) In order to effect reduction in overall inventory of maintenance stores, we need to be guided by the broad principles, viz. (i) "Reduce Consumption Cost" of maintenance items (ii) "Reduce Stocking Cost" of maintenance items. *True or False? Why?*

(60) TPM is somewhat analogical to family team approach where all family members are ready to co-operate and act as a harmonious team to contribute to common objectives and solve problems jointly. For example, in TPM, both production and maintenance need to share a common objective, i.e. maximum overall equipment effectiveness. *True or False?*

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