Accelerated Reliability Centered Maintenance: A New Maintenance Strategy

KEYWORDS Reliability, RCM, A-RCM, Accelerated Reliability Centered Maintenance, Maintenance Management

Deepak Prabhakar P
Research Scholar, Dept. of Management Studies & Research, Karpagam University, Coimbatore

Dr. Jagathy Raj V. P.
Professor, School of Management, Cochin University of Science & Technology, Cochin

ABSTRACT *Reliability Centered Maintenance is an established methodology for identifying maintenance tasks. This method is used primarily in the fields of airline maintenance and certain automobile industries. In the process and petroleum refining industries, where equipment reliability is as much a concern as that of the airline industry, this methodology has found only limited application. This is due to the complexity of the original approach which requires dedicated resources and a long gestation period for accrual of benefits. With a view to simplify the process of RCM, the authors have developed an alternate methodology of RCM known as Accelerated Reliability Centered Maintenance or A-RCM. This paper provides the details the model as well as the methodology of the A-RCM process.*

INTRODUCTION

Process industries, particularly petroleum refineries operate on very low margins. These industries also face both raw material as well as product price volatility resulting in an operating environment where the plants are forced to operate well beyond capacity and without shutdowns for long periods. This results in high pressure on the physical assets to perform for these extended periods without downtime. In order to ensure that the equipment operate for extended periods, asset management methods in process industries, particularly maintenance management, needs to innovate continually so as to keep up with the demands of the operating environment. However, due to the lack of research in the field of maintenance management very little innovation has been seen. It is a telling commentary on the state of affairs that Reliability Centered Maintenance (RCM) which is presently being offered as a solution to asset management issues by various consultants and software vendors was first developed in the 1950s and applied successfully in the aviation industry for the past 50 years. This gap in what other industries have adopted and what is being projected as state of the art for process plants is a clear indication that the asset management in process units suffers from a lack of innovation and that RCM as a methodology has found limited application. This paper evaluates the RCM methodology, explores reasons for the poor acceptance of the methodology in process units and then presents an alternate approach that addresses the limitations of RCM and adapts it to the needs of process industries.

CONVENTIONAL APPROACHES TO MAINTENANCE MANAGEMENT

The conventional maintenance response to the need for preventing failures has been to have a Predictive Maintenance program that has both condition-based tasks and time-driven tasks (Mobley, 2002). Condition-based tasks are derived mainly from Vibration analysis (Renwick, Babson, 1985). Time-driven tasks typically arise out of equipment manufacturer recommendations and are conventionally referred to as PM Tasks or PM Plans. In addition to the PM Plans and the PdM plans, most organizations employ a Root Cause Failure Analysis program (RCFA).

Endrenyi et al (2001) in their report state that in the past, maintenance routines consisted of pre-defined activities carried out at regular intervals (scheduled or preventive maintenance). They further state that such policies may be inefficient and in the long run costly. This they say has resulted in this program being replaced by more flexible programs based on the analysis of needs which constitute the system of Predictive Maintenance (Endrenyi et al, 2001)

Proactive or preventative maintenance (PM) strategies are an essential component of an effective maintenance program. The PM strategy known as condition-based maintenance (CBM) provides a dynamic understanding of equipment condition while in operation and is used to predict failure in mechanical systems through fault diagnosis from condition monitoring signals using diagnostics and prognostics. CBM strategies are currently a major focus of maintenance and maintenance management research due to the aforementioned trends and challenges, increased complexity in industrial technologies, and advances in condition monitoring techniques that include the use of online systems. Current literature on CBM applications in the oil and gas industry illustrates the effectiveness of this strategy as a way to improve maintenance management, prevent accidents, and optimise production. (Telford, Muhammed & Howard, 2011)

In the case of Indian refineries the Oil Industry Safety Directorate (OISD) has through its standards specified the type of maintenance strategies to be adopted by these refineries. These standards prescribe that as a minimum, the refineries have a PM Program (OISD-119, 2008), a PdM program (OISD-124, 2007) and an RCFA program (OISD-124). This ensures that a preliminary level of reliability assurance is achieved in these plants.

Mobley (2011) provides the list of current maintenance strategies as – Run to failure, Preventive and Predictive. He also summarizes the conventional state of maintenance management as in Figure 1.

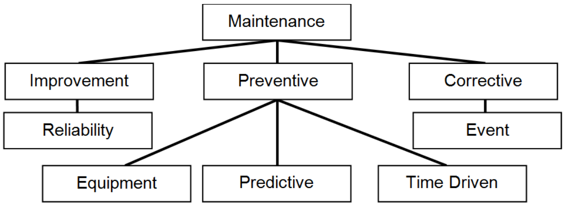

Figure 1 – Current Maintenance Strategies (Mobley, 2011)

RELIABILITY CENTERED MAINTENANCE

Reliability Centered Maintenance is a process that has evolved out of the work of Nowlan and Heap in the late 1970s. This was primarily aid at the airline industry and RCM became the accepted strategy for reliability management in the commercial and the military aviation sector.

Overman (2003) summarized the development of RCM as follows. "In 1978, the Department of Defense asked Stanley Nolan and Howard Heap, both from United Airlines, to expound upon "MSG philosophies" for application to military aviation. Their report coined the name "Reliability-Centered Maintenance". After this, RCM development followed three distinct and separate tracks. The three tracks are the commercial aviation track, the military aviation track (led by the Navy) and the commercial industry track. The commercial industry track became the most diverse track with many different groups and people entering the market. RCM became divided into 2 main groups; the "classical" RCM processes and hybrid RCM processes. Hybrid RCM includes various attempts at taking short cuts with the RCM process, usually by leaving out some steps. The Society of Automotive Engineers (which involves every mode of transportation including rail, aviation, automobiles, and space) saw a need to write a standard3 that defines what a process should include in order for it to be a "true" RCM process – that is, a process that conforms to the original RCM concept and one that includes all of the steps necessary to keep from being dangerous" (Overman, 2003). This standard was the JA1012 which is now accepted as the guiding standard for 'classical' implementation of RCM.

The RCM process as defined in the SAE standard in summarized below (SAE, 2003; Prabhakar, Sunil, Kulkarni, 2007):

Function: The first step is defining the function of the equipment. The function definition needs to be clear and needs to contain 'a verb, object and a performance standard'. The performance standard as defined in this statement needs to be what is desired by the organization. An example statement is "Pump ABC shall deliver flow of 200 m3/hr at 20 bar discharge pressure".

Functional Failures: All failure states that can happen to equipment need to be defined for all the equipments. This can be in the form of deviation or absence of performance. Low Flow, No Flow, Low pressure are examples of functional failures.

Failure Modes: Once failures have been defined, the failure modes need to be defined. The requirement is that modes that are 'reasonably likely' to cause each failure needs to be identified. The responsibility of what constitutes a likely failure is again what is required for the organization. Normal modes like wear, design deficiencies and human error needs to be identified in this step.

Failure Effects: After identification of the failure modes the effects of the failures needs to be identified in case specific action is not adopted in order to prevent the failure. Failure effects need to contain the information needed to support the evaluation of the consequences. Some examples of failure effects would be – Leakage, Fire

Failure Consequences: Failure effects lead to certain consequences which need to be highlighted for each failure effect and then has to be further categorized as hidden and evident. Additionally the consequences also need to be categorized as pure economic or as affecting environment and safety. The consequences are evaluated assuming that there is no specific method to anticipate, prevent or detect the failure, unlike the failure effects, which are evaluated considering the presence of a anticipation/ prevention/ detection mechanism.

Failure Management Policy Selection: Once consequences are identified for each failure, the organization needs to choose what policy it will follow for each of these failures. The policy needs to be to either prevent the failure from taking place or to predict the failure as it happens (called proactive tasks). When any one of these policies is adopted a preventive maintenance program and/or a predictive maintenance program should be in place.

Default Actions: In case the organization is unable to find a suitable proactive task to be applied to a failure, a policy of run to failure or a one-time change may be adopted. The run to failure task can to be selected only if the failure does not have any impact on the environment or safety.

The key steps in the process are, establishing reasonable likelihood and carrying out FMECA. These are described below.

Reasonable Likelihood

Reasonable likelihood is often described as 'a likelihood that meets the test of reasonableness, when applied by trained and knowledgeable people' (SAE, 1999). However, in reality this is difficult to achieve and can cause disputes between the implementers and the verifiers, mainly due to the lack of an objective measure of reasonability. This forces the implementers to default to carrying out a FMECA on the equipment. In fact one of the major criticisms from the classical school of RCM against any alternate approached has been the establishment of reasonable likelihood (Prabhakar, Raj, 2013).

FMECA

The only way to remove the ambiguity in assuring reasonableness would be to carry out Failure, Mode, Effects and Criticality Analysis (FMEA or FMECA) on their equipment as suggested in the process, known as RCM-II developed by Moubray (2001). The normal approach to carrying out FMECA is by evaluating the equipment from the design angle and this result in an implementation that involves evaluating large number of failure modes per equipment. The method of FMECA was standardized in the MIL standard MIL-1629A (MIL, 1980) and in the IEC standard 60812 (IEC, 2006).

LIMITATIONS OF THE CONVENTIONAL RCM PROCESS

The process of carrying out conventional RCM has a few major limitations, which has prevented its wide application. The major of these are described below:

FMECA

Considering that that there are 33 failure modes prescribed in IEC60812 which need to be evaluated, the total number of analyses for a medium size refinery would be to the order of nearly 50000, assuming that medium sized refineries have close to 2000 rotating machinery. This makes the task of carrying out FMECA highly time-consuming. It is now quite obvious that refiners with limited manpower are not in a position to carry out this analysis in a small time frame (Prabhakar & Raj, 2013). An extreme case where the RCM analysis of nuclear plant with 80 systems resulted in analysis that filled 40 boxes with close to hundred thousand pages of analysis has also been reported with the result that it made it easier to ignore the results of the analysis (August, Ramey, Vasudevan, 2009).

Experience and Skill

RCM approach requires experience and judgment and it takes a long time before enough data is collected before these judgments can be made. It is based on regular assessment of equipment condition and does not apply rigid schedules. RCM is also a fluid concept and defined differently in various sources and is stated as almost always empirical. (Endrenyi et al, 2001)

Discounting Previous Programs

The classical RCM process ignores previous PM program content (as advised by Nowlan and Heap) which creates a practical dilemma. Building a maintenance program on a factual basis requires specific analytical skills. This can lead to the specific exclusion of people who are involved in the day to day work of planning, namely the schedulers, planners and the executors. (August, Ramey, Vasudevan, 2009)

ALTERNATIVES TO CLASSICAL RCM

Understanding the limitations of RCM, many alternate approaches have been proposed. These alternates can be divided as either research driven or consultant driven. Research driven approaches, where a large number of models with mathematical or probabilistic approaches (Dekker, 1996), (Selvik, Aven, 2011), (Schuman, Brent, 2005), have not found many practical applications mainly due to the high levels of skill, often mathematical, required in handling these models. Similarly, quite a few consultant driven approaches have also been proposed – prominent among them being the Streamlined RCM (or SRCM) (Moubray, 2000), the PM Optimization (PMO) from Turner (2001) and TPM which in India is spearheaded by the Confederation of Indian Industries (CII).

SRCM

Streamlined RCM or SRCM is an approach that has been put forth as simplifying the RCM implementation and was initially applied in the nuclear industry. This method consists of "identifying the failure mode that each existing maintenance task is supposed to be preventing and then work forward again through the last three steps of the RCM decision process to re-examine the consequences of each failure and to identify a more cost-effective failure management policy". Further this approach concentrates on analyzing critical equipment, critical failures and concentrating on the last 3 steps of the RCM process. SRCM has been criticized for being focused more on maintenance cost optimization rather than on reliability improvement (Moubray, 2000).

PMO or PREMO

PM Optimization is another alternative to RCM. This process, which closely mirrors the classical RCM process, but with a difference in the order of the execution as in SRCM starts with review of existing tasks, and then carries out an analysis of the failure modes as a group rather than individually as done for RCM. The functional analysis which is mandatory in an RCM process is an optional step and the stated aim is to "generate a list of failure modes from the current maintenance program, an assessment of known failures and by scrutiny of technical documentation – primarily Piping and Instrumentation Diagrams (P&IDs)"(Turner,2001). This process too has been criticized for ignoring the function failures and for concentrating on the realization of an effective PM program rather than on overall reliability improvement (Moubray, 2001).

TPM

Total Productive Maintenance or TPM is used as an alternate to improve the effectiveness of equipment. The focus of TPM is more on involvement of people from various functions in the equipment operation and which thereby raises equipment effectiveness. TPM has been demonstrated as beneficial in reducing equipment breakdowns, minimizing idling and minor stops (indispensable in unmanned plants), lessening quality defects and claims, boosting productivity, trimming labour and costs, shrinking inventory, cutting accidents, and promoting employee involvement (Ahuja, Khamba, 2008). Review of published literature suggest that while TPM has found acceptance in manufacturing industries, in the process industries particularly in refineries the application has been limited. TPM has also been criticized for not being a unique process by itself, but rather seems to borrow aspects from many areas like Business Process Reengineering & Continual Improvement (Boaden, 1996)

As can be seen from the alternate methods and their criticisms, there is a lack of convergence between the requirements and the benefits possible on a full-fledged conventional RCM implementation and the alternate methods currently in practice. This opens the need to develop an alternative approach to RCM that to a large extent, eases the complexity of implementation, allows for a high degree of accuracy and also considers the inputs of the prevalent maintenance program. It is also clear from the alternatives and their criticism, that, though the depth of analysis can be limited, the methodology needs to closely mirror the prescription of the standard methodology to accrue the true benefits of RCM. (Prabhakar & Raj, 2013)

THE ACCELERATED RELIABILITY CENTERED MAINTENANCE PROCESS

The limitations if the classical RCM can be summarized as below:

- Difficulty in defining reasonable likelihood of failure
- Necessity of large pool of trained manpower
- Long drawn out implementation
- Large volume of analysis which will be beyond the capability of the industry
- Ignoring present approaches

The approach described in this section addresses these limitations and presents an alternative to the current approaches while ensuring that all failures that are reasonably likely to happen are addressed, thereby staying true to the intent of RCM.

As described earlier most of the process industries have a maintenance program that as a minimum contains a Preventive Maintenance program, a Predictive Maintenance program and inevitably the Breakdown Maintenance program. Most modern process industries, under the safety statutes are also required to carry out failure analysis. The alternative model that is proposed includes these existing approaches as the starting point of the RCM process, thus addressing one of the limitations of conventional approaches – that of ignoring current practices.

The model further does not wait for the process to get completed before corrective actions are rolled out. To do this in a logical way, the entire ARCM process is codified into a 4 stage approach as described below:

Stage 1 – Reliability Audits

It is important to know the prevailing state of reliability of the equipment. For this it is essential to carry out a complete listing of the previous failure modes of the equipment. This can be achieved by carrying out a simple listing of past failures. This involves collecting information from the equipment history from the ERP/ CMMS system. The information collected needs to be organized in the form of Audit sheets. The types of failures and the number of instances of the failure has occurred in the past is listed out in the form of a frequency table. This listing gives an immediate understanding of the top failure modes of each and every equipment in the plant. This information, along with a brief note on the type of failures that have been faced, forms the Reliability Audit Sheet. Such sheets need to be generated for all equipment under consideration. This listing will provide the most value only if all equipment that have an impact on the operation of the plant are considered for analysis.

The next step in this stage is to carry out the Root Cause Failure Analysis (RCFA) of the failures, if not already done. RCFA is normally done for most failures and this step consolidates failure causes and recommendations

In process plants, most of the rotating machinery have an operating standby. Once the audit sheets are prepared, the first step in acceleration of the RCM process is to immediately carry out the RCFA recommendations of the failed equipment, on all the standby equipment, irrespective of whether the said failure has been experienced by the standby or not. This immediately prevents a potential failure mode from occurring again.

Volume : 3 | Issue : 12 | Dec 2013 | ISSN - 2249-555X

The second step while carrying out the audit is to identify the failure modes that have occurred most frequently in each of the equipment. These failure modes need to be flagged as critical failure modes. Here it needs to be noted that there may be persistent minor issues that, though not considered as a failure, may be contributing to the poor MTBF of the equipment in the long run. A very representative sample was observed by the author while carrying out the reliability audit at his refinery. In this equipment, the seal had an MTBF of around 24 months which was high enough to get the equipment excluded from the 'bad actors'. However on closer examination of the equipment history, it was observed that the seal flush lines used to get de-choked once every 8 months. Flush is an important aspect of seal performance and though maintenance was being carried out, these were post the chokage, resulting in the seal running in less optimal operating conditions for some time. The cleaning of flush line was moved to a 6 month preventive task and the seal MTBF has thence more than doubled.

The third step in this is to identify the top 10% equipment that have had the largest number of failures. These are to be considered as the 'bad actors'. These equipment need to be analyzed first. This step too results in a quicker accrual of the benefits, as the bad actors result in a significant reduction of recurrent failures.

In summary, the activities in this stage are: a) Carry out reliability audits and list equipment wise failure modes b) Apply RCFA actions of failed equipment to its standby c) Identify activities that occurred the most frequently and address these immediately & d) Identify the bad actors on the basis of highest number of failures and further analyze these first. The expected outcomes of this stage are a) List of equipment wise failure modes b) Action on standby equipment of failed equipment c) Identification of 'bad actors'

The net result of this stage is that a list of failure modes applicable is now available for all equipment. This stage also results in actual implementation of some reliability improvement programs.

Stage 2 – Identifying Failure Modes

The process in stage 1 will result in a listing of the failure modes of individual equipment. Once the list of failure modes, which have already occurred in the location or plant is available, the identification of likely failure modes need to be carried out. It is to be noted that the stage 1 will result in the identification of a large number of failure modes and causes. In order to identify only those failures that have a reasonable likelihood of occurrence in particular equipment, this failure data needs to be stratified. Analysis of the failure data from the author's refinery gives commonality of failure modes of the following groups:

Make & Model for the drive part of the equipment (Bearings, couplings etc)

Process Fluid for wetted parts of the equipment (Impellers, Seals, Corrosion etc)

This commonality of failure modes and causes in equipment of same model irrespective of service and of similar service irrespective of model is an important factor in deciding the likelihood of occurrence. In order to evolve the reasonable likelihood, the equipment needs to be grouped into the following groups:

Group1 – Make & Model: The first grouping needs to be on the basis of Make and Model. Grouping along the lines of the Make and Model of the equipment provides the failure modes that are inherent to that particular model of equipment and help in faster implementation of the actions to prevent failure.

Group2 – Service: The second grouping that needs to be done is in terms of the service. In this equipment, though belonging to different units of a plant, but handling similar service can be clubbed together for analysis. This grouping gives the advantage of being able to map failures due to service, irrespective of the location of the equipment.

Once the groupings of all the equipments have been done as above, then all the failure modes that equipments in the particular group have experienced, are treated as potential failures for all equipment in that particular group. There will be two distinct sets of failure modes & causes – for the drive side and for the wetted side, which emerges out of this stage.

However, as we had stated earlier, the objective of this method is to provide immediate improvement in reliability. Therefore, as soon as or even concurrently as the failure modes are identified for the group, the equipment on which the failure had occurred, need to be evaluated for the cause of the failure and a proactive method with which this failure can be prevented must be identified. This prevention needs to be applied for all equipment belonging to the particular group.

On completion of this stage, it is likely that there will be a large number of Preventive and Predictive actions emerging. In mature plants, where robust PM/ PdM efforts are already in place, the design change actions will be high. The prioritization of the actions for implementation now becomes important. Actions on critical equipment are to be done first and then on semi-critical and subsequently on non-critical equipment.

This stage may also result in groups that have had no previous failures. For these groups, there is no option but to carry out the FMECA in Stage-3 of the implementation, as otherwise potential failure modes will remain hidden and the whole purpose of the RCM exercise is defeated.

In summary, the activities in this stage are a) Stratify the equipment on basis of make & model and on the basis of service b) List all failure modes / causes encountered by all equipment in a particular group c) Extend the failure modes & causes for each group, as potential failures for all equipment of the group d) Apply the default actions (preventive, predictive or design changes) that prevent these failure modes from occurring to all the equipment. The expected outcomes are: a) Grouping of failure modes & causes b) Preventive & Predictive actions for all equipment belonging to a particular group c) Design changes that will be required d) Groups where there have been no failures.

This stage provides the quick identification of a large number of 'highly probable' failure modes and causes as well as the actions required to prevent these modes from occurring. This stage can lead to the highest gains in reliability.

Stage 3 – FMECA on Critical Equipment

The previous stages helped identify failures with a reasonable likelihood of occurrence. These stages also ensured that some action is implemented concurrently in order to prevent failures or predict the potential failures. The next stage in the A-RCM process is the carrying out of the FMECA on the Critical Equipment. This is an important variation of the A-RCM approach in that it is only after a large portion of the work is done that FMECA is taken up. This activity, identified for the critical equipment under the A-RCM process, is delayed due to the fact that critical equipments in process industries, especially refineries, are built following stringent standards like API 612, API610 etc and hence have very high inherent reliability.

In order to carry out the FMECA, the methodology suggested by the MIL1629A standard as well as the SAEJA1012 is recommended (MIL, 1980) (SAE, 2002). To categorize the consequences, the Risk Priority Number (RPN) method as detailed in API RP 580 (API, 2002) can be used. Alternate methods that can quantify the consequences in terms of indices can also be used. Based on the FMECA, the Preventive, Predictive of Design Change actions are identified for the Critical Equipment.

Once analysis of critical equipments has been completed, then the groups where no failures were observed (identified in stage 2) are taken up for FMECA and potential failure modes and causes are identified along with the actions necessary to prevent these from occurring.

This stage provides the final set of actions for implementation. In practice the FMECA on critical equipment will yield very few actions and whatever such actions do get generated, will require large investment of cost and effort to implement.

Stage 4 – Sustaining the Program

While the above three stages were based on the past data of the equipment, the implementation becomes a 'living' program only when it also contains steps to sustain the implementation. There are two important steps to sustenance – feedback and measurement.

Feedback: Subsequent to the rollout of the program, in the event of any failure, RCFA as well as the A-RCM Stage1 & Stage2 needs to be carried out immediately, but only for the group in which the equipment belongs. In case of a failure whose cause was already identified, then it can be concluded that the action that was being followed was incapable of preventing the failure and a new action needs to be finalized. This action now needs to be deployed across all the equipment in the group. In case the failure mode / cause is new, then the new action identified by the RCFA needs to be deployed across all equipment in the group. This will ensure that the model continuously 'learns' and updates itself and errors become lesser as time progresses.

Measurement: The simplest measure of increased reliability is the number of failures in a time period. To further refine measurements, the MTBF and the average MTBF of the plant can be calculated. Failures can me modeled on a statistical distribution and the parameters trended to record the improvements.

CONCLUSION

The A-RCM process is a maintenance management tool that can help in increasing the overall reliability of equipment, particular rotating machinery, in process plants. The paper highlighted the current methodologies and the limitations of these methodologies particularly with respect to coverage and effort. The need for an alternate methodology that provides visible and quick gains in reliability, but has relative ease of implementation is clearly apparent and the A-RCM methodology suggested here is a viable alternative to the approaches in practice. The paper also detailed the steps that organizations need to take in order put this methodology into practice. The authors propose to carry out further study of the implementation and the future work will focus on the effectiveness of A-RCM as an alternate maintenance management strategy.

REFERENCE

[1] Ahuja, I. P. S., and J. S. Khamba (2008): "Total Productive Maintenance: Literature Review and Directions", International Journal of Quality & Reliability Management25.7: 709-756. | [2] API (2002):"RP580 - Risk Based Inspection";1st Edition, American Petroleum Institute (Standard) | [3] Boaden, Ruth J. (1996): "Is Total Quality Management Really Unique?", Total Quality Management 7.5: 553-570. | [4] Dekker, Rommert (1996), "Applications of Maintenance Optimization Models: A Review and Analysis", Reliability Engineering & System Safety 51.3 (1996): 229-240. | [5] Endrenyi, J., Aboresheid, S., Allan, R. N., Anders, G. J., Asgarpoor, S., Billinton, R., ... & Singh, C. (2001). The present status of maintenance strategies and the impact of maintenance on reliability. Power Systems, IEEE Transactions on, 16(4), 638-646. | [6] International Electrotechnical Commission. "IEC 60812: Analysis Techniques for System Reliability– Procedure for Failure Mode and Effects Analysis (FMEA)." (2006) (Standard) | [7] Mobley, R. Keith (2002).:"An Introduction To Predictive Maintenance". Butterworth-Heinemann, (Book) | [8] Moubray, J. M. (2001): "Is Streamlined RCM worth the risk", Maintenance Technology. | [9] Moubray, John (2001). "RCM II: Reliability-Centered Maintenance", Industrial Press Inc. (Book) | [10] Moubray, John.(2000): "The Case Against Streamlined RCM." Aladon, UK. (Online Article) | [11] Nowlan, F.S. and Heap, H.F. (1978): "Reliability-Centered Maintenance"; Technical Report AD/A066-579. National Technical Information Service, US Department of Commerce, Springfield, Virginia, (Book) | [12] OISD Standard (2008), "OISD-RP-119: Selection, Operation and Maintenance of Pumps"; Oil Industry Safety Directorate (Standard) | [13] OISD Standard (2007), "OISD-RP-124: Predictive Maintenance Practices";Oil Industry Safety Directorate (Standard) | [14] OISD Standard (2007), "OISD-RP-126: Specific Practices for Installation and Maintenance of Rotary Equipments"; Oil Industry Safety Directorate (Standard) | [15] Prabhakar, Deepak; K, Sunil; Kulkarni, Arun (2007): "Accelerated Reliability Centered Maintenance"; Proceeds of the XIV Refinery Technology Meet, Centre for High Technology, Ministry of Petroleum & Natural Gas | [16] Prabhakar, Deepak, and Raj, Jagathy (2013). "A New Model For Reliability Centered Maintenance In Petroleum Refineries.", International Journal of Scientific & Technology Research, Vol 2, Issue 5, pp-56-64 | [17] Renwick, John T.; Babson, Paul E. (1985): "Vibration Analysis-A Proven Technique as a Predictive Maintenance Tool," Industry Applications, IEEE Transactions on Vol.IA-21, no.2, pp.324,332 | [18] S. A. E (1999). "JA1011-Evaluation Criteria For Reliability-Centered Maintenance Process." (Standard) | [19] S. A. E (1999): "JA1012-A Guide To The Reliability-Centered Maintenance (RCM) Standard." issued in January.(Standard) | [20] Schuman, Charles A., and Alan C. Brent.(2005): "Asset life cycle management: towards improving physical asset performance in the process industry", International Journal of Operations & Production Management 25.6: 566-579. | [21] Selvik, J. T., and T. Aven.(2011): "A Framework for Reliability and Risk Centered Maintenance." Reliability Engineering & System Safety 96.2: 324-331. | [22] Telford, Samuel, Muhammad Ilyas Mazhar, and Ian Howard (2011):. "Condition Based Maintenance (CBM) in the Oil and Gas Industry: An Overview of Methods and Techniques." | [23] Turner, S (2001). "PM Optimisation–Maintenance Analysis of the Future." ICOMS Annual Conference Melbourne. | [24] MIL (1980), "MIL-STD-1629A-Procedures for Performing a Failure Mode, Effect and Criticality Analysis." - US Military Standard (Standard)