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Reliability Based Maintenance Strategy Selection in Process Plants: A Case Study

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Abstract

The importance of maintenance function has increased due to its role in keeping and improving the availability, product quality, safety requirements and operating cost levels of the process plants. Accordingly, maintenance strategy selection became one of the most important decision making activity in the industry. This paper proposes a general approach to implement Reliability Centered Maintenance (RCM) in process plants. RCM is a recently evolved maintenance strategy that incorporates all the advantages of traditional maintenance strategies. More precisely, RCM selects the most appropriate and tailor made maintenance strategy for all the equipment in the plant based on its criticality score and reliability parameters. RCM implementation requires the collection and analysis of historical failure and maintenance data to determine current condition of the equipments. Subsequently, maintenance strategy is framed for the unit by following Analytical Hierarchy Process (AHP) based methodology. This should be done by taking expert opinions of personals from both the maintenance and production departments. RCM implementation model presented here is validated with the maintenance history data of a process plant manufacturing titanium dioxide with a production capacity of 20,000 metric tonnes per annum. Currently the firm follows a combination of scheduled and breakdown maintenance strategies. However, RCM implementation in this plant is justified by the maintenance simulation results that revealed the current poor availability and performance of the equipments.

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Keywords: Reliability Centered Maintenance; Maintenance Simulation; Analytical Hierarchy Process.

1. Introduction

In modern world all firms are striving hard to elevate key performance factors like quality, productivity and to reduce costs for either sustaining in the market or to make an edge against their competitor. Plant maintenance is one

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the areas having a vital role in determining the productivity. The main objective of plant maintenance is to achieve minimum breakdown and to keep the plant in good working condition at lowest possible cost. Thus maintenance should not be considered as a cost centre, but a profit generating function (Alsyouf, 2007). An improperly maintained or neglected plant will sooner or later require expensive and frequent repair, because with the passage of time all machines or other facilities will wear out. Therefore, plant maintenance plays a prominent role in production management because breakdown creates problems such as production loss, rescheduling of production, material loss (because of sudden stoppage), need of over time, need of subcontracting work and temporary work shortage.

General types of technical maintenance strategies are (1) Breakdown or Corrective or Run to failure Maintenance (BM) (2) Preventive maintenance (PM) (3) Planned maintenance (4) Proactive maintenance (PrM) (5) Condition-based maintenance (CbM) (6) Design-Out maintenance (7) Reliability centered maintenance. In which, Preventive maintenance (PM) is described as maintenance of equipment or systems before fault occurs, thus not letting the breakdown to happen. While preventive maintenance is generally considered to be worthwhile, there are some disadvantages such as huge cost and need of specialist labour. Therefore, PM need not be the cost effective strategy for every machinery/component especially for the noncritical assets that every industry possess. Non critical machineries/components are those assets whose breakdown will not affect the production or safety of employees beyond a limit. Therefore, instead of PM, Run-to failure approach of maintenance is appreciated in an economic point of view. Thus for proper maintenance of the plant, it is better to adopt a integrated method of breakdown and preventive maintenance strategies to make use of the respective strength alone, as a result Reliability centered Maintenance (RCM) was introduced.

RCM is one of the best known and most used device to preserve the operational efficiency in critical sectors like power plants, artillery system, aviation industry, railway networks, oil and gas industry and ship maintenance. (Khamis *et. al*, 2000; Carretero *et al*, 2000).However, RCM still remains unimplemented in many process plants, especially in India due to lack of proper methodology and tools. This paper proposes a general RCM model suitable for process plants having complex interconnected subsystems and critical components. The model is suitable for all kinds of process plants having any number of components and for any configuration. This framework will be a road map for developing database system to monitor RCM maintenance actions, levels and requirements of every machine and components in the plant in a cost effective manner to elevate equipment availability and the profitability of the industry. There is also scope for framing robust methods for scheduling the maintenance activities proposed by the model, copping up with the production schedule. This is very dynamic and complex activity and the authors are currently working in this direction.

The proposed framework is validated with a case study conducted in calcinator unit of Travancore Titanium Products Ltd. (TTP) which is a leading manufacturer and supplier of Titanium Dioxide (Anatase Grade) pigment in India with ISO 9001 Certification. The work identified most appropriate maintenance strategy for each equipment in the unit such that the overall production level can be elevated by providing appropriate maintenance work for the right equipment at the right time.

Nomenclature

MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
MTBDE	Mean Time between Downing Events
MDT	Mean down Time
MTBM	Mean Time between Maintenance
MRT	Mean Repair Time
A_0	Availability of the system

2. Literature Review

A plant is a place where men, materials, money, equipment, machinery etc are brought together for manufacturing products and maintenance has impact on business performance aspects of a plant such as productivity and profitability. A day's output lost because of an unplanned stoppage will never be recovered without additional costs being incurred (Alsyouf, 2007). The main responsibility of the maintenance department is to ensure the required level of system availability to get as much as output from the firm (Davies, 1990) and thus enhancing the productivity. On the other side, maintenance cost can exceed up to 20-30% of the plants total operating costs (VanRijn, 1987) and within many large-scale plant-based industries, maintenance costs can account as much as 40% of the operational budget (Dunn, 1998). Developing and implementing a maintenance concept is a difficult process that may be suffering from many problems, like that of a systematic and consistent methodology, in other words the lack of a framework (Waeyenbergh & Pintelon, 2004). Therefore, maintenance can be considered as a production task and a necessary evil simultaneously (Alsyouf, 2007). However, some researchers disagree and states maintenance activity as a profit generating function rather than just unpredictable and unavoidable expense (Al-Najjar *et al*., 2001; Al-Najjar and Alsyouf, 2004).

Industrial maintenance has two essential objectives; (1) a high availability of production equipment and (2) low maintenance costs (Kari, 2002). Since these two factors are contradictory in nature it is essential to optimize the maintenance activity synchronized with the dynamic objectives of the firm. This is done by framing or adopting the right maintenance strategy which consists of a mix of policies and strategies which vary from industry to industry (Dekker, 1996; Zeng 1997). There are two basic interventions in plant maintenance: Corrective maintenance and Preventive maintenance. According to the way these two basic interventions are applied, five basic maintenance policies can be distinguished: Failure Based maintenance, Design-Out Maintenance, Use Based Maintenance, Condition Based Maintenance and Detection Based Maintenance (Waeyenbergh, Pintelon, 2004). The vision statement for maintenance should be governed by current best-practice (CBP) as the benchmark. PM is usually based on an old-fashioned premise, namely fixed time maintenance (FTM) overhaul or even replacement of components. This approach is seldom justifiable, because less than 20% of all components fail within the usually prescribed periods, and hence relatively high costs incurred as a result of implementing PM. (Eti ed.s, 2006).Which imply the need of different maintenance strategies for different machine/components depending upon their criticality, which can be achieved by recently evolved Reliability Centered Maintenance (RCM).

RCM is the optimum mix of reactive, time or interval-based, condition-based, and proactive maintenance. It is actually a procedure to identify preventive maintenance (PM) requirements of complex systems. The countries applying RCM include the China, United States, Britain, Japan, etc. RCM was introduced into China in the late 1980s, and the first RCM standard GJB1378 was published and put into practice in 1992. Since then, RCM has been a popular methodology widely used in China's military to identify PM requirements of weapon systems. Numerous RCM programs of the in-service equipments have been developed. The major problem in the application of RCM is that the quality of RCM program is highly dependent on the experience and skills of the RCM analysts. In order to ensure the proper use of RCM, two steps can be followed (1) to strengthen the training of RCM group to ensure that the analysts have consistent understandings of RCM terms and principles; (2) to develop a computer aided RCM system (CARCMS) to ensure the consistency of the RCM procedures.(Cheng *et. al*, 2008).

Performance of an implemented maintenance strategy can be analyzed by means of various maintenance indicators like MTBF, MTTR, Productivity, Cost of maintenance, Availability of assets etc. The indicators are calculated as the change happened with the above parameters before and after the maintenance strategy is implemented (Kari, 2002).

3. Reliability Centered maintenance (RCM)

Reliability Centered maintenance (RCM) is the optimum mix of reactive, time or interval-based, condition-based, and proactive maintenance practices. These principal maintenance strategies, rather than being applied independently, are integrated to take advantage of their respective strengths in order to maximize facility and equipment reliability while minimizing life-cycle costs. Total productive maintenance (TPM), total maintenance assurance, preventive maintenance, reliability centered maintenance (RCM), and many other innovative approaches to maintenance problems all aim at enhancing the effectiveness of machines to ultimately improve productivity (Shayeri, 2007). RCM evolved in the airline industry during the 1960s and 1970s from the original work of the methods originators- F. Stanley Nowlan and Howard F. Heap, they stated that the logic of RCM is based on three questions, viz.:

- How does a failure occur?
- What are its consequences for safety or operability?
- What good can preventive maintenance do?

The framework for implementing RCM strategy is laid out (fig. 1) to guide the maintenance developer through the thought process for designing a preventive maintenance program for systems and equipment. The process consists of 10 phases when it comes to the case of process plants. Each phase is designed to make the developer consider and answer important questions outlined in the RCM process. The tasks and procedures developed are the best that can be written with the resources and knowledge available. In phases 1 – 3 the developer gathers detailed knowledge about the system and its functions so he can make most appropriate decisions regarding what failures will be of most concern in the intended system application. In phases 4 – 8 the developer considers all the failure modes that could result in loss of system function, and determines which failure modes are the greatest risk. These dominant failure modes are then analyzed in the decision logic tree/ Analytical Hierarchy Process (AHP) to determine the best course of action to manage the associated risk. This is carried out by conducting an expert survey among maintenance, production, management personals. These steps are the most critical part of the RCM process. In phase 8 the task descriptions resulting from the application of RCM decision logic are combined into accurate detailed procedures for accomplishment. Careful consideration is given to manpower, materials and training required and logical sequencing of steps to obtain the best procedure possible and determining the appropriate maintenance level for accomplishing the procedure.

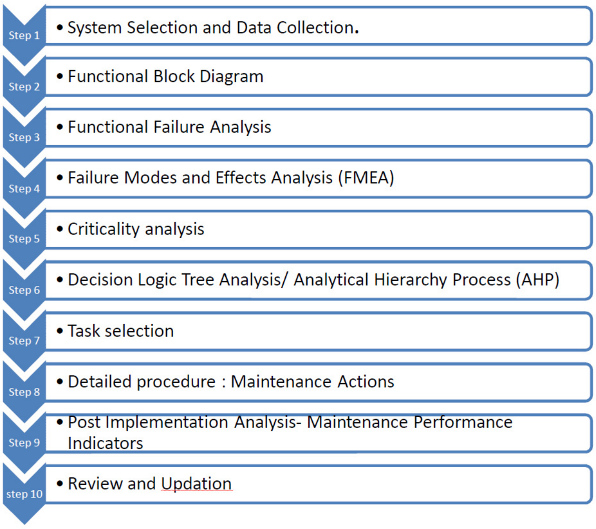

Fig.1. RCM implementation methodology

4. Case Study

Step1: System selection and data collection

The process unit selected for case analysis is calcinatory unit of Travancore Titanium Products Ltd (TTP). The function of this unit is to convert titanium hydroxide to titanium dioxide. Currently TTP follows scheduled maintenance strategy. The major machinery in the unit are 1)Feed screw conveyor 2)Rotary Kiln 3)Combustion Unit consisting two compressors, one gear pump and one heater 4)Cooler 5)Cooling tower 6)Electro Static Precipitator (ESP) 7)Induced Draft Fan (ID Fan) 8)Stack

Process: The intermediate product titanium dioxide is conveyed to rotary kiln in calcinator unit as depicted in the Fig. 1, by means of feed screw conveyor. It is in the rotary kiln, titanium hydroxide is actually converted to titanium dioxide which is the final product. This reaction is initiated by hot air produced by means of firing the kiln with the aid of combustion chamber. Rotary kiln is a tunnel having a length of 148 feet and 10 feet diameter, inside of which is covered with layer of refractory bricks. It is erected in an inclined manner just to assist the flow of titanium powder. After getting converted to titanium dioxide the product is then fed to another long tunnel called cooler, whose purpose is to cool down the titanium dioxide powder from 1100°C to 100°C. The final output of the unit is taken from the discharge end of cooler from which is taken to milling unit. A high capacity Induced Draft fan used to suck the flue gas and hot air from the firing end through the kiln up to the feed end to make sure the temperature is uniformly distributed. The fan sucks the air though a cooling tower and Electro Static Precipitator (ESP). The cooling tower is used to cool the air and to collect the heavier particles from air. The ESP is used to collect the dispensed particles in the air which may contain small amount of SO_3 and carbon. The air after going through the cooling tower and ESP enters to the fan and is directed to the stack where it is allowed to the atmosphere.

Step 2: Functional Block Diagram (FBD) of the unit.

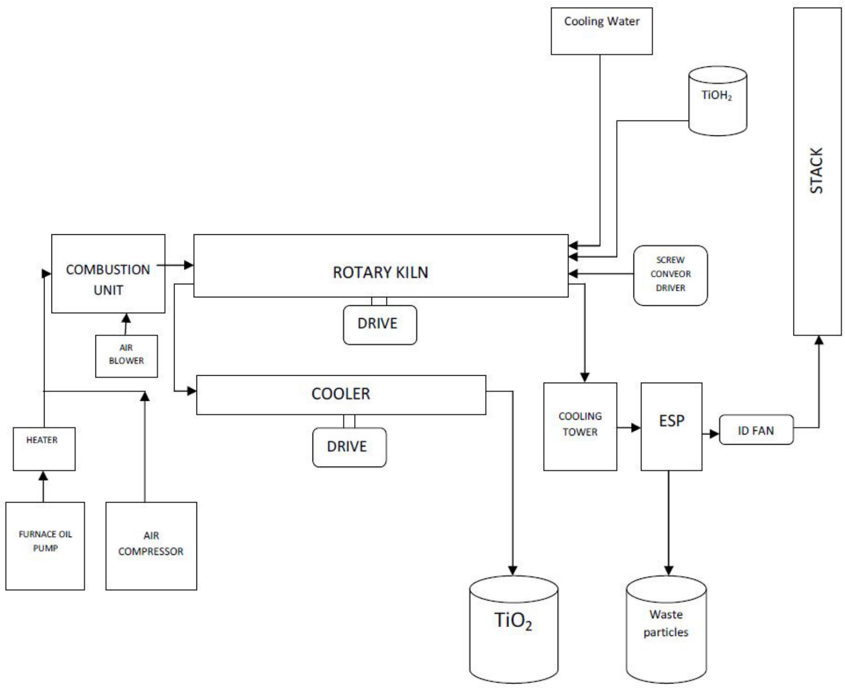

Fig.2. FBD of Calcinator unit of TTP

Step 3: Data Analysis and Simulation

Maintenance history data collected from the log book of the firm is used to calculate the failure and repair distribution corresponding to all equipments. This is done by conducting a goodness of fit test with the data points using the software Stat::Fit. Since the plant is old, most of the equipment showed an increasing trend in failure rate and thus most of them tend to follow lognormal and weibull distributions. These probability distributions are used to simulate the present production system using RAPTOR 4.0. RAPTOR 4.0 is Monte Carlo based software program developed by the U. S. Air Force in the 1980's exclusively for maintenance simulation. It can be downloaded, free of charge, from several internet sites.

The maintenance simulation modeling is done on the assumptions that, if any one component fails the whole system is interrupted. Since there is no redundant component the system was assumed of serial configuration. The mean availability of the ten simulation runs was 0.753 over ten years, this equates to approximately 4387.7 failures. This means 901.3 days that the system will be out of operation in ten years. Other reliability parameters as per the simulation are depicted in Tb. 1 This scenario is very poor and it clearly indicates the need to implement other effective maintenance strategy so that the overall availability (Ao) of the system can be elevated to a higher level.

Currently TTP is following scheduled maintenance irrespective of the criticality of the equipments, which is traditional and outdated approach in the competitive market.

Table1. Reliability parameters of components

Sl No	Component	MTTF(days)	MTTR (hrs)	Availability(%)
1	Feed Screw Conveyor	109	4	99.84
2	Rotary Kiln	90	24	98.67
3	Combustion Chamber	51.75	2	99.84
4	Compressor	44	2	99.81
5	Cooler	7	1	99.16
6	Electro Static Precipitator (ESP)	120	7	-
7	Induced Draft Fan (ID Fan)	113	2	99.86
8	Cooling Tower	540	5	-
9	Stack	1080	48	-
10	Storage Tanks	1080	24	-

Table2. Simulation Result

Sl No	Parameter	Mean Value
1	A_0	0.753067
2	MTBDE	0.626513
3	MDT	0.205432
4	MTBM	0.626513
5	MRT	0.205426
6	% Green Time	75.306765
7	% Yellow Time	0.00
8	% Red Time	24.693235
9	System Failures	4387.7

Table3. Criticality Analysis of the components in the unit

Component	Impact on production	Impact on safety	Availability of standby	Cost	Equipment Criticality (%)	Class
Feed Screw Conveyor	3	1	3	3	80	A
Rotary Kiln	3	2	2	2	76	A
Combustion Chamber	3	1	3	2	75	A
Compressor	1	1	1	1	33	D
Cooler	3	3	3	2	95	A
Electro Static Precipitator (ESP)	1	2	3	2	65	B
Induced Draft Fan (ID Fan)	2	2	3	2	75	A
Cooling Tower	1	2	2	1	51.67	C
Stack	1	2	2	1	51.67	C
Storage Tanks	1	1	1	1	33	D

Step 4: Criticality Analysis

Criticality analysis is a tool used to evaluate how equipment failures impact organizational performance in order to systematically rank plant assets for the purpose of work prioritization, material classification, PM/PdM development and reliability improvement initiatives (Gomaa, 2003). In general, failure modes and effects analysis (FMEA) form the basis of criticality analysis. The equipment criticality (EC) is assessed based on the effect of errors/faults, right from the time of installation and is quantified with scores 1, 2, 3 in Tb.3. The formula for calculating EC is:

$$EC = (30P + 30S + 25A + 15V)/3$$

where, EC: is the equipment criticality(%), P: is the production, S: is the safety, A: is the equipment stand by availability, V: is the capital cost.

Step 5: Logic Tree Analysis/AHP and Task Selection

Inferring the results of the above analysis five components of the calcinatory unit is identified as Maintenance Significant Items (MSI's) which belongs to Class A components (as depicted in the table). To make sure the failure doesn't affect neither the production nor the safety aspects and thus to elevate the profitability of the system appropriate maintenance strategy must be selected. This is carried out following an AHP based methodology.

AHP should be applied for each component (MSI's) separately to decide the maintenance strategy. Maintenance, production and management personals of the firm are consulted to make their preferences after making them aware of the above results. Basic Breakdown Maintenance (BM) and major Preventive Maintenance (PM) strategies like Scheduled Maintenance (SM), Proactive Maintenance (PrM), Condition Based Maintenance (CbM) and Design-out Maintenance (DoM) are considered pair-wise comparison. A nine point scaling is used in which the preference is made keeping in mind the component criticality score, MTTF, MTTR and the applicability of each strategy with the component.

Fig.3. AHP Preference Scale

The methodology is applied to all components and appropriate maintenance strategies are determined as depicted in table 4. Decision making consistency is analysed by calculating consistency ratio (CR) in AHP result that is found to be less than 0.1. Thus the judgments are found acceptable.

Table4. Maintenance Strategies

Sl No	Component	MTTF(days)	Maintenance Strategy
1	Feed Screw Conveyor	109	SM
2	Rotary Kiln	90	SM
3	Combustion Chamber	51.75	PrM
4	Compressor	44	BM
5	Cooler	7	CbM
6	Electro Static Precipitator (ESP)	120	BM
7	Induced Draft Fan (ID Fan)	113	SM
8	Cooling Tower	540	BM
9	Stack	1080	BM
10	Storage Tanks	1080	BM

5. Conclusion

This paper proposes an AHP based framework for reliability centered maintenance strategy selection for process plants. The model is validated with the maintenance history data of a process unit of titanium dioxide plant of Travancore Titanium Products Ltd. The maintenance simulation result justified the reconsideration of the currently adopted scheduled maintenance strategy in the plant. The methodology identified optimal maintenance strategies separately for each equipment or machinery based on its criticality and FMEA study. The final result reflects all Class A criticality equipments needed preventive maintenance strategy rather than Scheduled maintenance and breakdown maintenance is enough for all other equipments. Hence, the extra cost incurred by adopting preventive maintenance will get balanced with the cost saving by adopting breakdown maintenance for the rest of the machines.

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