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Performance Reliability Improvement by Optimizing Maintenance Practices through Failure Analysis in Process Industry – A Comprehensive Literature Review

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Abstract:*Performance reliability of continuous process industries is of interest to many applications in maintenance engineering. Very limited researches seem to have been done on the performance reliability improvement of process industries by optimizing maintenance practices through failure analysis. The objective of this paper is to understand the condition of process industries and to evaluate performance reliability on the basis of improvement in maintenance plan through failure analysis. It will help to understand about the working lives of components and associated failures, which lead to reengineer new technologies efficiently and to gain the operational advantage. A comprehensive literature review related to the scenario of reliability and maintenance issues is presented in this paper. The review of literature is subdivided into reliability analysis, maintenance plan in process industries and maintenance optimization.*
Keywords: *Failure analysis, Maintenance, Maintenance Optimization, Process industry, Reliability*

I. Introduction

Reliability oriented maintenance is a relatively new tool for mechanical engineering in India to addresses reliability issues in process industries. It analyzes the system and sub system of plant and tries to find out the failure modes, effects and consequences of the failure. Also, the study can be at preventing or reducing such failures. The growing need for higher reliability arises from the requirement to develop and validate the maintenance plan which continuously performs in the most efficient manner possible.

It is a growing need of failure analysis for processing plants as they are large and complex engineering systems. Reliability analysis and planned maintenance needs to be carried out to avoid loss of availability of equipment/systems which will help the plant managers to optimize the performance of the systems and maintenance task as well.

II. Brief Overview About Reliability

A. Concept

Reliability is the probability that a system or component will perform its desired function without failure under stated conditions for a stated period of time. For systems with repairable components, repairs must be considered in the calculation of reliability. This parameter can be calculated for specific points in time.

- Reliability is a time dependent characteristic.
- It can only be determined after an elapsed time but can be predicted at any time.
- It is the probability that a product or service will operate properly for a specified period of time (design life) under the design operating conditions without failure.

B. Measure of Reliability

Some important reliability parameters can be calculated as follows:

$$MTBF = U_t / N \quad (1)$$
$$H_r = N / U_t = 1/MTBF \quad (2)$$
$$MDT = D_t / N \quad (3)$$
$$MTTR = 0.3 \times MDT \quad (4)$$
$$MTBM = [T_t / N] – MDT \quad (5)$$
$$A_{op} = MTBF / (MTBM + MDT) \quad (6)$$
$$A_{in} = MTBF / (MTBF + MTTR) \quad (7)$$

Where; MTBF is Mean Time Between Failure, N is frequency of failure, Hr is hazard rate, Ut is Uptime, MDT is Mean Down Time, Dt is Down time, MTTR is Mean Time to Repair, MTBM is Mean Time Between Maintenance, Tt is Total time, Aop is Operational Availability, Ain is Inherent Availability

C. Significant of Bath-tub Curve in Reliability Engineering

The probability of failure that is known as the failure rate can go through three distinct failure patterns. Batches of components can display one, two or all three (Figure 1 Bath tub Curve) of these patterns (stages) through their lifetime.

In the first of the three stages, the failure rate plunges downward rapidly from a very high starting point - this is "infant mortality". Failure during this stage can be attributed almost entirely to manufacturing & installation defects.

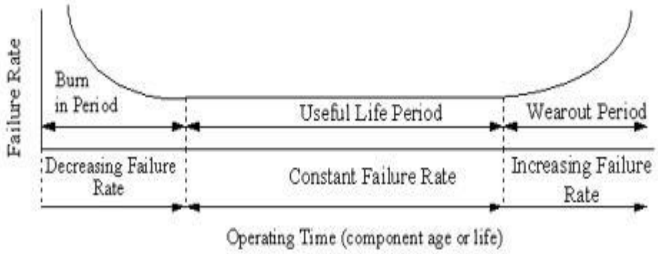

Fig. 1: Bath-tub Curve

Failure caused by manufacturing defects or poor installation tends to show up almost immediately, accounting for the high starting point. The term "Burn In" which can also be used to describe this period comes from the computer industry where new machines are run in a hot environment before dispatch. Any hardware faults will show up quickly in this elevated temperature. Once a machine passes it shall have a long trouble-free life. Equipment can also return to the infant mortality stage after maintenance intervention. For various reasons, equipment can suffer problems as a result of maintenance. Planned maintenance can actually reduce its availability.

D. Failure Distribution Function for Reliability Analysis

Reliability failure data collected from either experiment or field trials have to check for their appropriate distribution since data are random in nature. Sometimes it is difficult to collect sufficient data for accurate analysis, knowing the pattern or distribution the same can be generated to follow the family appropriately.

Following are the useful failure distributions for reliability analysis:

(i) Normal distribution
(ii) Log-Normal distribution
(iii) Poison distribution
(iv) Exponential distribution
(v) Weibull distribution
(vi) Gamma distribution
(vii) Binomial distribution

Out of all above, Weibull distribution is an important distribution used in the analysis of reliability of a equipment/system. By properly selecting the parameters the curve obtained can represent a variety of experimental/field.

III. Brief Overview About Maintenance

A. Concept

Maintenance is an art of optimizing the available resources of man power, material, tools and test equipment etc. within asset of constraining to achieve goals and objective of an organization i.e. profit making or perform a mission in a cost effective manner.

The maintenance philosophy of a plant is basically to maintain a minimum level of maintenance staff that is consistent with the optimization of production and plant availability without compromising safety. For achieving this philosophy, the following strategy can play an effective role if applied in the right mix and fashion.

1. Breakdown Maintenance.
2. Scheduled Maintenance.
3. Preventive Maintenance.
4. Total Productive Maintenance
5. Condition-based (Predictive) Maintenance.
6. Reliability – Centered Maintenance

B. Systematic Step-by-step Method for Planning Maintenance Program

Step 1 – Determine critical plant units and production windows.

- Determine the nature of plant process (continues, batch, etc.)
- Classify the plant into units.
- Carry out failure analysis and estimate the lost of production.
- Determine the production plan and availabilities.

Step 2 – Classify the plant into constituent items.

- This will be a complete classification in the case of critical units, and a partial classification in case of non-critical units.

Step 3 – Determine and rank the effective procedure.

- Determine the effective procedures for each item and the best of this from a cost and safety viewpoint.

Step 4 – Establish a plan for the identified work.

- This depends upon the type and complexity of plant unit, as either continues or batch or etc.

Step 5 – Establish a schedule for on-line maintenance, the off-line maintenance, condition based maintenance and the shutdown work.

The main aim of all the case is to smooth the maintenance workload in order to make the best use of in-plant resources. However condition based maintenance plan is in operation then only inspection checks can be scheduled because timing of the work depends on the results of these checks.

Step 6 – Establish corrective maintenance guidelines.

- In spite of preventive maintenance there will still be some unexpected failures, which can be planned for in terms of spares and manpower.

IV. Literature Review

A. Historical Background

Reliability engineering is considered as most demanding discipline for nearly the past five decades. A study of the development of reliability engineering discipline helps to understand the difficulties involved in analysis of repairable systems as far as their reliability, availability and maintainability are concerned. Development of reliability engineering is well inter connected with quality control and its development.

In early 1920s American Society for Mechanical Engineers along with Bell laboratories were using statistical quality control methods then after mathematical aspect of reliability were used for the development of technology for militaries during Second World War in 1939. In late 1930’s, the subject of fatigue life in materials and related subject of extreme value theory were studied by Weibull and proposed a distribution in 1939 which fits actual observation better than any other known distribution function today itself specially for reliability analysis.

B. Reliability Analysis Issue

The reliability analysis issues were discussed almost half century back by many researchers like; Morse (1958), Barlow and Hunter (1960), Sandler (1963). Such analyses are considered as a useful tool in field of risk analysis, availability and maintainability studies, design of systems, maintenance planning etc. Various methods exist in literature for reliability and availability analysis of systems, like Reliability Block Diagrams (RBD), Monte Carlo Simulation, Markov Modeling, Failure Mode and Effect Analysis (FMEA)), Fault Tree Analysis (FTA) and Petri Nets (PN) proposed by Singer (1990), Bradley and Dawson (1998), Modarres and Kaminsky (1999), Bing et al. (2000), Cochran (2000), Gandhi et al. (2003), Parveen et al. (2003), Adamyan and David (2004), Arthur (2004), Barbady et al. (2006), Panja and Ray (2007), Bhamare et al. (2008).

C. Comprehensive Literature Review

J. Ashayeri, A. Teelen & W. Selenj (1996) developed a mixed-integer linear programming model to simultaneously plan preventive maintenance and production in a process industry environment where maintenance planning is extremely important.

Santos, Amancio, Dourado, Antonio (1999) proposed need for the process industries exhibit an increasing need for efficient management of all the factors that can reduce their operating costs, leading to the necessity for a global multi-objective optimization methodology that will enable the generation of optimum strategies, fulfilling the required restrictions. They developed a genetic algorithm for the optimal assignment of all the production sections in a particular mill in the kraft pulp and paper industry, in order to optimize energy the costs and production rate changes. This system is intended to implement all programmed or forced maintenance shutdowns, as well as all the reductions imposed in production rates.

Parida S., Kotu N. R., Prasad M. M (2000) describes the efforts made d, by Rourkela Steel Plant, Steel Authority of India Limited (SAIL), in close association with Research & Development Centre for Iron and Steel (RDCIS), SAIL, to implement Vibration Analysis and related methods as effective Non-Destructive Testing tools to implement Total Productive Maintenance Program in an integrated Iron & Steel works. They recommended Vibration monitoring and analysis is ideally suited for Total Productive Maintenance (TPM) in which it may be used by both maintenance and production personnel.

Marzio Marseguerra, Enrico Zio, Luca Podofillini (2002) considered a continuously monitored multi-component system and use a Genetic Algorithm (GA) for determining the optimal degradation level beyond which preventive maintenance has to be performed. The problem is framed as a multi-objective search aiming at simultaneously optimizing two typical objectives of interest, profit and availability. For a closer adherence to reality, the predictive model describing the evolution of the degrading system is based on the use of Monte Carlo (MC) simulation.

LeiZhi Chen, Sing Kiong Nguang, Xiao Dong Chen, Xue Mei Li (2004) studied optimization of a fed-batch bioreactor using a cascade recurrent neural network (RNN) model and modified genetic algorithm (GA). The complex nonlinear relationship between the manipulated feed rate and the biomass product is described by two recurrent neural sub-models, in which outputs of one sub-model are fed into another sub-model to provide meaningful information for the biomass prediction. The simulation results show that the error of prediction is less than 8%. Based on the neural network model, a modified GA is employed to determine a smooth optimal feed rate.

N. Sortrakul, H.L. Nachtmann, C.R. Cassady developed (2005) heuristics based on genetic algorithms to solve an integrated optimization model for production scheduling and preventive maintenance planning. The numerical results on several problem sizes indicate that the proposed genetic algorithms are very efficient for optimizing the integrated problem.

Abdullah Konak, David W. Coit and Alice E. Smith (2006) presented an overview and tutorial on genetic algorithms (GA) developed specifically for problems with multiple objectives. They differ primarily from traditional GA by using specialized fitness functions and introducing methods to promote solution diversity.

Eti M. C., Ogaji S.O.T., Probert S. D (2006) discussed a methodology for the development of PM using the modern approaches of FMEA, root cause analysis, and fault-tree analysis. They recommended developing a standard CM procedure documentation to define the need for CM as part of PM

Ghosh Devarun, Roy Sandip (2006) demonstrates an improved technique involving the maximization of reliability-based benefit-to-cost ratio (BCR),. Also; discussion on methodology to optimize the PM schedule for process units whose reliability function is either exponential or follows a Weibull distribution was made. A sensitivity analysis has also been performed to demonstrate the effect of various model parameters on the benefit-to-cost ratio. They recommended future work scope in decision-making, both the reliability of a system as well as the risk that would result as a consequence of a random equipment failure need (constrained to be below a maximum permissible level) to be considered.

Nastac L., Thatte A. A (2006) discussed about heuristic approach based potential fault locations with software tool and a genetic algorithm based search. The implementation and evaluation results of this tool have been presented. As a future work, they suggest use of other stochastic optimization methods will be evaluated. Use of other intelligent methods such as fuzzy logic and neural networks will be investigated

Dusmanta Kumar Mohanta, Pradip Kumar Sadhu, R. Chakrabarti (2007) presented a comparison of results for optimization of captive power plant maintenance scheduling using genetic algorithm (GA) as well as hybrid GA/simulated annealing (SA) techniques. As utilities catered by captive power plants are very sensitive to power failure, therefore both deterministic and stochastic reliability objective functions have been considered to incorporate statutory safety regulations for maintenance of boilers, turbines and generators. The significant contribution of the work is to incorporate stochastic feature of generating units and that of load using levelized risk method and to evaluate confidence interval for loss of load probability (LOLP) because some variations from optimum schedule are anticipated while executing maintenance schedules due to different real-life unforeseen exigencies.

DuyQuang Nguyen and Miguel Bagajewicz (2008) discussed about a new methodology designed to optimize both the planning of preventive maintenance based on the use of a Montecarlo simulation integrated with Genetic algorithm optimization to evaluate the expected cost of maintenance as well as the expected economic loss, an economical indicator

Sikorska J (2008) show that it is possible to retrospectively improve the quality of failure histories stored in computerized maintenance management systems (CMMS). A tool was developed to help reliability professionals assign the most appropriate failure mode to a particular work order. Case-based reasoning is used to contextualize the data and reduce the number of possible options to a list of most likely candidates; the case-bank is developed from FMEA based studies such as RCM. He suggests development of the cost evaluation algorithm which is computationally intensive, particularly when the number of components and the number of covariates become large. More efficient cost evaluation algorithms are desired in future research. Another future research topic is to develop CBM methods for multi-component systems with different types of components instead of identical components.

Andrawus J. A., Watson John, Kishk Mohammed (2009) discussed the concept, relevance and applicability of the MSF and DTMM techniques to the wind energy industry. Institutional consideration as well as the benefits of practical implementation of the techniques are highlighted and discussed. It has also discussed the relevance and applicability of the techniques to optimize the maintenance of wind turbines. They highlighted further research work scope to collate field failure and maintenance data from collaborating wind farm operators. The collated data will be analyzed and results of the analyses will be compared and the overall outcome is to be used in developing an optimized maintenance strategy for wind turbines.

Sachdeva et al. (2009) presented a multi-factor decision-making approach for prioritizing failure modes for paper industry as an alternative using TOPSIS.

Mahadevan ML, Paul Robert T, Vignesh kumar V and Sridhar S (2010) presented maintenance planning problem for a process industry. The problem is formulated to determine which of the possible actions viz. maintenance or replacement is to be carried out for the subsystems during the planning period. Maintenance is carried out by analyzing improvement in the parameters (viz. MTBF & MTTR) during the planning period. The objective is to minimize the present value of total costs that are incurred by the decision taken during the planning period. The problem is effectively solved by hybrid genetic algorithm (HGA) technique.

Mahadevan M. L., Pooran kumar S., Vinodh R (2010) discussed maintenance planning problem for a process industry. The problem is formulated to predict which of the two possible actions (viz. imperfect maintenance or component replacement) is to be carried out for each of the components during the planning period. Two search techniques, Simulated Annealing (SA) and Genetic Algorithms (GAs), are used to solve the problem. They recommended a continuation of this work intends to investigate the impact of component reliability on the decision making process. The work can be extended to solve the maintenance problem of any process industries.

Nguyen DuyQuang, Bagajewicz Miguel (2010) proposed a genetic algorithm to obtain an economically optimal preventive maintenance frequency for different equipment, the parts inventory policy (number and type of spare parts to keep in stock), and labor allocation in process plants was made. They recommended the performance of the genetic algorithm by using either or both of the followings: (i) expanding list of candidates for crossover methods, mutation rate, and population size, (ii) performing experimental design techniques to determine optimal set of GA methods and parameters. Other improvements suggested in this work are, rigorous treatment of other types of distributions and other types of preventive maintenance policies can be done by modifying the simulation procedure, which will be addressed in future work.

Sanjeev Kumar (2010) highlighted to develop the availability models (under steady state conditions), the performance analysis and optimization of some operating systems of a fertilizer plant concerned. He reported future research work like; (i) Performance models can be developed for various process industries assuming simultaneous failures among various systems of a particular plant (ii) The present research work can be extended, where time dependent failure and repair rates would be considered. Then, the performance model seems to be an appropriate one because most of the subsystems/systems in the fertilizer plant are such that they are exposed to continuous wear (iii) Similar studies can be extended to evaluate the performance of other process industries such as petroleum, food processing and textile etc. by using Reliability Block Diagram (RBD), Failure Mode Effect Analysis (FMEA) and Petri Nets (PN) etc (iv) The Genetic Algorithm can be further utilized in optimizing the system's performance while considering the availability, maintenance cost and life cycle costs as the criteria for optimization

Verma A. K., Srividya A., Ramesh P. G (2010) suggested a three pronged strategy for the successful implementation of e-maintenance for LEPs. Firstly, an integrated condition and time based maintenance framework is proposed for LEPs. Secondly, reference is drawn to models for condition and time based maintenance at systemic levels. Thirdly, emphasis is laid on the information and expertise available in the domain of plant design, operation and maintenance and the same is tapped for incorporation in maintenance decision making. They highlights the scope of the results of the optimization as inputs to assess the need to reconfigure or upgrade the condition monitoring arrangement. Likewise the other parameters required for the maintenance optimization models can be developed.

Maniya K. D. and Bhatt M. G. (2011) presented an alternative multi attribute decision making methodology for solving optimal facility layout design selection problems based on Preference Selection Index method.

Moghaddass R., Zuo M. J., Qu Zian (2011) studied the - out-of- systems under three different cases of shut-off rules and derivation of closed form solutions for SSA, MTTF, and MTTFF of repairable -out-of systems with identical components, and different numbers of identical repairmen was done efficiency. They suggest availability analysis of the repairable -out-of- systems with non-identical components, and general repair and failure distributions are to be investigated in future research.

Vasili Mehdi, Tand Sai Hong, Ismail Nepsiah, Vasili Mohammadreza (2011) discussed maintenance optimization models with the mathematical models focused on finding either the optimal balance between costs and benefits of maintenance or the most appropriate time to execute maintenance. They also presented a brief review of existing maintenance optimization models. Several reliable models and methods in this area are discussed and future prospects are investigated. They advised further research on; (i) Optimization models with Simultaneous analysis of CM and PM (rather than assuming CMs as minimal repairs or replacements), (ii) Optimization models for integrating the risk based maintenance in the business and maintenance management; (iii) Models and approaches for simultaneously optimize the maintenance policies and different aspects of the maintenance management tasks.

Godwin Barnabas1, Maran M, Nixon G S and I Ambrose Edward (2012) worked on the raw mill section due to its critical failure nature. The various subsystems of the raw mill system are: air slide, conveyor assembly, impact crusher, separator, elevator and gear assembly were identified to determine the optimal maintenance policy by means of Analytical Hierarchy Process (AHP) and it is combined with Goal Programming (GP) to minimize the total maintenance cost.

Zhixian Yang, Guobin Yang (2012) established the optimization model of Aircraft Maintenance based on the objective function of minimization cost. Genetic Algorithm is used to solve the problem. The feasibility of the model and algorithm is verified by an example of an airline.

P. Lynch, K. Adendorff, V.S.S. Yadavalli, O. Adetunji (2013) investigated the influence of an effective maintenance system on the efficient performance of any industrial system. The core concept of the research explains that the simultaneous focus on the spares inventory subsystem as well as on the preventive maintenance subsystem must be considered when developing a quality maintenance programme. In their research, the optimization heuristic, a genetic algorithm, which was used to solve the research problem is explained

Tao Chen, Jiawen Li, Ping Jin, Guobiao Cai (2013) suggested about preventive maintenance (PM) scheduling problem of reusable rocket engine (RRE), which is different from the ordinary repairable systems, by genetic algorithm. Three types of PM activities for RRE are considered and modeled by introducing the concept of effective age. The impacts of PM on all subsystems' aging processes are evaluated based on improvement factor model. Then the reliability of engine is formulated by considering the accumulated time effect. After that, optimization model subjected to reliability constraint is developed for RRE PM scheduling at fixed interval.

Adhikary & Bose (2013) presented multi-criteria FMECA for coal-fired thermal power station using COPRAS-G method.

V. Conclusion

There is huge scope of reliability analysis of various systems in different process industries. A lot of research has taken place in this direction in different industries like sugar mills, soap industries, foundry units and fertilizer industries etc., but quality research is lacking in important segment of process industry; specifically with the use of multi-criteria decision making methods for failure analysis of critical components.

The outcome of comprehensive literature review presented here will open opportunities and future scope to optimally develop a maintenance model for identified process industry and as a general acceptable model; which includes a quantitative relationship between failure rate and maintenance and relates the effect of maintenance to the impact in system reliability and total cost.

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