**COMBINED APPLICATION OF RELIABILITY AND CONDITION BASED MAINTENANCE SUPPORTED BY PFMEA**

Claudia R. Carvalho de Oliveira

Mestrando em Gestão de Sistemas de Engenharia – UCP

[claudia.carvalho@ge.com](mailto:claudia.carvalho@ge.com)

Luiz Felipe da Silva Oliveira

Engenharia Mecânica – UCP

[luizfelipedasilva.oliveira@ge.com](mailto:luizfelipedasilva.oliveira@ge.com)

José Cristiano Pereira

Professor Doutor, em Engenharia de Produção – UFF

[josec.pereira@ge.com](mailto:josec.pereira@ge.com)

**ABSTRACT**

Productivity is a key element to all companies looking for keeping competitiveness and being well prepared for the future in front of all challenges being brought from a globalized world. Operational Risks needs to be assessed and productivity needs to be clearly confirmed by operational results.

This paper covers assets maintenance effectiveness, one of the productivity evaluation components increasingly gaining business attention. The methodology proposed to achieve the required effectiveness on asset maintenance combines the concepts of Reliability Centered Maintenance (RCM) and Condition Based Maintenance (CBM), also supported by PFMEA (Process Failure Mode Effects Analysis), which is a successful and powerful risk management tool.

A case study was conducted on a high technology enterprise, focused on the application which combines these referred methodologies. The implementation process has used Fast Works concepts. During the implementation period, it was observed that the adequate treatment of manufacturing equipment, categorized by impact on production results, is key to program success and prototyping strategy. The main concept is based on suitable equipment sensitive inspections, vibration analysis and thermography which will guide the maintenance interventions, partially or totally replacing the previous traditional strategy.

The conclusion is that a significant risk and a consistent maintenance cost reduction is obtained together with a significant increase in equipment availability. In the first year of implementation, asset availability (related to maintenance) reached 95% and direct cost reduction achieved 5 to 10% level. OEE (overall equipment effectiveness) was directly impacted as well as business results, especially due to additional availability in production constrains.

The study and its applicationare a source of information for maintenance leaders and other professionals looking for gaining productivity through effective asset maintenance and risk management.

Keywords: Asset management; Reliability Centered Maintenance; CBM; Condition Based Maintenance; PFMEA.

1. **INTRODUCTION**

A robust asset maintenance process is required to guarantee a strategy of long-term growth for enterprises operating under an environment which requires a lean approach and high productivity levels.

The presented methodology combines concepts of Reliability Centered Maintenance and Condition Based Maintenance, bringing a need of culture change in relation to equipment maintenance strategy – specially for manufacturing companies still using the traditional asset maintenance strategy (which includes the ‘blocked’ periodic preventive maintenance). The reliability demand supported by the condition-based strategy, which is based upon diagnosis, aims to have precisely guaranteed equipment functions (i.e. expected deliverables to production, defined by equipment specific roles inside the production process). It is a response to present demands in which it is highly necessary to understand and increase equipment availability (OEE – overall equipment availability), specially under a lean environment where bottlenecks and/or constraints are known and requested to be optimized. Maintenance activity needs to stop being just efficient to become effective [1], meaning that it is not enough just to repair the equipment as quickly as possible, but, more important than that, it is necessary to maintain its function for the operation, avoiding failures, non-conformances andconformances and reducing the risks of unplanned shutdowns, hence the proposed combined methodology effectiveness.

Reliability Centered Maintenance, RCM, began in 1968 due to the need of the BOEING 747 aircraft line set up and related approval from FAA (Federal Aviation Administration). The use of traditional maintenance methodologies in manufacturing process of this complexity would simply make it impossible to meet the requirements of the Aeronautical Authorities and required lead times.

The concept of condition-based maintenance, CBM, was established at the beginning of this century with the objective of promoting the maintenance of the equipment (and systems) at the most appropriate moment, but before the equipment loses its required performance (and required function). Condition Based Maintenance strategy recommends that maintenance decisions be made through data obtained by monitoring the condition of the equipment and consider three basic steps [2]:

1. Data Collection
2. Data Analysis
3. Decision-making Process established by Maintenance team

A more current view of CBM methodology also recommends the technique of dividing the equipment into its subsystems to promote a careful and segregated evaluation, prioritizing their most important functions (deliverables) to production. This will enable maintenance interventions to be more effective, in a sense of being both efficacious and efficient. reducing the risks of unplanned shutdowns, hence the proposed combined methodology effectiveness.

There is a strong alignment between the combined application of these two methodologies for asset maintenance and the risk analysis proposed by PFMEA process, an effective methodology for failure mode and effects analysis. PFMEA basic implementation steps are:

1. Map the process
2. Look for failure modes
3. Evaluate failure risks, their probabilitiesof occurrence and related impacts (severity)
4. Prioritize and Drive actions accordingly
5. Keep adequate analysis record and review the process as required

The diagnosis and monitoring procedures demanded by the CBM strategy is enhanced by the FMEA process where the aim is to prevent a failure before any harm is done [3]. The Functional Requirements which is an essential portion of PFMEA application is totally aligned with the RCM demand of preserving equipment function as a mandatory guidance for asset maintenance strategy.

Thus, responses to the following research questions are proposed:

Research Question 1: How to optimize asset maintenance process?

Research Question 2: How could PFMEA methodology help asset maintenance optimization?

1. **DESCRIPTION& METHODOLOGY**

This article shares the principles and basic strategy to implement a combined application of the concepts brought from RCM and CBM, support by PFMEA failure analysis process. The combined application takes the best from Reliability Centered Maintenance and Condition Based Maintenance methodologies and could be set up even if the maintenance environment set in the company is the traditional periodic corrective and preventive maintenance, replacing its current practices of maintaining the equipment and bringing it back into operation to an effective maintenance program aligned with production needs.

The proposed methodology was viewed and explored from multiple perspectives and the collection and comparison of data in real production enhanced data quality. A prolonged and intense exposure to the process and its context was necessary so that multiple perspectives could be collected and understood. The parameters were shared with different engineers, mechanics and operation personnel, who had the opportunity to discuss, clarify the interpretation of parameters and contribute with new or additional perspectives on the key factors. Data was then converged in the analysis process. Each piece of data source contributed to the understanding of the whole process. This convergence added strength to the findings as the various strands of data were braided together to promote a better understanding of the case.

Reliability Centered Maintenance (RCM) methodology is a process used to determine what should be done to ensure that any asset or equipment continues to do what its users expect it to do in its present context. This maintenance model or strategy is based on using the various resources known in the maintenance area to allow, in the best possible cost-benefit ratio, the maximum level of reliability and safety that can be obtained from a plant or production system. It is also a data driven methodology where a complete failure, causes and fixes registering process is key to effectiveness. Its main objective is to optimize maintenance planning strategies to increase the reliability of the production system and minimize maintenance costs by eliminating activities that have little or no influence on the reliability of the system [2, 4].

Condition-Based Maintenance, which might also be known as Predictive Maintenance, is widely applied in the aeronautical branch but is largely applicable in other fields as well. Unlike periodic preventive maintenance, which performs services on the assets even if there are no apparent defects, the condition-based maintenance only performs equipment interventions after finding a real defect, even though no present fault has been caused, and only after assessing its deterioration profile. This type of maintenance consists in the inspection and measurement (monitoring) of operating parameters of machines and systems by means of specific devices specially developed for this purpose [4, 5].

The combined strategy is based on:

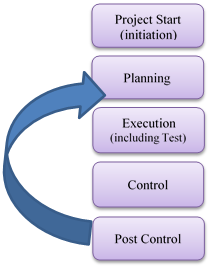
1. A strong emphasis on standardized and methodologically derived records to be a source of information (not just data)
2. Effective people training program as it implies cultural changes using Lean Manufacturing concepts
3. Inspection plans duly designed by the maintenance engineering team, taking advantage of the preventive and corrective maintenance team expertise;
4. An active participation of the equipment operators, their shop leadership and Process Engineering is a fundamental part of the success of the implementation process.This is not a program only developed by maintenance team tosupport the operation. Operations team participation is key.

Another requirement of the combined strategy, an essential one and which is a risk to program effectiveness, is the detailed analysis of unexpected failures and intervention procedures. Although much less than previously, failures are expected to happen so, it is crucial that maintenance teams proper selects and segregate a formal time to perform the required analysis, receive operations feedback and promote the necessary adjustments [4]. PFMEA risk management methodology stronglyassists in this process.

The combined application of assets maintenance has been applied in a high technology aeronautical company, with a significant demand for equipment reliability and availability due to a continuous growth environment. The presented results are related to a real implementation case.

**2.1 Basic Strategy for Project approval, development & implementation – 5 phases**

To promote an effective implementation process (start-up) and get the adequate approval and support, the following phases are required, aligned with PMBOK guidance [6], as per figure 1:



**Figure 1** – 5 steps basic strategy for CBM + RCM implementation (PMBOK, 2017)

A comprehensive set of activities needs to be performed as presented in table 1. These activities include elements of project initiation as the *project presentation to leadership* which shares a good view of business benefits. Implementation accomplishment need to be very well prepared and organized by the Planning phase. The Execution phase will be supported by an identification of effective metrics [7,8] and count on a piloting step. This step is very important to help the team to clearly understand the methodology aims and create an actual set of activities for following areas where the methodology will be later implemented. Implementation team needs to identify one or two areas, maximum, to test the proposed methodology; in the referred enterprise, the methodology used has been based on Fast Works/Lean Start up [9].Execution phase has also to be supported by a solid training program with the help of external consultants and using technics of Lean Manufacturing. Specific training sessions comparing *status quo* to new maintenance practices and believes, brought by the proposal, are guided by available literature [10]. PFMEA is a strong support to this step, specially recommended for critical pieces of equipment (A category), helping to mitigate the risk of failures and its impacts. Metrics are also key to control phaseshowing project effectivity and guiding required adjustments.



**Table 1** - CBM + RCM Implementation guidance (article authors, 2019)

* 1. **PFMEA and Combined Application of RCM and CBM**

Process Failure Mode and Effect Analysis (PFMEA) can be used to indicate that the following steps are vital to maximize the success of a task: identify current maintenance practices; evaluate the detection systems currently adopted; to raise failure rates and types of failure related to the studied subject; collect the evaluations of the specialists who work in the permanent maintenance process and also of specialists who have experience in the area of reliability of manufacturing processes of benchmark segment components[11].

Anticipation is a key element for reliability, condition monitoring and PFMEA. Figure 2 shows how a sooner identification of failures could cause maintenance cost reduction. These costs are related to maintenance direct expensesand financial impacts associated to production disruptions.

**No**

**Preventive**

**x**

**2x**

**3x**

**10x**

**Equipment Deterioration**

**Under Monitoring**

**Effective Preventive**

**Tradicional Maintenance**

**If you discover a reliability problem sooner…**

**RCM + CBM + PFMEA**

**It costs much more to treat a failure at a later stage(all related costs)**

**Figure 2 -**Reliability and Condition Based Maintenance with PFMEA(based on effective FMEA [12]) - adapted to Maintenance strategy effectiveness by article authors, 2019

* 1. **Lean Manufacturing concepts applied to Asset Maintenance Effectiveness**

Lean Manufacturing principals are an important help to an effective implementation of the proposed combined application of Condition and Reliability centered Maintenance. As part of the preparation in a pre-implementation phase, a 5S event is a requirement, helping to clean and organize the area for the new behavior, helping to adjust mindset. Figure 3 shows how Lean Manufacturing concept associated to waste elimination could help an effective asset maintenance operation.

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**Figure 3**– Lean Concepts applied to Asset Maintenance –Eliminating wastes Combined Application of CBM + RCM(Article authors, 2019)

1. **DIS****CUSSION & RESULTS**

Equipment availability in the enterprise where the new methodology is being implemented has significantlyincreased as per presented results. One of the key factors for this improvement is an effective failure analysis process promoted by Maintenance Engineering with the participation of related players. If the availability target is not achieved, additional reviews are promoted to identify additional actions for reliability and availability improvement.

After the combined strategy implementation, the following benefits have been verified (MVPs areas):

1 Reduction in equipment downtime and OEE increase related to failure or maintenance

2 Reduction of the average time between repairs

3 Sustainable reduction of maintenance costs

4 Higher customer satisfaction

5 Operation risk reduction and other environment benefits

Specifically, verified results (12 months period) are aligned with expectations:

- Asset availability reached 95 to 98%, impacting OEE (overall equipment effectiveness);

- Expenses reductionwas also an important goal achieved. Current results show that a 5 to 10% level range are achievable in two year after implementation.

Production deliverables together with business results were also positively impacted, especially due to additional availability on production constrains.

1. **CONCLUSION**

In answering the Research Question 1, this paper presents a proposal for a more effective asset maintenance strategy, both in terms of equipment availability and maintenance costs reduction. By answering Research Question 2, moreover, it is possible to bring more robustness to the requirement of maintaining equipment required functions and reducing the risk of failures.

Mainly, this implementation process guides the companies which are still under the traditional maintenance environment to achieve their aims with just one step, following the proposed combined methodology, avoiding the previous two steps implementation process and achieving significant impact in operational results, like equipment availability and reliability, cost reduction, representing significant productivity gains. [13]. This is exactly what has happened with the company where new methodology implementation has been carried out

Nevertheless, even for companies into a Reliability Centered Environment (RCM) or the ones which are already moving into a Condition Based Maintenance strategy (CBM), the proposed strategy can enrich their asset management program, helping the changing process to be more effective. The combination of the concepts behind these strategies, enhanced by PFMEA risk management methodology, enable any enterprise to effective gain productivity through asset management.

This case shows evidence that the quality of the maintenance process is affected by several factors, some of them capable of compromising the reliability and safety of the maintenance process.

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