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# APPLICATIONS AND BARRIERS OF RELIABILITY CENTERED MAINTENANCE (RCM) IN VARIOUS INDUSTRIES: A REVIEW

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**Abstract**

*The purpose of this paper is to highlight the applications of Reliability Centered Maintenance (RCM) in various industries. The paper highlighted the need of the organizations to adopt effective and efficient maintenance strategies such as Reliability Centered Maintenance (RCM) in view of the changing scenario of the growth of mechanization and automation. The paper gives a comprehensive approach to the numerous applications of RCM in different fields and further it also highlights the various barriers of RCM implementation. The study will definitely be useful to researchers, maintenance professionals and other concerned with maintenance to understand the importance of maintenance management.*

***Keywords: Reliability Centered Maintenance, Maintenance, Barriers of RCM Implementation.***

## I. INTRODUCTION

Any process or operation done on machine or its parts to enhance the efficiency of machine before or after the breakdown is called maintenance. A concern may be said to be successful over the years, when it run non-interrupted and maintains a smooth flow consistently at optimum productivity level. Machines, buildings and other facilities deteriorates due to their use and exposure to environmental conditions. The objective of maintenance in an industry is to keep the production plant, equipment, building and other facilities in an efficient operating condition so that the intended function can be performed satisfactorily and at minimum cost. It has been realized and well accepted by manufacturing organizations that the equipment maintenance and reliability are important strategies that can considerably influence the organization's ability to compete effectively (Madu, 2000). Thus, ever increasing business pressures have been putting maintenance function under spotlight (Garg and Deshmukh, 2006).

In today's dynamic environment, a reliable production system must be seen as a critical factor for competitiveness, thus maintenance has become a strategic issue for manufacturers (Brah and Chong, 2004). As organizations have been increasing their investments in capital intensive equipment, the performance of maintenance operations have become a major management issue. It has now become a strategic tool to increase competitiveness rather than simply an overhead expense that must be controlled (Waeyenbergh and Pintelon, 2007). The effective integration of maintenance function with engineering and other manufacturing functions in the organization can help to save huge amounts of time, money, and the useful resources in dealing with reliability, maintainability and performances issues (Moubray, 1997). There is an increasing trend among manufacturing organizations in recognizing maintenance of assets and machines as an essential part of operations function, while realizing that an effective maintenance strategy can contribute significantly to the production activities (Bamber et al.1999). Therefore, effective and due consideration has to be given to the maintenance function. In recent times, the growth of mechanization and automation has meant that reliability and availability have now become key issues in sectors as diverse as health care, data processing, telecommunications and building management. Condition monitoring, condition based maintenance and maintenance management information systems began to be used in the industry and in the beginning of 1980's many systematic concepts had been proposed such as TPM and RCM (Alysouf, 2007).

### A. Reliability Centered Maintenance (RCM)

Originally, Reliability Centered Maintenance was designed for the aircraft industry and the so called RCM-II concept was designed for use in general industry (Waeyenbergh and Pintelon, 2002). RCM approach is a maintenance process based on system functions, consequences of failures and failure modes (NASA, 2008).

### B. Introduction to RCM

The main objective of RCM is to reduce the maintenance cost, by focusing on the most important functions of the systems and avoiding or removing maintenance actions that are not strictly necessary. It is based on the assumption that the inherent reliability of the equipment is a function of the design and built quality. RCM is a technique for developing an effective preventive maintenance (PM) program. While developing the PM program, it should be realized that RCM will never be a substitute for poor design, inadequate build quality or bad maintenance practices. In some fundamental aspects RCM is very different from what the norm among maintenance practitioners is today and it requires very basic changes in our mindset. The basic concept of RCM is quite simple, and might be viewed as organized common sense (Hinchcliffe and Smith, 2004). According to Moubray (1997), RCM is the maintenance performed to ensure that physical assets continue to do what their users wants them to do. An RCM analysis basically provides answers to the following seven questions (Rausand, 1998):

1.What are the functions and associated performance standards of the equipment in its present operating context?

2. In what ways does it fail to fulfill its functions?

3. What is the cause of each functional failure?

4. What happens when each failure occurs?

5. In what way does each failure matter?

6. What can be done to prevent each failure?

7. What should be done if a suitable preventive task cannot be found?

### C. RCM Terminology

RCM focuses on the maintenance of system other than equipment operation. Significant terms in RCM method are:

1. **System**: System is the overall plant or plant subsection that has been identified for RCM analysis.

2. **Subsystem**: It is the assembly of equipments or components that came together provide one or more functions and can be considered a functionally separate unit within the system.

3. **Function failure**: Every subsystem performs certain function. Functional failures describe how failures of each can occur.

4. **Failure mode**: A failure mode identifies each specific equipment related condition that can cause the loss of subsystem failure.

### D. Steps in RCM

1. **Define system and subsystem boundaries**: The system is divided into mutually interfaces with separate non overlapping boundaries. Everything that crosses these interfaces is identified.

2. **Define subsystem interface, functions and functional failure:** Each system has in interfaces indicating what comes into the subsystem and out interfaces indicating what goes out of the subsystem. These functions and how they can fail are enumerated.

3. **Define failure mode for each functional failure:** Specific equipment and component failure that cause each functional failure are identified.

4. **Categorize maintenance tasks**: This deal with the allotment of critically classes (C.C) to each of the failure mode.

5. **Implement maintenance tasks**: The last step is to group task in RCM. In this step, the maintenance tasks that will be implemented to address the problems identified by each failure mode are developed.

### E. Evolution of Reliability Centered Maintenance

It was during the World War-II, nearly 60 percent of the airborne equipment shipped to the far East was damaged on arrival and 50 percent of the spare parts and equipments in storage became unserviceable before they were used. According to a report in 1949, about 70 percent of the electronic equipments possessed by the US navy were not operating properly. In December 1950, the US air force formed an adhoc group on reliability of electronic equipment, to study the situation and recommended measures that would increase the reliability of equipment and reduce maintenance.

The approach to maintenance has changed dramatically over the last century. Blischkke and Murthy, (2000) stated that till 1940, maintenance costs were considered as unavoidable costs and the only maintenance plasticized was corrective maintenance (CM). Whenever an equipment failure occurred, a specialized maintenance workforce was called on for returning the system to operation.

In 1970s, a more integrated approach to maintenance evolved in both the Government and private sectors. New costly defence acquisitions by the US government required a life cycle costing approach, with maintenance cost being a significant factor. The close linkage between reliability (R) and maintainability (M) was recognized. Consequently, Remote Site Maintenance (RSM) became more widely used term in defence related systems. This concept was also adopted by manufacturers and operators of civilian aircraft through the methodology of reliability centered maintenance (RCM) in the USA. In the RCM approach maintenance is carried out at the component level and the maintenance effort for a component is a function of the reliability of the component and the consequence of its failure under normal operation (Moubray, 1997; Fonseca and Knapp, 2000; Deshpande and Modak 2002; Carretero et al. 2003). The approach uses failure mode effect analysis (FMEA) and to a large extent is qualitative. At the same time, the Japanese's evolved the concept of total productive maintenance (TPM) in the context of manufacturing (Eti et al. 2004; Lopez Jaquez, 2007). Here maintenance is viewed in terms of its impact on the manufacturing through its effects on equipment availability, production rate and output quality.

RCM is a unique tool used by reliability, safety or maintenance engineers for developing optimum maintenance plans that define requirements and tasks to be performed in restoring or maintaining the operation capability of a system or equipment. The concept of RCM was developed in the early 1970 by the commercial air line industry maintenance steering group and was endorsed by the Air Transport Association and the US Federal Aviation Administration. This new maintenance policy was designated MSG-1 updated as MSG-2 and most recently in a revised form MSG-3. RCM is now acceptable to a vast range of maintenance important areas including Nuclear power, plants weapon system and products.

### F. Benefits of Reliability Centered Maintenance

1. **Greater Maintenance Cost-effectiveness:** The activities which have the highest impact on the plant's performance are in focus of RCM. This helps to ensure that maintenance resources are spent where it will do the most good.

2. **Greater Safety and Environmental Integrity:** The safety and environmental influence for each failure mode are considered before its effect on operations.

3. **A Comprehensive Database:** When an RCM review is finished there is a fully documented and comprehensive record of the maintenance requirements of all the significant assets available. Also a clearer view of the skills required to maintain each asset is provided.

1. **Improved Teamwork:** An easily understood and common language for all maintenance personnel are provided by RCM. This gives maintenance and operations people an increased knowledge of what can or cannot be achieved, as well as how to achieve it, by maintenance.

2. **Increased Motivation of Individuals:** The RCM process and review provides an improved understanding of the assets and also a wider "ownership" of maintenance problems. Improvement programs are already dealing with these types of issues, and they are also a part of the mainstream of maintenance management. However, an important difference is that RCM provides an effective step-by-step framework for dealing with all the issues at once and also for involving everyone concerned (Moubray, 1997).

### G. The RCM Approach

RCM integrates Preventive Maintenance (PM), Predictive Maintenance (PdM), Corrective, and Proactive Maintenance to increase the probability that equipment will function as required over its design life-cycle with a minimum amount of downtime and maintenance. These maintenance strategies are optimally integrated to take advantage of their respective strengths, and maximize the reliability and availability of equipment while minimizing life-cycle costs. Maintenance decisions are required to be supported by sound economic and technical justification by the RCM process.

## II. RELIABILITY CENTERED MAINTENANCE (RCM) AND ITS APPLICATIONS: LITERATURE REVIEW

Reliability centered maintenance is a maintenance process based on system functions, consequences and failure mode (NASA, 2008). Richet et al. (1995) revealed the application of RCM in the foundry sector and emphasized that this approach can be used for a selective or general analysis of production equipments, its failures and their causes. Mokashi et al. (2002) emphasized that RCM need not to be looked as a methodology but it should be considered as a philosophy. The process is named RCM to emphasize the importance of reliability when focusing preventive maintenance activities on the retention of inherent design reliability of the equipment (Hinchcliffe and Smith, 2004). Backlund and Akersten (2003) proposed the introduction of RCM approach based on process and requirement management aspects. The need for a holistic view while managing RCM introduction was emphasized. RCM approach has been accepted by department of defense and aircraft, spacecraft and nuclear industry for a long time but it is a relatively a new maintenance approach within industries outside these four arenas (NASA, 2008). Recently Tarar (2014) revealed that the successful RCM implementation in any industry can ensure better performance to take competitive advantage in global market. RCM integrates corrective maintenance (CM), preventive maintenance (PM), predictive maintenance (PdM), proactive maintenance to increase the probability that equipment will function as required over its design life cycle with a minimum amount of downtime and maintenance. So, RCM is a systematic process for developing a maintenance policy for a system and RCM methodology offers the best available strategy for PM optimization (Deshpande and Modak, 2002).

Abdul-Nour et al. (1998) developed a methodology that was used in an aluminium plant to select critical machines and to develop an optimal maintenance policy based on reliability data of each machine, safety consequences of system failure, lead time, repair time and components criticality.

Good fellow (2000) emphasized that the application of RCM to electric distribution system maintenance is an opportunity to sustain and improve the reliability and also to optimize maintenance resource allocation.

Deshpande and Modak (2001) applied the concept of RCM to process of vacuum degassing/vacuum oxygen decarburizing in the steel melting shop of a medium scale steel industry. RCM based preventive maintenance schedule was formulated and it was recommended that RCM methodology can be applied to industry for establishing the PM schedule based on safety as well as economical consequences.

Mokashi et al. (2002) identified specific problems likely to be encountered in endeavour of implementing RCM on ships. A ship owner or manager is perpetually concerned with need to reduce the operating costs as well as to improve the safety, which can be delivered by RCM. It was analyzed that considerable savings in time and effort can also be achieved by using a reverse logic where the failures modes are identified by analyzing the maintenance tasks. A fuel oil purification system was used as a case study. Pareto's 80-20 principle was used to analyze all the failures that have occurred over a fixed period and to see their frequencies and consequences. Then the authors removed the top 20%, which contribute to 80% of the risk and analyzed the 20% of the system that were responsible for 80% of the failures. The purpose was to locate the most troublesome failures and their causes. The authors also advocated the needs of total productive maintenance in implementation of RCM.

Arthur (2004) presented the application of Reliability centered maintenance to high speed centrifugal dairy separation equipment at two New Zealand dairy sites. He concluded that the RCM process resulted in an optimized maintenance regime for the separation and classification of equipment under consideration. From the maintenance optimization process, it was clear that significant savings were achievable. These savings are conservatively estimated as being of the order of

NZ$254,000 per annum for the two sites when compared with the previous maintenance strategies.

Colosimo and Pontel (2007) proposed RCM program in a cement company. The company wanted to compare the system failure histories before and after the RCM program to verify the success of the program. The goal of this work was to present some techniques to evaluate multiple systems trend and also new test for this purpose was suggested. Some important and popular graphical methods and tests for the non homogeneous Poisson process model were used in order to attain the goal. Comparing an important system failures history before and after the program, it was expected an increasing time between failures as well as system availability improvements. The authors examined that after the implementation of the RCM program, time between failures in the process occurred in random fashion indicating that there is no trend, but larger than the first period. The implementation of RCM brought benefits to the cement company as the number of failures decrease after the implementation of the program.

Bae et al. (2009) introduced an advanced reliability centered maintenance planning method using computational techniques and applied the method to a standard electric motor unit (EMU) of a transportation system. The maintenance plan was established considering the safety and cost. The research helped in reducing the 23.25% of maintenance cost without affecting the system operating conditions.

Carazas and Souza (2009) applied RCM in a complex gas turbine and presented a method based on system reliability concepts such as functional tree development; application of failure mode and effect analysis to identify critical components for improvement in an electric power station. The RCM concept was used as guidelines for ranking the maintenance policy for the critical components aiming to improve the overall availability of the gas turbine.

Acharya et al. (2010) has adopted RCM in Tarapur Atomic power station -1&2 (TAPS# 1&2) for all the plant equipments. Two important Probability Safety Assessment (PSA) measures were used as screening tools namely: risk achievement worth (RAW) and Fussell-Vesey (FV) to identify potentially safety-significant components or systems. Based on this information condition and reliability assessment of equipments was done. This enabled to incorporate possible changes in design, maintenance strategy and surveillance requirements to avoid the unplanned breakdowns. The implementation of RCM helped TAPS to operate in safe, efficient, and economical manner.

Afefy (2010) applied Reliability Centered Maintenance methodology to the development of maintenance plan for a steam process plant. The main objective of RCM was the cost effective maintenance of the plant components inherent reliability value. The steam process plant consists of fire-tube boiler, steam distribution, dryer, feed- water pump and process heater. The RCM had great impact on the PM tasks. The study presented a method based on system reliability concepts such as system root cause failure analysis, application of failure mode and effects analysis to identify the critical components. The Run to failure (RTF) frequency has been decreased. Applying RCM methodology showed that mean time between failures for the plant equipments and the probability of sudden equipment failures are decreased. RCM helped in decreasing the labor cost from 295200$/year to 220800$/year (25%) for the proposed preventive maintenance planning. The proposed PM planning results indicated a saving of about 80% of the total downtime cost as compared with that of current maintenance. The author also highlighted that about 22.17% of the annual spare parts cost can be saved with the proposed preventive maintenance planning.

**Table 1.1: Literature on Reliability Centered Maintenance and its Applications.**

| S. No | Author | Year | Field of application | Objective |
|---|---|---|---|---|
| 1 | Gupta and Mishra | 2016 | Conventional Milling Machine | RCM Implementation (Case study) |
| 2 | Sabouhi et al. | 2016 | Combined cycle Power plants | RCM Implementation (Case study) |
| 3 | Bhangu et al. | 2013 | Thermal power plant | RCM Implementation (Case study) |
| 4 | Chen and Zhang | 2012 | Nuclear Energy Field | RCM Implementation (Case study) |
| 5 | Liang et al. | 2012 | Reciprocating compressor | RCM Implementation (Case study) |
| 6 | Bugaj | 2012 | Aviation | RCM Implementation (Case Study) |
| 7 | Selvik and Aven | 2011 | Oil and Gas Industry | RCM Implementation (Case study) |
| 8 | Majid et al. | 2011 | Process equipment | RCM Implementation (Case study) |
| 9 | Jaarsveld and Dekker | 2011 | Petrochemical company | RCM Implementation (Case study) |
| 10 | Pourjavad et al. | 2011 | Mining factory | RCM Implementation (case study) |
| 11 | Acharya et al. | 2010 | Tarapur atomic power station | RCM Implementation (Case study) |

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|---|---|---|---|---|
| 12 | Afefy | 2010 | Process steam plant components | RCM Implementation (case study) / Maintenance policy selection |
| 13 | Robinson | 2010 | Paper Mill | RCM Implementation (case study) |
| 14 | Carazas and Souza | 2009 | Gas turbine in power plant | RCM Implementation (Case study) |
| 15 | Bae et al. | 2009 | Electric motor unit | RCM Implementation (Case study) |
| 16 | Cheng et al. | 2008 | Military equipment | RCM Implementation (Case study) |
| 17 | Colosimo and Pontel | 2007 | Cement company | RCM Implementation (Case study) |
| 18 | Chan et al. | 2005 | Circuit breakers | RCM implementation (Case study) |
| 19 | Penrose | 2005 | Electric motors | RCM Implementation (Case study) |
| 20 | Bertling | 2005 | Electric Power system | RCM Implementation (Case study) |
| 21 | Mostafa | 2004 | Glass company | RCM Implementation (Case study) |
| 22 | Deshpande and Modak | 2003 | Rolling mill | RCM Implementation (case study) |
| 23 | Mokashi et al. | 2002 | Maritime equipment | RCM Implementation (case study) |
| 24 | Deshpande and Modak | 2001 | Medium scale Industry | RCM Implementation (Case study)/Maintenance policy selection |
| 25 | Goodfellow | 2000 | Overhead distribution system | RCM Implementation (Case study) |
| 26 | Fonseca and Knapp | 2000 | Chemical Process industry | RCM Implementation (Case study) |
| 27 | Richet et.al | 1995 | Foundries | RCM Implementation (Case study) |

Li and Gao (2010) implemented Root cause analysis (RCA) on a system failure to perform Radical

Maintenance (RM) which was then combined with RCM analysis to improve the quality of maintenance strategies. The proposed theory and analysis procedure of RCM considering RM were applied to an ethylene plant in China. The author claimed that using RM can help assign maintenance resources rationally and improve the quality of maintenance strategies considerably.

Niu et al. (2010) presented a condition based maintenance system that uses reliability centered maintenance mechanism to optimize maintenance cost and employs data fusion strategy for improving the condition monitoring, health assessment and prognostics. The proposed system showed that optimized maintenance performance can be achieved.

Selvik and Aven (2011) presented the reliability and risk centered maintenance (RRCM) based on the framework of RCM. The study improved the risk and uncertainty assessment by adding some additional features to the existing RCM methodology. The study was implemented in oil and gas industry. The author further extended the work of Eisinger and Rakowsky with an aim to determine the maintenance strategy subsea flow line.

Liang et al. (2012) implemented the RCM on the reciprocating compressor which is considered the key equipment in the process industry such as refinery, chemical plants and so on. The author with the help of logic decision recommended the suitable maintenance strategy for the various parts of the reciprocating compressor. The selected maintenance strategies for various components have resulted in smooth, efficient, safe and reliable operation.

Bugaj (2012) highlighted that the failure consequences are a primary inherent reliability characteristics and summarized that the analysis or investigative steps in RCM process in which functional failures, failure mode and failure analysis was studied for the aviation industry. Liang et al (2012) used the RCM to evaluate the reciprocating compressor which is considered as key equipment in the process of industry production such as oil refinery and chemical plants based on FMEA analysis.

Igba et al. (2013) proposed interaction between RCM approach and wind turbine gearbox. It was emphasized that RCM optimize the various maintenance strategies based on findings from the functional failure analysis.

Yssaad et al. (2014) studied the application of RCM model to optimize the maintenance management for power distribution system. The feasibility of conducting an optimization method of RCM based on FMECA analysis was studied.

Supsomboon and Hongthanapach (2014) proposed preventive maintenance plan under reliability centered maintenance for a semiconductor factory. The research methodology included the procedures such as priority of critical components in test machine, analyzing the damage and risk level by using failure mode and effect analysis, calculating the suitable replacement period through reliability estimation and optimizing the preventive maintenance plan.

Salah et.al (2017) proposed a RCM approach that is combined with evolutionary optimization to develop optimal maintenance plan for hospital facilities. The result demonstrated that by using RCM and optimization approach saving range is 6 to 16% in maintenance cost as compared to traditional preventive maintenance approach taken by the hospital in the area of Intensive care units, emergency rooms, operating rooms, regular patient rooms.

Ahmad and Karim (2017) suggested and developed a framework on application of RCM for lead oxide production process in the battery industry. Standard RCM method is used here through Failure Mode and Effect Analysis (FMEA) and decision making criteria is established in view of criticality and logic tree analysis (LTA). This resulted in shift of maintenance culture and thinking while maximizing equipment availability and enhancing reliability in this industry.

Martinetti et al. (2018) highlighted the importance of a framework to provide a scalable maintenance program for unmanned aircraft system (UAS) in order to choose the most suitable and feasible maintenance strategy in terms of reliability.

## III. BARRIERS OF RCM IMPLEMENTATION

Backlund, (2003) highlighted that RCM is successfully implemented in the aircraft industry as it has been applied already in the design stage and there have been few constraints and moreover many specialists have performed the RCM analyses whereas in traditional basic industries like Power, Processing and Manufacturing sectors the RCM is applied to existing plants that have been individually designed.

In basic industry, it is clearly not possible to borrow the basic information requirement for this initial assessment from the date on a similar functional system(Harris and Mos,1994, Backlund,2003).

According to Srikrishna et al (2016) the quantitative approach to RCM has taken a back seat compared to qualitative approach because of the unavailability of plan specific historical data and appropriate statistical methods to interpret data. Based on the differences in preconditions implementing RCM is a confounding and stressful change for many basic industry organizations (August 1997). The major barriers for RCM implementation are discussed below:

**A. Training and Data Management:** Training and education are activities that develop employee competence, skills and knowledge (Hansson et al.2003; Bardoel and Sohal, 1999; Thomas, 1994; Chopra et al. 2014). The literature highlighted the importance of training, availability of operating manuals and drawings in evaluating the maintenance of the complex process plants.

**B. Lack of Employee and Leadership Commitment:** Hansson et al. (2003); Chopra et al. (2014) also highlighted the role of management and employee commitment for implementing and executing RCM process. Leadership support, strategic planning, training monitoring and evaluation, empowerment and communication are essential for successful RCM implementation. (Worledge, 1993b, Schawn and Khan, 1994; Moubray,1997; Backlund,2003), added that the some of the main reason why the RCM introduction becomes problematic or fails are technical in nature, but the majority of problems are managerial and organizational.

**C. Budget Allocation and High Implementing Cost:** Essential Budget allocation is required for the maintenance and RCM implementation. Chopra et al. (2014). It was observed that 50% of the companies give only 10% of the budget allocation to the maintenance purposes (Chopra et al., 2014). Some companies have failed to adopt RCM because of high initial costs. The underestimation of these costs has led to withdrawal of management support (Worledge 1993a; Bowler et al.1995). Some companies have failed to introduce RCM because of lack of evaluation of return on investment (Bowler etal.1995; Hipkin1998; Hipkin and Decock, 2000).

**D. Equipment Categorization:** The equipment or parts must be categorized depending upon their respective criticality in order to identify appropriate maintenance policy such as preventive maintenance, repair, condition monitoring and replacement (Rausand1998; Sachdeva, 2008; Chopra et al, 2016). The failure mode of every component must be studied in order to assess the best maintenance solution in accordance with its failure pattern, impact and cost on the whole system (Sachdeva, 2008; Chopra et al. 2016).

**E. Lack of Usage of Scientific Techniques:** Major barrier of RCM implementation depends upon the usage of scientific techniques for analysis of cause of failure and analysis of Mean time to Failure (MTTF), Mean Time to repair (MTTR) and failure rate for various components. The companies must categorize the equipments on the basis of cost incurred on maintenance and calculating the criticality associated with each failure mode and employ scientific tools like FMECA to find criticality index.

**F. Lack of Communication:** The need of communication and especially informal meetings of management and various stakeholders to discuss RCM implementation were needed to complement formal communication to generate increased interest and acceptance (Hansson et al. 2003)

## IV. CONCLUSION

Proper and effective maintenance approach considerably contributes to overall business performance which will ultimately enhance the productivity and quality of the business enterprise. The industries with effective maintenance approach will have a competitive edge in the stiff competition global scenario which in turn will improve the company image with higher profitability and satisfied customers and large base of shareholders. The paper highlighted the applications and barriers of implementation of RCM in various fields taking into consideration the changing requirement of machines and technology.

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