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# Literature Review: Comparison of the Effectiveness of Reliability-Centered Maintenance and Preventive Maintenance on Cost and Risk

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**Abstract.** The modern industrial era is characterized by the high complexity of systems and the demand for operational efficiency, making maintenance systems play a crucial role in ensuring reliability, safety, and sustainability of production processes. Reliability-Centered Maintenance (RCM) has emerged as a strategic approach to replace conventional Preventive Maintenance (PM) methods, which are often static and inefficient. This study compares the effectiveness of RCM and PM in terms of maintenance cost and risk through a literature review across various industrial sectors, including power generation, automotive, maritime, food and beverage, and energy distribution systems. The results show that RCM implementation can reduce unplanned downtime by up to 55.77%, increase system reliability by 28%, lower maintenance costs from 20% to 70%, and raise system availability from 57% to over 90% in some cases. RCM has also proven to be more adaptive to actual equipment conditions, supports risk-based decision-making, and is more effective in scheduling maintenance for critical assets. Although its implementation requires more data resources and technical expertise, RCM demonstrates superior long-term performance. This study recommends the integration of a hybrid strategy that combines the strengths of RCM, PM, and predictive approaches powered by digital technologies to comprehensively enhance the efficiency and reliability of maintenance systems.

**Keywords:** reliability centered maintenance; preventive maintenance; maintenance cost

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## 1. Introduction

Maintenance systems are one of the key elements in ensuring the continuity of operations in modern industries. As equipment complexity and efficiency demands continue to rise, an appropriate maintenance strategy not only affects technical reliability but also impacts operational costs, productivity, and workplace safety. In practice, many industries still rely on the Preventive Maintenance (PM) approach, which involves maintenance based on fixed time schedules without considering the actual condition of the equipment. Although this method is relatively easy to implement, it often leads to over-maintenance or even under-maintenance, ultimately contributing to cost inefficiencies and the risk of unexpected failures (1, 2).

As an evolution of Preventive Maintenance (PM), the Reliability-Centered Maintenance (RCM) approach was developed. RCM focuses on identifying the critical functions of a system, potential failure modes, system reliability, and their impact on operations, thereby enabling maintenance strategies to be designed more effectively and risk-based (3). RCM takes into account the actual condition of components, historical failure data, and operational consequences, which allows for reduced maintenance costs, increased system reliability, and minimized downtime and operational risks (4,5). Several studies have shown that RCM can reduce total maintenance costs by up to 40% (6), improve system availability from 57% to over 90% (7), and decrease unplanned downtime by up to 37% (8). However, the implementation of RCM is not without challenges, such as the need for accurate technical data, advanced analytical skills, and initial investments in training and supporting systems (9).

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Based on these considerations, this study aims to conduct a systematic literature review of various studies that compare the effectiveness of Reliability-Centered Maintenance (RCM) and Preventive Maintenance (PM) across multiple industrial sectors. The main focus of this research is to assess the extent to which the RCM approach can reduce maintenance costs and operational risks compared to conventional PM methods, as well as to identify opportunities for integrating hybrid strategies into modern maintenance practices (10,11). However, there is still a lack of review studies that quantitatively compare the effectiveness of RCM and PM across different industries as presented in this research. Therefore, this study is expected to fill that gap and provide a new contribution to maintenance strategy decision-making.

Several alternative approaches to RCM have also been developed in various studies, such as Fuzzy-RCM (12), digitally-based hybrid RCM, and game theory-based methods, all of which have been proven to significantly enhance maintenance planning efficiency (13). SIn addition, the development of Predictive Maintenance (PdM) and Condition-Based Maintenance (CBM) strategies indicates the evolutionary shift of maintenance systems from fixed-schedule approaches toward data-driven and risk-based systems (14,15,16,17). This trend further reinforces the relevance of this study in positioning RCM as a foundational strategy for future industrial maintenance practices.

## 2. Methodology

This study employs a systematic literature review (SLR) approach to analyze and compare the effectiveness of Reliability-Centered Maintenance (RCM) and Preventive Maintenance (PM) in relation to maintenance costs and operational risks. This strategy was chosen to obtain a comprehensive understanding based on empirical data across various industrial sectors. Data were collected from international peer-reviewed journals published between 2015 and 2025, using search terms such as *"Reliability Centered Maintenance," "Preventive Maintenance," "RCM vs PM," "maintenance cost," "downtime," "availability,"* and *"maintenance risk."* The sources were obtained from reputable databases, including ScienceDirect, Springer, MDPI, IEEE, arXiv, and others.

After gathering all relevant data from the selected studies, an analysis was conducted to evaluate the effectiveness of RCM and PM implementations. The comparison was based on key maintenance performance indicators such as cost, failure risk level, downtime, and system reliability. The results were then summarized to identify the most effective and efficient maintenance approach across different industrial contexts.

## 3. Results and Discussions

### *3.1 Tools for Developing RCM Strategies*

Tools in Reliability-Centered Maintenance (RCM) refer to a set of analytical methods, systematic techniques, and data-driven approaches designed to assist maintenance teams in identifying, evaluating, and determining the most appropriate maintenance strategies for each equipment function (18).

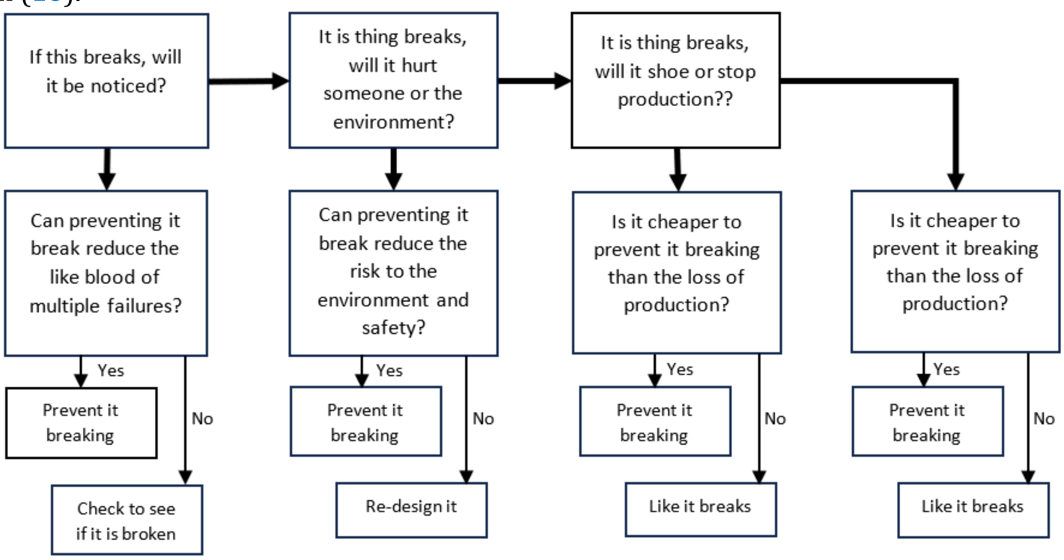


**Figure 1.** RCM decision diagram (19)

*a. Decision diagrams & RCM Worksheet*

A Decision Diagram is a logical flowchart used to assist in the decision-making process regarding the most appropriate maintenance action based on the type of failure mode, its impact, and the consequences of the failure (19).

*b. Failure mode and effects analysis*

It is a widely used risk management tool for identifying potential failure modes, their effects, and for developing mitigation strategies based on the severity, frequency, and detectability of the failures (20).

**Table 1**. FMEA worksheet (21)

| System : | | | | | | Report no : | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Component : | | | | | | Prepared By : | | | | | |
| Team : | | | | | | Date : | | | | | |
| Fail mode | Fail Cause | Fail Effect | Ctrl Mech | S | O | D | RPN | Priority | WRPN | New Priority | Action Required |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | | | | | | | | | | | |

*c. Risk control matrix*

The Risk Control Matrix generally refers to a tabular tool that links the likelihood and consequences of a failure in order to classify and prioritize risks (22).

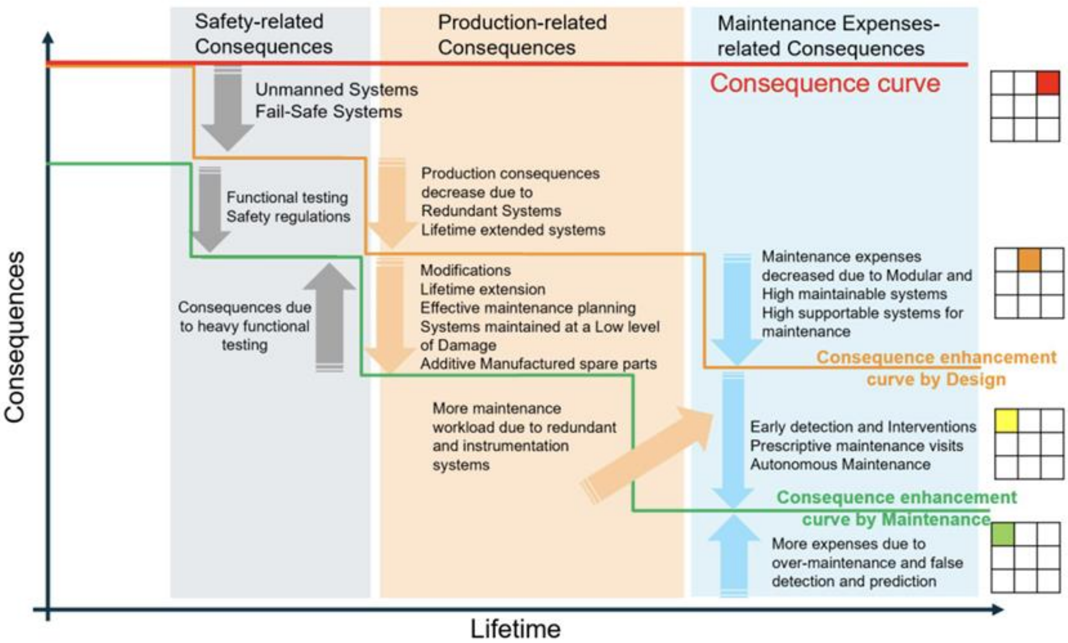


**Figure 2.** Relationship between Consequence and Probability (Lifetime) (22)

*d. Fault tree analysis*

Fault Tree Analysis (FTA) is a qualitative and quantitative analysis method used to identify and visualize the logical relationships between component-level failures (*basic events*) and system-level failures (*top event*) by using logic gates such as AND and OR (23).

*e. Predictive Testing & Inspection*

It is a condition-based maintenance method that relies on the actual condition of the machine, rather than following a fixed time schedule like Preventive Maintenance (PM). This approach involves monitoring parameters such as vibration, temperature, pressure, and others (24).

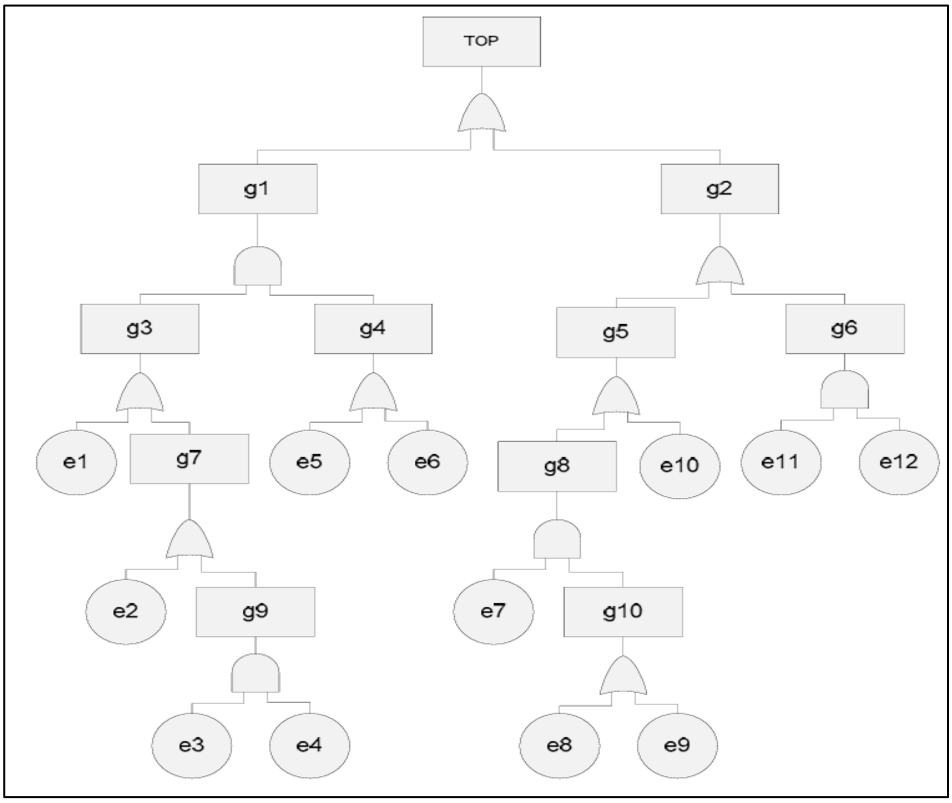


**Figure 3.** Fault Tree analysis example (24)

### *3.2 Maintenance Cost Effectiveness*

The findings of this review indicate that the Reliability-Centered Maintenance (RCM) approach generally offers significant cost efficiency compared to Preventive Maintenance (PM). Several studies have reported that RCM implementation can reduce total maintenance costs by 20% to 70%, depending on system complexity and the specific industrial sector (25, 26). In contrast, PM tends to incur higher costs due to the replacement of components that have not yet failed (over-maintenance) or delayed response to failures (under-maintenance) (27). RCM optimized with FMEA and hotline/coldline strategies has been shown to reduce total maintenance and outage costs by at least 7%, compared to conventional PM strategies (28). Moreover, RCM that incorporates stochastic programming for multi-component systems demonstrates that group-based maintenance scheduling can achieve significantly higher cost efficiency than static PM, with improvements ranging from 10% to 20%, depending on system complexity and the number of components involved (29).

**Table 2.** Maintenance cost efficiency: PM vs. RCM

| No | Industrial Context | Cost Efficiency (%) |
|---|---|---|
| 1 | Diesel Power Plant | 40 |
| 2 | Transmission Substation | 70 |
| 3 | Sugar Industry | 52 |
| 4 | Autonomous Truck | 47 |
| 5 | Maritime Industry | 37 |
| 6 | Textile Boiler | 20.32 |
| 7 | Manufacturing Industry | 30 |

### *3.3 Risk and Downtime Reduction*

One of the key advantages of Reliability-Centered Maintenance (RCM) is its ability to reduce the risk of critical system failures. Several studies have shown that RCM can reduce unplanned downtime by up to 55.77%, and improve system performance metrics, such as Mean Time Between Failure (MTBF), by up to 37% (7, 8, 30). This is partly achieved because RCM enables the development of a failure database that allows for more accurate diagnosis compared to PM (31). Risk-based RCM implementation in autonomous vehicles has been shown to reduce economic risk by up to 47% (32).

The competence of maintenance technicians also plays a significant role in maintenance effectiveness, where appropriate training can contribute to simultaneously reducing costs and system failure risks.

RCM emphasizes condition-based maintenance and failure analysis, rather than time-based schedules, enabling maintenance interventions to be carried out at the most technically and economically effective moments.

**Table 3.** Downtime reduction: PM vs. RCM

| No | Industrial Context | Downtime Reduction (%) |
|---|---|---|
| 1 | Sugar Industry | 55.77 |
| 2 | Food & Beverage Industry | 30 |
| 3 | Maritime Industry | 40 |

### *3.4 Improvement in Availability*

The implementation of Reliability-Centered Maintenance (RCM) also has a direct impact on improving system reliability and availability. A study conducted on a sugar production system reported an increase in availability from 57% to 90% following the implementation of an RCM framework based on FMECA and criticality analysis (7). CM systematically filters components that have a high impact on the core functions of a system, allowing maintenance actions to be more targeted and reducing recurring failures (33).

### *3.5 Challenges in Implementing RCM*

Despite its positive outcomes, the implementation of RCM in industrial settings also faces several challenges. These include the need for accurate historical data, strong technical analysis capabilities, and initial investments in workforce training and supporting systems (34). Moreover, not all types of assets require RCM; for low-risk assets with low replacement costs, Preventive Maintenance (PM) is still considered sufficiently efficient (34, 35).

### *3.6 Potential of Hybrid Strategies and Digital Integration*

Recent studies encourage the adoption of hybrid maintenance strategies that combine RCM, Preventive Maintenance (PM), and data-driven predictive approaches (*Predictive Maintenance/PdM*) to align maintenance strategies with asset characteristics and organizational capabilities. This approach is becoming increasingly relevant in the context of Industry 4.0, where the integration of sensor data, artificial intelligence (AI), and digital systems enables more adaptive, efficient, and real-time maintenance planning (35, 37).

The development of RCM support systems through the fuzzy-RCM approach, which allows for PM scheduling even with incomplete failure data, has been shown to reduce maintenance budget by 40% annually (38). In another study, the integration of RCM with Acoustic Fiber Optic (AFO) monitoring in prestressed concrete pipe systems was able to predict failures up to two years earlier than conventional PM methods (39).

## 4. Conclusions

Reliability-Centered Maintenance (RCM) has proven to be a more effective and efficient maintenance approach compared to Preventive Maintenance (PM) across various industrial sectors, particularly in terms of cost efficiency and operational risk reduction. Based on the literature review, the implementation of RCM can reduce maintenance costs by up to 70%, decrease unplanned downtime by up to 55.77%, and improve system reliability and availability from 57% to 90%. In addition, in certain industrial applications such as autonomous systems, RCM has also been shown to reduce economic risk by up to 47%. Beyond cost efficiency, RCM has demonstrated its effectiveness in significantly reducing maintenance-related risks, including potential failures of critical functions, unexpected incidents, and systemic operational losses. The main advantage of RCM lies in its approach, which is based on functional analysis, actual equipment conditions, and failure risk evaluation. This enables maintenance strategies to be more precisely targeted and aligned with real operational needs. However, the success of RCM implementation heavily depends on the quality of historical data, the technical competence of the maintenance team, and the readiness of supporting systems. Therefore, the selection of an appropriate maintenance strategy should take into account asset characteristics, risk levels, and organizational capacity. In practice, integrating RCM with conventional PM and data-driven predictive technologies can offer an adaptive solution for achieving sustainable efficiency, risk control, and maintenance reliability.

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