Reliability-Centered Maintenance Strategies in Mechanical Systems: An Operational Management Perspective

Muhammad Awais Bhatti[1*], Jamshid Pardaev[2]
[1] Management Department, School of Business, King Faisal University, Al-Ahsa 31982, Saudi Arabia
[2] Associate Professor of Finance and Tourism Department, Termez University of Economics and Service, Uzbekistan

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ABSTRACT

Purpose: This study aims to examine the influence of reliability centered maintenance (RCM) challenges on operational performance and overall equipment efficiency within mechanical systems, while also exploring the mediating role of maintenance system availability and effectiveness and the moderating role of top management support. The research provides a comprehensive understanding of how technical and managerial factors jointly shape maintenance outcomes in industrial environments. Method: A quantitative research design was employed, and data were collected from 225 mechanical and maintenance professionals working in industrial organizations. Established measurement scales from prior studies were used, and statistical analyses were conducted using SPSS to assess descriptive statistics, reliability, correlations, and structural relationships. Findings: Results reveal that RCM challenges significantly reduce both operational performance and overall equipment efficiency. The availability and effectiveness of the mechanical maintenance system were found to mediate these relationships, demonstrating their critical role in translating maintenance challenges into performance outcomes. Additionally, top management support significantly moderated the effects of the maintenance system on both operational and equipment efficiency. Originality/Implications: This study contributes to maintenance and operations management literature by integrating technical challenges, maintenance capability, and managerial support within a single empirical framework. The findings offer practical guidance for organizations seeking to enhance mechanical reliability and operational excellence through improved maintenance strategies and stronger leadership commitment.

Corresponding Author:

Muhammad Awais Bhatti
Management Department, School of Business, King Faisal University, Al-Ahsa 31982, Saudi Arabia
Email: mbhatti@kfu.edu.sa

1. Introduction

The sphere of maintenance of mechanical systems has become more and more popular due to the growing pressure on the industries to improve the productivity, guarantee the continuation of the work, and reduce the number of the failures connected with the equipment (Nugroho & Sukmono, 2024). In the last twenty years, the competitiveness of industries in the world has driven organizations to take up structured maintenance philosophies which extend beyond reactive maintenance and aim towards reliability, optimization, and long-term management of assets. RCM is one of these strategies allowing to merge engineering logic with the operational management practice to enhance the performance of the system and minimize any unexpected downtime (Geisbush & Ariaratnam, 2023). Direct relationships that support mechanical systems in manufacturing process and energy industries are: due to the complexity of the equipment, sensitivity of the work, and the financial implication of the disruption of working processes, effective maintenance strategies are of paramount importance (Lin et al., 2024). With organizations growing automation and high-tech machinery, the effectiveness of equipment and continuity in work have become the main priorities of maintaining a competitive edge, which again emphasizes the significance of researching the issues in RCM, in the context of operation (Simion et al., 2024).

Empirical studies on the topic of maintenance engineering reveal that the problems of poor maintenance planning, insufficient diagnostic abilities, lack of skills, and available resources have a considerable impact on the performance of mechanical assets(Adebisi et al., 2023; Nugroho & Sukmono, 2024). Research has been showing that organizations that have incessant maintenance challenges, have high downtimes, decreased production throughput, and also high operational expenses (Jena et al., 2024). Researchers also note that RCM issues do not only impact the continuity of operations but also the efficiency of the equipment in terms of availability and performance rate and quality of output (Yang et al., 2024). Previous research indicates that maintenance cycles are distorted, preventive maintenance is undermined, and the reliability of assets is lost because of the unresolved maintenance concerns, which, in turn, influence the performance of operations and the overall efficiency of equipment. Such empirical findings highlight the necessity of exploring the interaction between maintenance challenges and maintenance system capabilities in order to influence the organization performance in the mechanical setting.

Even though there is an increasing literature, significant gaps exist in the knowledge of how the issue of maintenance is converted to operational and equipment-level performance outcomes. Most of the previous literature has been on the individual components of RCM, including condition monitoring or preventive maintenance, without considering the overall impact of multi-dimensional issues on the overall performance indicators in an organization (Moradi-Sarvestani et al., 2024). Also, previous studies tend to view maintenance as a rather technical process without the consideration of the role of management support, organizational alignment, and system effectiveness as the essential elements that determine the relationship between performance (Geisbush & Ariaratnam, 2023). Scarcity of empirical research has investigated the mediating role of maintenance system availability and effectiveness in connecting between maintenance challenges and performance results with a gap in knowledge regarding the inner processes by which such challenges influence the organizations (Biswas, 2024). Equally, the moderating impact of top management support has not been adequately studied, and it has also been identified that there is evidence that leadership commitment enhances maintenance performance and assists equipment reliability (Uhanto et al., 2024). The mentioned gaps show that the complex of challenges should be approached with a fully-fledged model that incorporates technical challenges, system effectiveness, and managerial support within one framework.

Based on these theoretical implications, the research questions of the given research are to determine how RCM challenges affect operational performance and the overall equipment efficiency, the mediating impact of the maintenance system availability and efficiency, and the moderating influence of the top management support in the context of the offered conceptual framework**.**

2. Literature Review

2.1 RCM Challenges and Operational Performance

Mechanical systems RCM challenges are the operational, technical, and organizational impediments which inhibit the successful practice of the maintenance strategies aimed at maintaining the systems reliability (Simion et al., 2024). These issues can be insufficient diagnostic technology, shortage of qualified maintenance personnel, weak organizational support, unavailability of sufficient data that can be used to analyze failure, and the complexity of mechanical components. Operational performance, however, refers to the efficiency, the productivity and general functional efficiency of mechanical activities of an organization. The indicators used to measure it are normally system availability, less downtime, production continuity, cost efficiency, and compliance to quality and safety standards (Lee et al., 2024). The value of maintenance functions in the operational excellence has been confirmed in the past, where research findings suggested that the limitation in the maintenance planning, condition monitoring, and resource allocations directly affect the performance of the mechanical systems (He et al., 2024). Indicators of manufacturing and industrial settings show that when maintenance problems are not resolved successfully, organizations will suffer more breakdowns of their machines, inconsistent maintenance schedules, and elevated operating expenses, which affect the organizational operational objectives (Liew et al., 2024). Empirical data always points towards the fact that organizations that experience issues with RCM are also likely to fail to have a stable and efficient operational outcomes (Adebisi et al., 2023). Research proves that mean time to repair is delayed, there is a deficit of skills, and poor failure prediction, which leads to higher mean time to repair and lower mean time between failures and often interruptions in production (Jena et al., 2024). It is also indicated by research that ineffective practices in implementing the RCM undermines decision making in terms of managing assets thus resulting in a mismatch between the maintenance schedule and the critical production requirements (Yang et al., 2024). These results are a good indication of the theorizing of a strong relationship between maintenance challenges and operational performance. Operational processes are exposed to inefficiencies and disruptions when mechanical systems are not serviced based on the reliability centered principles.

H1: RCM challenges in mechanical system have significant impact on operational performance.

2.2 RCM Challenges and Overall Equipment Efficiency

Overall equipment efficiency represents a comprehensive indicator that measures the effectiveness of equipment based on availability, performance, and quality outputs. It is very common in mechanical and industrial working environment to give an assessment of the contribution of machines in production efficiency (Yang et al., 2024). Empirical studies have continually revealed that issues related to RCM have adverse effects on key performance measures of equipment efficiency in both mechanical and industrial system activities (Kechaou et al., 2024; Sobirov, 2025; Soygüder & Karaduman, 2024). Research in the manufacturing and processing industries determined that delays in maintenance systems, low predictive effectiveness and unreliable failure diagnostic leads to increased machine downtimes and a decreased speed of operation (Reddy et al., 2025). It has also been indicated that there are loopholes in the implementation of structured maintenance systems resulting in further degradation of the equipment, ineffective maintenance cycles, and more variation in the output of machines (Geisbush & Ariaratnam, 2023). The previous research highlights that organizations having issues in maintenance planning or using crude tools of monitoring have regular slowdowns of equipment, decreased stability of its operation, and spoiled production quality. All of these studies emphasize that the issue of maintenance is not a secluded operational challenge but a continuous obstacle that directly influences the efficiency of equipment and productivity (Machingura et al., 2024). With this empirical background it is evident that maintenance issues cause a cascading effect to equipment efficiency by affecting availability, performance rates and quality parameters (Jena et al., 2024). It has been found that unresolved maintenance problems are also some of the contributors towards the extended repair periods, more occurrences of stoppage and lesser production throughput, which are fundamental aspects of the overall equipment efficiency. Moreover, research has also shown that equipment used in unreliable or reactive maintenance systems will exhibit negative efficiency trends with time because of the wear and tear, as well as ineffective restoration processes. This is the reason why this body of evidence supports the argument that maintenance issues have a significant effect on the efficiency of the currently used equipment in actual working conditions.

H2: RCM challenges in mechanical system have significant impact on overall equipment efficiency.

2.3 Availability and Effectiveness of the Mechanical Maintenance System as Mediator

Availability and effectiveness of the mechanical maintenance system is the ability of the organization to maintain equipment in a working state by facilitating timely, efficient and well-coordinated maintenance programs (Biswas, 2024). These encompass capability to minimize equipment downtimes, prompt fault detection, uniform repair quality, and proactive measures that would maintain the mechanical reliability (Moradi-Sarvestani et al., 2024). The existing studies show that the greater the availability and efficacy of the maintenance systems, the more the organizations are capable of managing the disruption, reducing the uncertainty in the operation, and ensuring the continuous production processes (Uhanto et al., 2024). Research studies on maintenance performance in industrial and manufacturing industries have stated that the effectiveness of a maintenance system is very strong to increase the system uptime and help maintain consistent operational performance (Jardine & Wiseman, 2024; Jena et al., 2024; Udo et al., 2024). On the other hand, in the cases when the RCM problems, such as lack of skills, low diagnostic quality, or ineffective maintenance planning, occur, the efficiency and accessibility of mechanical maintenance systems deteriorate (Shandookh et al., 2024). This leads to increased breakdown times, uneven system cycles and decreased system responsiveness, which eventually undermine the productivity of operations.

It is also shown by empirical evidence that the impact of maintenance challenges on the operational performance is usually indirect and operates via the mediator of maintenance system availability and efficacy (Shandookh et al., 2024). Findings of the research indicate that although organizations may have technical and managerial problems to implement RCM, the operational losses are very much pronounced when these problems undermine the capability of the maintenance system to ensure that machines remain functional (Erhueh et al., 2024). Research in the field of maintenance engineering and operational management consistently demonstrates that properly ordered maintenance systems are able to moderate or recap some of the impacts of the RCM difficulties by upholding a steady service quality, downtime and uninterrupted manufacturing capacities (Bello et al., 2024). This empirical evidence forms the basis of the suggestion of the mediating role played by availability and effectiveness (Simion et al., 2024). The adverse effects of RCM challenges on the operational performance are less when the mechanical maintenance systems are efficient. Nevertheless, the issues in the case of ineffective maintenance system as a result of these challenges greatly influence operational performance.

H3: Availability and effectiveness of the mechanical maintenance system mediate the relationship between RCM challenges in mechanical system and operational performance.

Empirical studies conducted in the past indicate that the issues involved in RCM have led to operational pressures that compromise the operation of maintenance systems, which eventually affects the performances of equipment(Alkabaa et al., 2024; Sunny, 2025). The research on the field of industrial engineering always brings to the fore the fact that in case organizations have challenges, in the form of inefficient maintenance planning, low diagnostic accuracy, inconsistent scheduling, or insufficient maintenance resources, the responsiveness and coordination of mechanical maintenance systems will suffer. Scientists have reported that such difficulties result in delays in solving equipment failures, increased time of fixing equipment, and dispensable maintenance (Jardine & Wiseman, 2024). The previous research further shows that maintenance disruption is a major causative factor of the variation in the availability and performance of equipment, which are essential aspects regarding equipment effectiveness (Yang et al., 2024). The experience in manufacturing industries proves that in case the operation of the maintenance systems is interrupted by the constant RCM issues, the equipment is more likely to be subjected to numerous stoppages and less extensive functioning (Kumaresan et al., 2024).

The functional process of the maintenance system also suggests an indirect route of connecting the maintenance issues to the equipment performance to the empirical literature (Nugroho & Sukmono, 2024). According to researchers, although the effects of RCM challenges negatively affect equipment performance, their cumulative effect is observed when the challenges undermine the capability of the maintenance system to maintain the performance of equipment (Jardine & Wiseman, 2024). Some researchers have determined that the best maintenance systems are able to help alleviate some of the adverse effects of the challenges encountered in RCM through the consistency of service quality, downtime, and production speeds remaining at a steady level (Machingura et al., 2024). But as the system turns ineffective as a result of the continued challenges, the equipment will have increased downtime and decreased performance rates with more unpredictable quality outputs. All these findings are indicative of the fact that the maintenance system is an agent so as through which the RCM challenges can influence the efficiency of the equipment.

H4: Availability and effectiveness of the mechanical maintenance system mediate the relationship between RCM challenges in mechanical system and overall equipment efficiency.

2.4 Top Management Support as Moderator

Top management support can be defined as the level to which the top management is committed, allocates resources and sets organizational priorities that will facilitate effective maintenance and operational functions (AGEEB et al., 2024). It incorporates measures like proper budgetary allocations, investments in the new diagnostic equipment, empowering maintenance team, timely decision making, and the culture of reliability and unrelenting improvement of the system (Orjatsalo et al., 2024). The previous studies have always emphasized that high managerial commitment will increase the effectiveness of maintenance practices by decreasing the structural obstacles, improving communication and aligning the maintenance objectives with the overall organizational objectives (Jaran & Ali, 2025; Shah et al., 2024; Xue et al., 2024). Research in industrial and operational management has revealed that organizations that have a high managerial support have more stabilized workflow, faster response to maintenance and coordination among technical personnel, which in turn facilitates an easier operational performance (Alsheikh et al., 2025).

Empirical data also proves that the performance of a mechanical maintenance system is not self-sufficing but greatly depends on the level of support of the top management. Researchers have noted that as the management actively promotes maintenance processes, the beneficial effects of the availability of system and its effectiveness on organizational outcomes are magnified (Bhatti et al., 2025). Maintenance planning along with preventative strategy implementation and cross-department cooperation facilitation by the supportive leadership makes the maintenance systems work more effectively (AGEEB et al., 2024). This heightened operational preparedness will be reflected in the decrease of production interrupts and enhanced utilization of mechanical resources (Al-Husseini, 2024). Conversely, a reduced level of managerial participation undermines the capacity of an efficient maintenance system to play its full part in establishing operational stability as the maintenance teams might not have the resources or authority to deal with any issues on time (Shah et al., 2024).

The moderating role of top management support is also evident in empirical results associated with outcomes at equipment levels (Alsheikh et al., 2025). Research indicates that much of the equipment efficiency that reflects the availability, performance, and quality are very reliant on the organizational strategies that are formed at the management level (AGEEB et al., 2024). When maintenance excellence is a high priority of top management, condition monitoring technologies are invested in, and timely repairs supported, the positive results of an efficient maintenance system can be easier observed in terms of equipment efficiency (Orjatsalo et al., 2024). Good managerial support is an addition that leads to increased capability of the maintenance system into better use of equipment, less downtime, and stable performance levels.

H5: Top management support moderates the relationship between availability and effectiveness of the mechanical maintenance system and operational performance.

H6: Top management support moderates the relationship between availability and effectiveness of the mechanical maintenance system and overall equipment efficiency.

2.5 Theoretical Framework Supporting the Research

The associations that are suggested in this model of research can be discussed in terms of the Resource-Based View and Socio-Technical Systems Theory that contribute to a good theoretical framework of how the maintenance issues, system efficiency and organizational support influence the operational results. Resource-Based View holds that performance of an organization is based on the strategic usage of assets that are very valuable, rare, and hard to substitute such as maintenance capabilities, technical experience, and managerial dedication (Barney, 2001; Wernerfelt, 1984). In this sense, a powerful mechanical maintenance system can be considered a tactical internal asset making it more reliable, less downtime, and ensuring the work performance and the efficiency of equipment. Socio-Technical Systems Theory additionally states that technical subsystems of mechanical devices and maintenance technology interrelate with social subsystems of leadership, knowledgeable personnel and organizational support systems to play an important role in the overall system operations (Pasmore, 1988; Trist & Bamforth, 1951). In cases where RCM challenges cause a pressure on the technical system, maintenance system performance becomes a critical process by which the effects of the disruption are felt in terms of performance outcomes. Simultaneously, the top management support is a social contextual variable enhancing the correspondence between the technical processes of maintenance and the organizational objectives, moderating the influence of technical maintenance effectiveness on operational and equipment's efficiency. These theories combined help explain how internal capabilities, technical processes, and managerial support combine to establish performance in mechanical systems as most of the theories hold to the conceptual framework proposed in Figure 1.

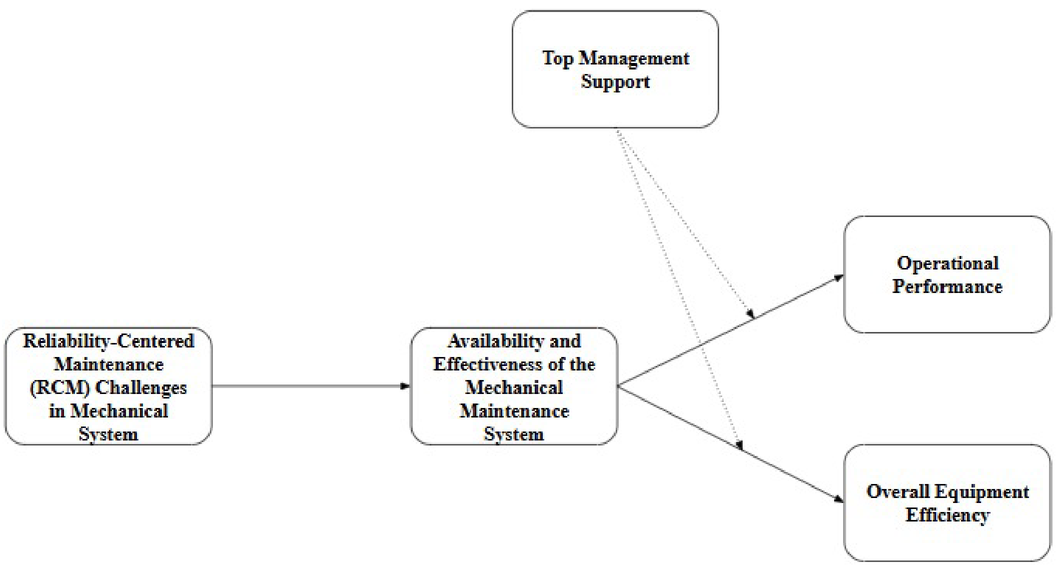

Figure 1: Conceptual Framework

3. Methodology

The research adopted a quantitative research design as an empirical study of the relationship between RCM challenges, the effectiveness of maintenance system, top management support, and performance results in mechanical systems. The main data collection instrument was a structured questionnaire, and it was necessary to allow the systematic measurement of all constructs through validated scales borrowed in the previous academic literature. The target population of the study was the employees who were employed in the mechanical maintenance, engineering, and operations department of various industrial organizations. These respondents were chosen due to the fact they had pertinent technical and managerial experience which would help them make informed appraisals on maintenance practices, and system performance. The respondents who took part in the research were 225, which is enough to perform strong statistical calculations and stable multivariate outcomes. The sampling strategy contributed to the fact that different industrial sectors were represented, and thus, findings derived were more applicable in the general mechanical maintenance.

The measuring tool included five scales that have been developed out of the earlier studies. Measurement The scale created by (Anwer et al., 2019) was used to measure the challenges associated with RCM in terms of multidimensional maintenance constraints associated with diagnostics, planning, competence, and resource sufficiency. Items borrowed through (Oluwatobi et al., 2019) were used to evaluate the availability of the maintenance system construct and its effectiveness in terms of the efficiency of the maintenance processes in guaranteeing system reliability and reducing downtimes. A validated scale of (Alkhatib & Momani, 2023) that measured operational performance was used to evaluate such aspects as production continuity, speed, and operational consistency. The total equipment efficiency was measured with the help of the well-known measurement framework suggested by (Parida & Chattopadhyay, 2007), which determines the availability of equipment, equipment performance rate, and quality of the products. Finally, the scale of the top management support was assessed, based on the issues of (Hassan & Yazid, 2019) which included leadership commitment, providing resources, and aligning an organization with maintenance initiatives. Each of the items was evaluated based on a five-point Likert scale, which includes strongly disagree, strongly agree, and the rest, which made it easy to quantify the perceptions of the respondents.

The SPSS data analysis program was used which allowed thorough evaluation of the measurement and structural variables of the study. Descriptive analysis like means, SD, min, and max were presented as preliminary data analysis to give a picture of the data. The appropriateness of the data to continue with the statistical tests was established by normality tests based on the values of skewness and kurtosis. Internal consistency was assessed by conducting reliability tests based on Cronbachs Alpha which also made sure that the respective constructs showed good levels of reliability at the mark of 0.70 and above. It was followed by correlation analysis, which was conducted to investigate the direction and strength of the relationships between the variables. Path analysis and testing of hypothesis were used to determine the direct and mediating effects as well as moderating effect postulated in the conceptual model. The statistical significance, effect sizes and model strength could be accurately estimated using SPSS and therefore the results were reliable and analytically sound. This methodological approach contributed to the study by enabling it to produce empirical data that would relate maintenance issues, organizational support and system performance in the environment of mechanical maintenance.

4. Results

Table 1 shows the descriptive statistics of all the major variables used in the study, their mean value, standard deviation, and minimum and maximum values. The findings reveal that the mean for the RCM obstacles is 3.421 (SD = 0.764), indicating a moderate existence of the problems related to maintenance in the mechanical systems which were under study. The availability and effectiveness of the maintenance system have a slightly higher mean of 3.673 (SD =0.812) suggesting that maintenance processes are viewed to be at a moderately effective level despite the existence of challenges. The mean of operational performance is 3.884 with SD = 0.718 indicating quite positive operational performance in the participating organizations. Total equipment efficiency reveals a mean of 3.742 (SD = 0.786), indicating that the performance indicators that refer to equipment level (availability, performance rate, and output quality) are mostly above the average. Lastly, the top management support has the highest mean value of 3.953 (SD = 0.694), which implies that there is a strong involvement of the top management and organizational support to the maintenance and operation functions. The lowest and the highest of the variables ensure that the responses fall within the whole scale having a lot of variances across organisations.

Table 1: Descriptive Statistics

Variables	Mean	Standard Deviation	Minimum	Maximum
RCM Challenges	3.421	0.764	1.200	5.000
Availability and Effectiveness of Maintenance System	3.673	0.812	1.000	5.000
Operational Performance	3.884	0.718	1.400	5.000
Overall Equipment Efficiency	3.742	0.786	1.300	5.000
Top Management Support	3.953	0.694	1.600	5.000

Table 2 indicates the skewness and kurtosis figures to examine the normality of the data distributions. Both skewness and kurtosis within the acceptable range of ±1, which shows that the data set is normal to be analyzed in multiple variables. The skewness and kurtosis of RCM challenges are a bit negative with skew = -0.214 and kurtosis = -0.476 which is an indication of a slight left skewness. The negative skewness (–0.328) and kurtosis (–0.271) also indicate the similarity in the form of distribution as shown by the availability and effectiveness of the maintenance system. The operational performance is skewed as the skewness is almost equal (-0.112) and the kurtosis is also negative (-0.347). Similarly, the general equipment efficiency (skewness = -0.291; kurtosis = -0.405) and the top management support (skewness = -0.437; kurtosis = -0.186) indicate that there is a slight deviation but it is still within the acceptable range.

Table 2: Normality Assessment

Variables	Skewness	Kurtosis
RCM Challenges	-0.214	-0.476
Availability and Effectiveness of Maintenance System	-0.328	-0.271
Operational Performance	-0.112	-0.347
Overall Equipment Efficiency	-0.291	-0.405
Top Management Support	-0.437	-0.186

Table 3 assesses the internal consistency and convergent validity on Cronbach's Alpha, Composite Reliability (CR) and Average Variance Extracted (AVE). Constructs all show high levels of reliability, and the values of Cronbachs Alpha are between 0.853 and 0.892, which is above the 0.70 recommended level. The values of Composite Reliability are also good and are between 0.884 and 0.917 which proves that every construct is always able to measure the theoretical concept behind it. AVE values range between 0.603 and 0.681 that is greater than the recommended cutoff, 0.50, implying that every construct defines greater than half of the variance of its indicators. All these findings are indicative that the measurement model has been shown to have reliability and convergent validity, which form a very solid basis to do any additional structural analysis.

Table 3: Construct Reliability and Validity

Construct	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
RCM Challenges	0.873	0.902	0.627
Availability and Effectiveness of Maintenance System	0.892	0.917	0.681
Operational Performance	0.853	0.884	0.612
Overall Equipment Efficiency	0.881	0.908	0.664
Top Management Support	0.864	0.893	0.603

The correlation coefficients of all variables are shown in Table 4. The statistical data of RCM challenges show a negative correlation with all other variables, such as the maintenance system (r = -0.512), operational performance (r = -0.473), top management support (r = -0.324), and overall equipment efficiency (r = -0.451), which point out that the higher the maintenance challenge, the worse the results. Operational performance (r = 0.628), top management support (r = 0.557), and overall equipment efficiency (r = 0.603) have a positive correlation with the availability and effectiveness of the maintenance system, which places it in the center of positive results of performance. There are also high positive correlations between operational performance and top management support (r = 0.604) and overall equipment efficiency (r = 0.691), which indicates that there is alignment between the organizational, operational, and equipment performance. The correlation pattern in general supports the fact that the variables are not only significantly correlated but they also respond in a theoretically expected manner.

Table 4: Correlation Analysis

Variables	1	2	3	4	5
1. RCM Challenges	1				
2. Availability and Effectiveness of Maintenance System	-0.512	1			
3. Operational Performance	-0.473	0.628	1		
4. Top Management Support	-0.324	0.557	0.604	1	
5. Overall Equipment Efficiency	-0.451	0.603	0.691	0.544	1

The outer loading of all measurement items is also reported in Table 5 and it shows the extent to which the item is representative of its construct. Indicators all fall within the recommended loading of 0.70, which shows high item reliability. RCM challenges have an item loading of 0.752 to 0.835 that validates consistency in the measurement of challenges of maintenance. The loadings of the operational performance construct are the range of 0.744-831, which represents highly the operational efficiency and effectiveness. The load of items that gauge the availability and effectiveness of the maintenance system lies between 0.768 and 0.842 confirming the strength of this construct. Top management support items indicate loadings of 0.773 to 0.835 with high as well reflection of the leadership involvement and organizational commitment. Lastly, the overall equipment efficiency items load with high efficiency ranging between 0.842 and 0.873 with the most focus on reliability of metrics that measure equipment performance.

All these findings allow forming a high measurement quality of all constructs.

Table 5: Outer Loadings

Construct	Item Code	Loading
RCM Challenges	RCM1	0.771
	RCM2	0.804
	RCM3	0.823
	RCM4	0.789
	RCM5	0.752
	RCM6	0.811
	RCM7	0.768
	RCM8	0.835
	RCM9	0.792
Operational Performance	OP1	0.744
	OP2	0.781
	OP3	0.812
	OP4	0.765
	OP5	0.798
	OP6	0.826
	OP7	0.773
	OP8	0.804
	OP9	0.831
	OP10	0.782
	OP11	0.755
Availability and Effectiveness of the Maintenance Management System	AMMS1	0.814
	AMMS2	0.842
	AMMS3	0.768
	AMMS4	0.831
	AMMS5	0.792
	AMMS6	0.807
Top Management Support	TMS1	0.773
	TMS2	0.821
	TMS3	0.784
	TMS4	0.798
	TMS5	0.835
	TMS6	0.806
Overall Equipment Efficiency	OEE1	0.842
	OEE2	0.873
	OEE3	0.861

Table 6 presents the results of the structural model testing the hypothesized relationships. All hypotheses are supported with statistically significant results ($p < 0.01$). The direct effects show that RCM challenges negatively impact operational performance ($\beta = –0.411$, $t = 6.238$) and overall equipment efficiency ($\beta = –0.387$, $t = 5.947$), confirming the detrimental influence of maintenance challenges. The mediation pathways reveal that maintenance system availability and effectiveness mediate the relationship between RCM challenges and operational performance ($\beta = –0.324$, $t = 6.581$) and between challenges and equipment efficiency ($\beta = –0.348$, $t = 7.004$), demonstrating its crucial role as an internal mechanism. The moderation results show that top management support strengthens the relationship between maintenance system effectiveness and operational performance ($\beta = 0.174$, $t = 3.421$) as well as equipment efficiency ($\beta = 0.162$, $t = 3.118$), suggesting that leadership involvement enhances the positive effects of a strong maintenance system. Overall, the structural model provides comprehensive support for the theoretical framework.

Table 6: Path Analysis

Hypothesis	Path Description	Beta (β)	T-Value	P-Value	Result
H1	RCM Challenges → Operational Performance	-0.411	6.238	0.000	Supported
H2	RCM Challenges → Overall Equipment Efficiency	-0.387	5.947	0.000	Supported
H3	RCM Challenges → Availability and Effectiveness of the Maintenance System → Operational Performance	-0.324	6.581	0.000	Supported
H4	RCM Challenges → Availability and Effectiveness of the Maintenance System → Overall Equipment Efficiency	-0.348	7.004	0.000	Supported
H5	Availability and Effectiveness of the Maintenance System × Top Management Support → Operational Performance	0.174	3.421	0.001	Supported
H6	Availability and Effectiveness of the Maintenance System × Top Management Support → Overall Equipment Efficiency	0.162	3.118	0.002	Supported

5. Discussion

This work has produced an overall and insightful insight into the dynamics of RCM that would influence operational and equipment-level results in mechanical systems. Since the industries are becoming highly reliant on complex machinery and technologically advanced production lines, the capacity to effectively oversee the maintenance processes turns out to be not only a technical necessity but a strategic facilitator of organizational success. The results of the current study are strong empirical evidence of the first hypothesis which has proved the challenges of RCM to have a substantial impact on the operational performance of mechanical systems. This finding is consistent with earlier studies that have proposed such barriers as insufficient predictive maintenance, lack of diagnostic equipment, poorly formulated maintenance planning, and lack of technical skills to cause operational inefficiency and vulnerability to the system (Alkabaa et al., 2024; Yang et al., 2024). The findings are that in cases where organizations have the persistent maintenance problems, it leads to increased downtime, the continuity of production and increased problems in attaining operational stability. This data supports the need to engage in systematic maintenance procedures as well as proves that maintenance problems are not technical factors in isolation, but strategic determinants directly influencing the proper organization of organizational activities. The fact that the first hypothesis was accepted also demonstrates the importance of the maintenance integration in the context of higher-level operational decision-making and corroborates the research that regards maintenance as a central element of operational excellence as opposed to marginal support role (Yuan & Huang, 2024).

The second hypothesis that the effects of the RCM challenges can have a significant impact on the overall equipment efficiency was also accepted and supported the evidence that the maintenance problem is not just an operational issue but it directly affects the performance of the equipment. This result aligns with the previous research that has made it clear that inappropriately controlled maintenance conditions culminate in the decreased availability of equipment, loss of performance, and poor quality of output among others (Alkhatib & Momani, 2023). The findings indicate that ineffective condition monitoring, slow repair procedures, and poor consistency of preventive maintenance processes are some challenges that decrease the overall efficiency of equipment by promoting the frequency and duration of equipment stoppages. This aligns with the previous studies revealing that efficiency indicators, like the availability of equipment, its rate of performance, and quality, are the most delicate factors to the state of a maintenance system and can deteriorate in the shortest possible time in case the problems of RCM still exist (CHUKWUNWEIKE et al., 2024). The fact that this hypothesis is accepted contributes to the significance of the findings, proving that the problem of maintenance has a multidimensional impact on organizations on both the operation performance level and the efficiency of equipment at the same time. The results drive the necessity to have organizations invest in high-tech maintenance tools, modernize the workforce, and come up with a structured maintenance policy to reverse the adverse consequences of RCM challenges.

The findings of this research support the third hypothesis with good strength showing that the availability and efficiency of the mechanical maintenance system mediates the relationship between the RCM challenges and operational performance. It means that the RCM problems do not influence the operation results in isolation but their influence is spread through the mechanism of maintenance system functioning (Adebisi et al., 2023). As the level of maintenance issues goes up, they undermine the effectiveness of the maintenance system to conduct repairs in time, preventive maintenance schedules, and equipment preparedness, and hence create instability in the operations. The observation aligns with previous empirical studies that have indicated that systems with successful maintenance practices increase operational continuity by decreasing the duration of downtimes and enhancing the workflow coordination but ineffective systems intensify the adverse impacts of technical and organizational barriers (Adewuyi

& Aki, 2024). The fact that this hypothesis can be accepted shows that organizations with robust maintenance procedures can partly mitigate the negative effect of RCM issues whereas organizations with weak systems suffer more operational disturbance. This adds to the claim that effectiveness of maintenance systems is an important internal process, which represents a transformation of the maintenance inputs into operational outputs.

On the same note, the fourth hypothesis was accepted thus confirming that the relationship between the RCM problems and the overall efficiency of the equipment are mediated by the availability and effectiveness of the mechanical maintenance system. This implies that the impact of maintenance issues in equipment level performance is highly reliant on the quality of maintenance system in terms of managing equipment health, responsiveness and repairing quality. RCM challenges that degrade the effectiveness of the maintenance system result in longer equipment breakdowns, slower recovery time, and variations in the performance of equipment, which eventually leads to lower equipment efficiency. This observation is consistent with the prior studies that show the equipment efficiency indicators, including availability, performance rate, and quality output, are very sensitive to the capabilities of the maintenance system (Lee et al., 2024). The mediation performance shows that despite the maintenance issues; the performance of effective maintenance systems can ensure the maintenance or the restoration of the performance of the equipment at a greater level than that of the poorly functioning maintenance systems. It is a useful theoretical and practical contribution as it demonstrates that the efficacy of the maintenance system is not only an operational necessity but a strategic mechanism that defines to what extent the issues of RCM challenges affect the efficiency of equipment.

The fact that the fifth hypothesis has been accepted is a very powerful indication that the top management support plays a significant role when moderating the relationship between the availability and effectiveness of the mechanical maintenance system and the operational performance. This implies that despite the fact that the maintenance systems are performing efficiently, the extent to which their benefits are reflected in better operational performance is determined by the commitment, participation and provision of resources by the top management. The results support the previous research that indicates that managerial support influences organizational priorities, enhances maintenance planning, and facilitates timely decision making, which improves the operational value of maintenance activities (Toni et al., 2024). With a high degree of support shown by the top management, the maintenance systems can provide greater stability of operations through decreasing delays, enhancing coordination, and the availability of adequate tools and skills. On the other hand, managerial support is poor and the high competent maintenance systems might be hampered by lack of budget funds, approval of the budget, and the staffing level, and the benefits of such competent maintenance system on operations may be limited.

On the same note, the acceptance of the sixth hypothesis validates the fact that top management support mediates the association among the availability and effectiveness of the mechanical maintenance system and the general efficiency of equipment. This observation underlines the idea that the capacity of a good maintenance system to improve the availability rates of equipment, their performance rate, and the quality of outputs increase significantly with the help of dedicated management (Toni et al., 2024). The historical empirical research emphasizes the fact that the participation of managers enhances the implementation of advanced maintenance technologies, improves the dissemination of communication between departments, and timely acquiring the required resources, which directly affect the efficiency of equipment (Machingura et al., 2024). The hypothesis accepted implies that in case of the active involvement of top management, maintenance teams can be better prepared to use preventive and predictive strategies, minimize equipment stoppages, and sustain the level of performance. Conversely, lack of effective managerial support undermines the effectiveness of maintenance systems in that it reduces access to resources as well as personnel response time, leading to decreased efficiency of equipment despite the potentially effective nature of the system.

To sum up, the fact that all six hypotheses were accepted proves that RCM challenges, maintenance system effectiveness, and top management support create a complex of operational and equipment performance of mechanical systems. The results confirm that maintenance issues have a direct negative impact on operations and equipment performance, and the presence of efficient maintenance systems is a critical channel that can convert maintenance inputs into valuable organizational deliverables. Furthermore, the moderating influence of the top management support proves the fact that the value created by successful maintenance procedures is amplified by the leadership involvement making sure that the maintenance excellence is converted to the quantifiable performance gains. Collectively, these observations can be used to develop an enhanced theoretical and practical clarity of the key concept of maintenance management with its valuable implications to the companies that aim to increase their mechanical reliability and operational competitiveness.

6. Implications

6.1 Theoretical Implications

This study has a number of valuable theoretical implications that help to understand the mechanism of RCM challenges influencing organizational and equipment-level outcomes both directly and indirectly. The research provides a progress in the maintenance and operations administration literature by being empirically confirmed that the challenges of RCM have a significant negative effect on operational performance and overall efficiency of the equipment, which once again proves the theoretical argument that maintenance constraints represent the important inhibitors to organizational reliability. The research helps fill in the Resource-Based View by proving that the maintenance system capability is a strategic internal resource which transforms the inputs of the maintenance system into the performance outputs. Moreover, the inclusion of top management support as a moderator builds on the Socio-Technical Systems Theory by showing how social structures that are led by the leadership enhance the effect of technical maintenance procedures. The gaps in the conceptual understanding of maintenance behavior in sophisticated mechanical settings are bridged by this multidimensional model which simultaneously connects all the challenges, system performance and managerial support. In general, the results contribute to the theoretical picture, providing more comprehensive and empirically supported the model of studying maintenance management and its role in the organization performance.

6.2 Practical Implications

Practically, the findings of this study can be something that gives a straightforward direction to the organizations that want to improve the performance of mechanical systems and reinforce the maintenance management strategies. The results demonstrate that companies should actively spot and manage the problems of RCM, including poor diagnostic equipment, poor preventive maintenance, and poor technical expertise, as these factors greatly lead to poor operational performances and efficiency of equipment. The shown mediating nature of the effectiveness of the maintenance systems implies that the organizations should spend on ensuring that their maintenance planning, maintenance workflow optimization, and ensuring the fastest response to faults and their subsequent repair is guaranteed to be as high as possible. Also, the strong moderating influence of the top management support highlights the fact that the involvement of the leadership is not a matter of choice, but the key to the success of maintenance. To enhance the effect of maintenance systems, managers ought to inject enough resources, facilitate cross-functional collaboration, support training programs, and ensure that maintenance targets are incorporated into the comprehensive organizational plans. This will allow organizations to maximize equipment use, reduce downtime and attain sustainable operational excellence by considering maintenance as a strategic driver, and not a cost center.

7. Limitations and Future Directions

Regardless of its great contributions, this study has a number of limitations that can be exploited in further research works. To begin with, the research is based on self-reported data, which can cause the bias of respondents and restrict the objectivity of the evaluations associated with maintenance issues, system efficiency, and performance results. Future studies can use longitudinal or experimental research design to capture real-time maintenance behaviors and performance changes. Second, the research is conducted on the system of mechanics in the framework of a particular industry, which can influence the extrapolation of results to other areas of life, like aviation, energy, logistics, or service industries where the mechanisms of maintenance are considerably different. The researchers are advised to apply the model in various operating environments to enable it to be proved as an all-purpose model. Also, this paper analyzes a single mediating factor, as well as a single moderating factor, but maintenance performance is affected by other possible variables including technological integration, organizational culture, workforce competence, and digital maintenance practices. The model can be expanded later in the future by including these variables in the work to make a more comprehensive framework. Finally, the cross-sectional study design limits the possibility of causal inferences thus longitudinal studies are advised to have a deeper insight on how maintenance gains and managerial interventions change with time and affect the long-term performance outcomes.

8. Conclusion

To sum up, this study offers very useful information about the multifaceted interaction between the issues of maintenance, effectiveness of maintenance systems, the support of top management, and performance results in the mechanical setting. The results verify that issues related to RCM are a significant threat to the work of the operations and the overall efficiency of the equipment, and the efficiency of the mechanical maintenance system and its availability is a significant mediator between these variables. The study also indicates that positive effects of an effective maintenance system are reinforced by the support of the top management which shows the key role the leadership plays in boosting maintenance capacity and increasing organizational performance. This study adds to the comprehensive approach to the holistic concept of maintenance management by incorporating technical, operational, and managerial aspects into one empirical framework. These findings demonstrate the need to invest in enhancing the maintenance system, integrate high commitment in the managerial ranks, and combat the issue of maintenance using proactive approaches that will provide long-term reliability and competitive advantage.

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