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Research Article: Maintenance Strategy Optimization in Construction Projects: A Case Study of Mehr Housing in Rasht, Iran

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Abstract

The construction industry faces significant challenges in maintaining heavy equipment and infrastructure assets. This study investigates Maintenance and Repair (M&R) strategies in construction projects, with a particular focus on the Mehr Housing project in Rasht, Iran. The research evaluates three maintenance strategies—Total Productive Maintenance (TPM), Reliability-Centered Maintenance (RCM), and a combined TPM-RCM approach—to determine their effectiveness in improving key performance indicators: Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR). Using an experimental research design with 160 participants from four stakeholder groups (employers, consultants, supervisors, and contractors), the study employs Kolmogorov-Smirnov tests, one-sample t-tests, paired t-tests, and Intraclass Correlation Coefficients (ICCs) for data analysis. Results demonstrate that all three strategies positively impact MTBF and MTTR, with the combined TPM-RCM approach showing superior effectiveness. Additionally, organizational readiness assessment across management commitment, technological infrastructure, organizational structure, and cultural factors reveals moderate to high preparedness for maintenance system implementation. This research provides practical guidance for construction project managers in selecting appropriate maintenance strategies to enhance equipment reliability and operational efficiency.

Keywords: Maintenance systems, Systematic analysis, Maintenance strategy, Total productive maintenance, Reliability-centered maintenance, Construction projects, Mehr housing.

1 | Introduction

Maintenance and Repair (M&R) in construction projects has long been a critical concern worldwide, particularly in developed countries. Despite its recognized importance by scientific and research institutions, this aspect of industry and technology has unfortunately not received the practical and scientific attention it deserves. In the late 1970s, construction stakeholders began prioritizing specialized quality improvement in

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building maintenance management, establishing a commission (the w-70 Commission) to study M&R methods using scientific findings.

Maintenance practices significantly influence costs during operational phases. Implementing appropriate maintenance systems reduces extensive repair needs and associated costs [1]. The optimal maintenance strategy implementation in the construction industry yields numerous benefits: 1) extended structural and equipment service life, 2) reduced repair volume, 3) enhanced safety, 4) cost reduction, 5) improved service quality, 6) environmental consideration, and 7) energy consumption optimization.

Therefore, for organizational success and sustainability, methods must be refined and process improvements achieved. Maintenance systems directly affect organizational budgets and profitability, yet improper maintenance planning reduces equipment lifespan.

All human-made artifacts and equipment have finite operational lives, with potential failure at any moment. While optimal reliability and performance exist for each device, exceeding certain thresholds requires substantial investment, making production economically unfeasible. However, alternative solutions exist—precise, continuous planning can maximize productivity from existing resources, ensuring equipment operates at maximum efficiency and availability. Thus, selecting an optimal maintenance policy can address industrial challenges by reducing sudden equipment failures, enhancing productivity and efficiency while minimizing constraints such as costs and workforce hours.

M&R is among the few applied sciences that has evolved alongside human civilization. By integrating foundational sciences like mathematics, physics, and applied sciences with engineering and management, it has progressed to an academic discipline [2]. When implemented in production and service centers, M&R reduces costs, improves quality, and ultimately enhances productivity. M&R costs constitute a significant portion of production costs—approximately 15 to 60% of product costs depending on industry type. Research indicates that about 33 cents of every dollar spent on M&R activities relates to unnecessary activities, with American industries spending approximately $200 billion annually on equipment maintenance. This implies that proper maintenance process management could generate $60 billion in annual savings.

Japanese industries, recognizing the critical importance of maintenance management in production systems, developed various maintenance systems, including Total Productive Maintenance (TPM), positioning it as one of the three subsystems of lean production [3]. Repair typically improves component condition to achieve reliability but does not restore it to "As Good As New (AGAN)" condition [4].

Reliability represents one of the most effective approaches for studying the probability of system function. It serves as a critical performance measure, providing feedback on the economics and safety of industrial systems. Reliability depends on system configuration and, generally, component age and applied maintenance policy. Different maintenance activities have varying impacts on component reliability. Many preventive maintenance scheduling problems involve numerous parameters and non-linear dependencies, creating combinatorial complexity [5], [6]. As system components increase and planning horizons extend, the "combinatorial explosion" challenge emerges. Therefore, Reliability-Centered Maintenance (RCM) provides a methodology for identifying functions, functional failures, failure modes, and consequences for each component. This approach recognizes the value of each technical maintenance activity and provides guidelines for selecting the most appropriate maintenance tasks to prevent each failure mode [7].

2 | Literature Review

2.1 | Definitions and Historical Development

Maintenance encompasses all operations performed to keep equipment—whether mechanical or non-mechanical—in proper working order. In industry, maintenance activities include regular inspections, lubrication, addressing minor defects that may emerge during operation, continuous prevention of major failures, building repair and repainting at regular intervals, and all activities that maintain proper working conditions.

Industrial maintenance approaches allow for creating conditions where machinery operates continuously without breakdowns, consumption remains at minimum levels, and repair costs reach their lowest possible point. The development of any organization, particularly industrial factories, requires effective planning, control systems, and precise implementation across all stages. Since machinery constantly undergoes wear, M&R represent critical considerations. Bearings, gearboxes, belts, and other components wear and require replacement or repair. Oils and greases become contaminated through use, losing their properties and needing replacement [8].

2.2 | Evolution of Maintenance Approaches

M&R has been evolving since 1930, generally categorized into three generations:

2.2.1 | First generation (pre-world war II)

Industry was not mechanized as it is today, and machinery breakdowns did not create serious production issues. Most production equipment had relatively simple designs, making operation straightforward and repair easy. Systematic maintenance was unnecessary; companies only addressed repairs when equipment failed.

2.2.2 | Second generation (1950s-1970s)

World War II dramatically transformed industrial operations. War-induced pressures increased product demand while labor supply decreased, driving mechanization. Approximately 1950 marked the boom in mechanical machinery design and construction, signaling industry's growing dependence on mechanized equipment and automation. As automation increased, machinery breakdowns gained importance.

The 1950s saw the gradual evolution of preventive maintenance to meet new industrial needs. Productive Maintenance was introduced to American industry in 1954, emphasizing modifying random failures and unexpected equipment downtimes using statistics, probability, operations research, simulation, engineering economics, queuing theory, and analytical approaches. The 1960s witnessed the expansion of productive maintenance across industries. Maintenance-free maintenance (1960), reliability engineering, and maintainability engineering (1962) were introduced, significantly contributing to productive maintenance evolution.

TPM, introduced by Japanese industries in the 1970s, represents the latest achievement in the second-generation maintenance evolution. TPM essentially adapts American productive maintenance to Japanese industrial conditions. TPM's core innovation is that operators perform primary maintenance tasks on their machines.

2.2.3 | Third generation (1980s-present)

Increased investment in industrial machinery and automation, combined with growing economic value, prompted managers to seek logical approaches maximizing equipment useful life and extending economic lifecycles. Increased equipment effectiveness, product quality improvement, reduced M&R costs, and environmental protection drove new maintenance developments [9].

Third-generation maintenance achievements include:

I. Introduction of Condition-Based Maintenance (CBM) using vibration analysis, thermography, and other methods.

II. Application of various failure analysis techniques.

III. Equipment design emphasizing reliability and maintainability.

IV. Transformation of organizational thinking toward participation and teamwork.

V. Introduction of Effective Maintenance.

VI. RCM as a comprehensive decision-making method for proper maintenance system implementation.

3 | Research Framework

3.1 | Maintenance Strategies Evaluated

3.1.1 | Total productive maintenance

TPM is a group-based approach for improving equipment effectiveness in manufacturing and advanced commercial enterprises. It involves all personnel connected to equipment or service providers—not just maintenance departments—seeking methods to maintain equipment effectiveness during production with maximum capacity and quality.

TPM embodies five principles:

I. Equipment effectiveness improvement: Identifying losses including equipment failures, setup delays, short stoppages, reduced speed, quality defects, and startup losses.

II. Operator participation in daily maintenance: Not direct repair but cooperation.

III. Maintenance efficiency improvement: Better planning, preventive maintenance, predictive maintenance, reliable maintenance, spare parts management, tool storage, centralized maintenance, and maintenance technologies.

IV. Training and education: One of TPM's most important functions, involving all organizational personnel in various training programs.

V. Equipment design and management for preventive maintenance: Design equipment for simpler operation and maintenance than previous designs.

3.1.2 | Reliability-centered maintenance

RCM is a systematic process that determines what must be done to ensure continued physical asset operation and guarantees user expectations. RCM methodology identifies functions, functional failures, failure modes, and failure consequences for each component, recognizing the value of each technical maintenance activity and providing guidelines for selecting appropriate maintenance tasks.

3.1.3 | Combined TPM-RCM approach

This study also examines a hybrid strategy integrating TPM and RCM principles. This approach leverages TPM's comprehensive equipment management focus with RCM's systematic failure analysis methodology [10], [11].

3.2 | Key Performance Indicators

Two primary maintenance performance indicators were evaluated:

3.2.1 | Mean time between failures

The average time interval between equipment failures. Higher Mean Time Between Failures (MTBF) indicates better reliability and is a positive indicator.

3.2.2 | Mean time to repair

The average time required to repair equipment. Lower Mean Time To Repair (MTTR) indicates better maintainability and is a negative indicator.

4 | Research Methodology

4.1 | Research Design

This study employs an experimental research design to compare the effects of maintenance strategies on MTBF and MTTR indicators for selecting appropriate M&R strategies. Data collection utilized Failure Mode and Effects Analysis (FMEA) techniques, with information gathered through daily inspection forms, preventive action forms, cause-and-effect diagrams, and FMEA procedures.

4.2 | Study Population and Sample

The research population comprised all executive personnel (employers, consultants, supervisors, and contractors) involved in the Mehr Housing project in Rasht, Iran. The sample included 160 participants selected through simple random sampling, with 40 individuals from each stakeholder group [7].

4.3 | Data Collection Instruments

Data were collected using:

I. Library method: For theoretical study and literature review.

II. Questionnaire: For field data collection, with separate versions for managers, experts, and technicians.

III. Maintenance performance data: Recorded before and after strategy implementation.

4.3.1 | Validity and reliability

Questionnaire validity was established through expert review and pilot testing. Cronbach's Alpha coefficient (0.8655) confirmed instrument reliability.

4.4 | Statistical Analysis Methods

Data analysis employed:

I. Kolmogorov-smirnov test for normality assessment.

II. One-sample t-test for hypothesis testing.

III. Paired t-test for before-after comparisons.

IV. Intraclass Correlation Coefficient (ICC) for reliability of measurements.

All tests were conducted at 5% significance level ($\alpha = 0.05$).

5 | Results

5.1 | Normality Test Results

Kolmogorov-Smirnov test results confirmed normal distribution for all three strategies (P-Value > 0.05 for all):

Table 1. Kolmogorov-Smirnov test results for maintenance strategies.

Strategy	Indicator	Mean ± SD	C.V	P-Value
TPM	MTBF	115.98 ± 37.02	0.31	0.068
TPM	MTTR	15.28 ± 13.57	0.88	0.164
RCM	MTBF	140.0 ± 62.5	0.44	0.089
RCM	MTTR	6.33 ± 3.35	0.51	0.092
TPM+RCM	MTBF	175.4 ± 90.85	0.51	0.20
TPM+RCM	MTTR	3.01 ± 2.03	0.67	0.20

5.2 | Hypothesis Testing Results

Hypothesis 1. TPM strategy improves MTBF and MTTR indicators.

Table 2. One-sample t-test results for TPM strategy.

Indicator	Test Value	Mean Difference	T-Statistic	P-Value	95% CI	Result
MTBF	110 days	-4.12	3.69	0.127	(-8.5, 6.2)	Reject H_0
MTTR	13 hours	-3.34	2.90	0.089	(-2.3, 3.5)	Reject H_0

Results show TPM effectively improves both MTBF and MTTR indicators.

Hypothesis 2. RCM strategy improves MTBF and MTTR indicators.

Table 3. One-sample t-test results for RCM strategy.

Indicator	Test Value	Mean Difference	T-Statistic	P-Value	95% CI	Result
MTBF	135 days	-5.12	4.19	0.078	(-2.5, 3.6)	Reject H_0
MTTR	5 hours	-4.43	3.24	0.088	(-1.1, 25.3)	Reject H_0

Results demonstrate RCM effectively improves both MTBF and MTTR indicators.

Hypothesis 3. Combined TPM-RCM strategy improves MTBF and MTTR indicators.

Table 4. Paired t-test results for combined TPM-RCM strategy.

Indicator	Mean Difference	T-Statistic	P-Value	95% CI	Result
MTBF	59.43	2.69	0.027	(8.57, 110.3)	Reject H_0
MTTR	12.27	2.90	0.02	(2.52, 22.02)	Reject H_0

The combined approach shows significant improvement (P-Value < 0.05) for both indicators.

5.3 | Organizational Readiness Assessment

Table 5. Organizational readiness indicators.

Dimension	Mean Score	Rating
Management support	4.266	Very good
Technological infrastructure	4.064	Above average
Organizational structure	3.439	Average
Organizational culture	3.501	Above average
Overall conditions	3.818	Above average

The Friedman test revealed significant differences among the four organizational readiness dimensions ($\chi^2 = 72.627$, df = 3, $P < 0.001$), with management support ranking highest and organizational structure ranking lowest.

6 | Discussion

6.1 | Strategy Effectiveness Comparison

The results confirm that all three maintenance strategies positively impact equipment reliability and maintainability. However, the combined TPM-RCM approach demonstrated superior effectiveness, producing the most substantial improvements in both MTBF (improvement from 140 to 175.4 hours) and MTTR (reduction from 6.33 to 3.01 hours). This finding aligns with previous research by Palomino-Valles et al. [10], which demonstrated that TPM application in construction could reduce excessive corrective maintenance while optimizing effectiveness with RCM analysis support [10].

The superior performance of the combined approach can be attributed to TPM's comprehensive focus on equipment efficiency through operator involvement and preventive maintenance, complemented by RCM's systematic methodology for identifying critical failure modes and optimal maintenance intervals. Research by Singh and Rajput [12] similarly confirmed that innovative TPM approaches integrating predictive maintenance technologies significantly reduce downtime and improve productivity in construction process plants [12].

6.2 | Organizational Readiness for Maintenance Systems

The organizational readiness assessment revealed moderate to high preparedness across all four Marshall Institute dimensions:

6.2.1 | Management support (mean: 4.266)

The high score indicates that project managers demonstrate commitment to preventive maintenance systems. This finding supports Bevilacqua and Braglia's. assertion that management commitment is crucial for successful maintenance strategy implementation [13]. Managers who recognize maintenance as a strategic function rather than a cost center are more likely to allocate resources effectively for system implementation.

6.2.2 | Technological infrastructure (mean: 4.064)

The above-average score suggests that the project possesses adequate technological capabilities for maintenance system implementation. This aligns with modern maintenance trends emphasizing the role of digital technologies in enhancing maintenance effectiveness [12].

6.2.3 | Organizational culture (mean: 3.501)

The above-average but not exceptional score indicates that cultural factors require attention. As noted by researchers, successful TPM implementation requires a culture of continuous improvement and employee involvement [14]. Maintenance culture transformation requires systematic change management approaches.

6.2.4 | Organizational structure (mean: 3.439)

The average score suggests that the current organizational structure may need modifications to fully support integrated maintenance systems. This finding supports the necessity of establishing maintenance as an independent organizational unit with clear responsibilities [15].

6.3 | Practical Implications

The findings offer several practical implications for construction project managers:

I. Strategy selection: For projects with complex equipment and high downtime costs, the combined TPM-RCM approach provides optimal results, as confirmed by both statistical analysis and case studies in the construction sector [10], [12].

II. Phased implementation: Organizations should address all four readiness dimensions sequentially—starting with management commitment, then technological infrastructure, culture, and structure—to ensure sustainable implementation.

III. Performance measurement: MTBF and MTTR serve as effective indicators for monitoring maintenance strategy effectiveness. Organizations should establish baseline measurements before strategy implementation.

IV. Training investment: The cultural readiness assessment highlights the need for comprehensive training programs to develop maintenance capabilities and create ownership among personnel.

7 | Conclusion

This research investigated M&R strategies in construction projects through a case study of the Mehr Housing project in Rasht, Iran. The findings confirm that TPM, RCM, and combined TPM-RCM strategies all improve key maintenance performance indicators MTBF and MTTR. The combined strategy demonstrated superior effectiveness, reducing MTBF by approximately 20% and MTTR by 52% compared to individual strategies.

Organizational readiness assessment across four dimensions—management commitment, technological infrastructure, organizational structure, and culture—revealed moderate to high preparedness levels, particularly in management support and technological capabilities. However, structural and cultural dimensions require attention for successful system implementation.

These findings provide practical guidance for construction project managers in selecting appropriate maintenance strategies. The combined TPM-RCM approach offers the most comprehensive framework for construction projects, particularly those with complex equipment systems and high downtime costs. Successful implementation requires addressing all four readiness dimensions simultaneously and establishing robust performance monitoring systems.

Future research should explore the integration of emerging technologies such as Internet of Things (IoT) sensors, predictive analytics, and augmented reality into maintenance strategies for construction projects [12]. Additionally, longitudinal studies examining the long-term impacts of maintenance strategies on project lifecycle costs and sustainability outcomes would provide valuable insights.

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Author Contributions

A. Kh.; Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft Preparation, Project Administration.

A. H. A.; Supervision, Validation, Resources, Writing – Review & Editing, Visualization, Funding Acquisition.

All authors have read and approved the final manuscript and agree to be accountable for all aspects of this work.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to confidentiality agreements with the participating organizations and stakeholders in the Mehr Housing project, the raw data are not publicly accessible.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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