# Development of a Framework for Reliability Centered Maintenance

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## Abstract

Reliability-centered maintenance (RCM) is a systematic process used to ensure that any physical facility will be able to meet its designed functions continuously in its current operating context. RCM suggests the appropriate maintenance strategies for performing the maintenance actions at the right time for a particular system. One of the important factors in developing an RCM within an organization is the adoption of a suitable framework that provides the required flow of various stages for proper selection of a maintenance plan based on reliability analysis. Several authors have proposed different frameworks for RCM. A comparative study has revealed that most of the frameworks are unique and mainly focused on the suggestion of the maintenance strategy only. This paper develops a framework based on strength, weakness, opportunity, and threats (SWOT) analysis of the existing frameworks using ISM-MICMAC approach.

**Keywords:**

Framework; RCM; Reliability analysis; FMECA; ISM-MICMAC

## 1. Introduction

RCM originated in the airline industry in the 1960s as a systematic process for development and optimization of the maintenance requirements of a physical resource in its operating context to realize its inherent reliability by logically incorporating the maintenance strategies like reactive, preventive, condition-based and proactive maintenance. Since RCM implementation is a strategic decision and assumes that managers tend to utilize a framework for implementation, they cannot afford to take a wrong step in the implementation process. In our previous work, 19 RCM frameworks collected from literature and categorized into four groups based on SWOT analysis Gupta and Mishra [1]. In addition, based on the SWOT analysis, it was found that most of the frameworks followed the qualitative analysis and few frameworks were followed quantitative analysis only. However, none of the framework available as comprehensive framework, which can implement based on qualitative and quantitative analysis together at a time.

In this paper, we have identified 10 elements, which can represent comprehensiveness with respect to qualitative as well as quantitative analysis out of the 33 elements, based on the SWOT analysis of these frameworks. In addition, contextual relationships among the identified elements are established and a new framework for RCM proposed with the help of interpretive structural modeling (ISM). ISM is seen as a useful tool for those who wish to exercise careful, logical thinking in approaching complex issues, and then to communicate the results of that thinking to others [2]. This paper is organized into 5 sections. In Section 2 a brief literature review of RCM and ISM presented, Section 3 describes the elements of RCM framework, Section 4 enumerates methodology used followed by ISM model development & discussion in section 5 and conclusion in section 6.

## 2. Literature Review

### 2.1 Reliability Centered Maintenance

In 1978, Nowlan & Heap [3] first defined RCM concept as "a scheduled-maintenance program designed to recognize the inherent reliability capabilities of equipment". Srikrishna et al. [4] developed RCM based methodology for coal power plant auxiliaries for reducing their downtime. Rausand [5] discussed the various steps of RCM implementation and emphasized on the gap between theoretical and practical implications of RCM. Deshpande & Modak [6] created an RCM framework for a medium scale industry. Gabbar et al. [7] proposed computer aided RCM framework for plant maintenance. Smith et al. [8] defined four principles of RCM and explained the nine steps for RCM implementation. Bertling et al. [9] presented the impact of RCM implementation in Power Distribution Systems. Niu & Pecht [10] developed an integrated model of condition-based maintenance (CBM), RCM and data fusion. Singh et al. [11] Presented a combination of total productive maintenance (TPM) and RCM. Kianfar & Kianfar [12] applied RCM with quality function deployment (QFD). Selvik & Aven [13] created a framework for reliability and risk centered maintenance. Chen & Zhang [14] described the application of RCM in China's nuclear plant. Liang et al. [15] Presented the application of RCM to analyze the principal parts of the reciprocating compressor. Dehghanian et al. [16] and Yssaad et al. [17] also developed a comprehensive framework for power distribution systems. Prabhakar et al. [18] Proposed an RCM framework for petroleum and refineries industries.

### 2.2. Interpretive structural modeling

Interpretive structural modeling is a technique for classifying the type of relationship among the different factors and helps in calculating their driving and dependence power individually for any process implementation. A plethora of authors have applied ISM technique in different areas. Table 1 presents the research work done by few authors on ISM application.

Table 1. Application of ISM

| S.no. | Authors | Application |
|---|---|---|
| 1 | Mandal and Deshmukh [19] | Vendor selection |
| 2 | Thakkar, Kanda, and Deshmukh [20] | IT-enablers for Indian manufacturing SMEs |
| 3 | Singh and Kant [21] | Knowledge management barriers |
| 4 | Upadhye, Deshmukh, and Garg [22] | Lean manufacturing system implementation barriers |
| 5 | Attri, Singh, and Mehra [23] | Analysis of interaction among the barriers to 5S implementation using interpretive structural modeling approach |

## 3. Identified elements for proposed framework

A framework can act as a guide and it provides a structured way to achieve its objectives. The existing 19 RCM frameworks collected from literature and categorized into four groups based on SWOT analysis by Gupta and Mishra [1]. 33 elements were found from all 19 frameworks. Out of them, many of the researchers used around 13 same elements in their framework just by changing the representation of element and remaining used in some unique framework. However, it was found that all these elements related to qualitative analysis. Based on the previous SWOT analysis, it was found that there is a need of comprehensive framework, which can be used for qualitative, as well as quantitative analysis while implementing the RCM. To overcome this issue, we have visited more than 10 industries and discussed the results of SWOT analysis with maintenance experts, who are having more than 10 years’ experience in the maintenance department and identified the below 10 elements for the further development of an RCM framework.

1) System selection and information collection
2) System description and function block diagram
3) Criticality analysis for subsystems/components
4) Failure mode effect and cause analysis (FMECA)
5) Determination of possible maintenance strategy
6) System reliability comparison
7) Managerial review and judgment
8) Make recommendation & package final maintenance program
9) Implementation
10) Feedback- Continuous re-evaluation & improvement

## 4. Methodology

In this paper, interpretive structural modeling (ISM) is used to develop RCM framework. Interpretive structural modeling is a technique for classifying the type of relationship among the different identified factors and calculates their driving and dependence power individually for any process implementation. It is interpretive as group of experts identify the kind of relationship among different factors; it is structural too as whole structure is prepared based on the contextual relationship among complex set of identified factors; off course it is modeling technique as contextual relationship and whole structure is depicted into a graphical structure. The following steps used for the development of RCM framework using ISM model.

### 4.1 Structural self-interaction matrix (SSIM)

Based on the opinion of group of professionals from academia and industries, interrelationships among the identified factors are developed. In order to develop SSIM, underneath four symbols are used to give directional relationships between factor (i and j). Table 2 represents the SSIM of identified factors. Factor 1 is supporting to achieve factor 10; factor 5 is supporting to achieve factor 2; factor 7 and 9 are supporting to achieve each other while factor 2 and 9 are isolated.

V - Depicts factor i will support to achieve factor j;
A - Depicts factor j will support to achieve factor i;
X - Depicts factor i and j will support to achieve each other;
O - Depicts both factors i and j are isolated

Table 2. Structured Self Intersection Matrix (SSIM)

| S.no | Factors name | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FMECA | V | V | V | V | O | A | V | A | A |
| 2 | criticality analysis for subsystems/components | V | O | V | V | V | A | V | A | |
| 3 | system description and functional block diagram | V | V | V | V | V | A | V | | |
| 4 | determination of possible maintenance strategy | V | V | V | O | V | A | | | |
| 5 | system selection and information collection | V | V | V | V | V | | | | |
| 6 | system reliability and comparison | V | O | V | V | | | | | |
| 7 | managerial review and judgment | X | V | V | | | | | | |
| 8 | make recommendation and package find a maintenance program | A | V | | | | | | | |
| 9 | feedback-continuous revaluation and implementation | A | | | | | | | | |
| 10 | implementation | | | | | | | | | |

### 4.2 Reachability Matrix

Jharkharia and Shankar, Mishra et al. [24, 25] given the following rules, in order to develop initial reachability matrix. Table 3 represents the initial reachability matrix.

- If the (i, j) entry in the SSIM is V, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0;
- If the (i, j) entry in the SSIM is A, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1;
- If the (i, j) entry in the SSIM is X, the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1; and
- If the (i, j) entry in the SSIM is O, the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.

To get the final reachability matrix transitivity needs to determine. The transitivity of the contextual relation in ISM define as if variable A is related to B and B is related to C, then A is necessarily related to C. In this study, factor 1 is helping to achieve factor 4 and factor 4 is helping to achieve factor 6 as per the experts opinion then, factor 1 must be supported to achieve 6 and this transitivity is presented by (*) in Table 4**.** The driving power and dependence for each element is calculated by adding the total number of 1's (including itself) row-wise and column-wise respectively.

Table 3. Initial Reachability Matrix

| S.no | Factors name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FMECA | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| 2 | Criticality analysis for subsystems/components | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 |
| 3 | System description and functional block diagram | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 |
| 4 | Determination of possible maintenance strategy | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| 5 | System selection and information collection | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6 | System reliability and comparison | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 |
| 7 | Managerial review and judgment | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 8 | Make recommendation and package find maintenance program | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| 9 | Feedback-continuous revaluation and implementation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 10 | Implementation | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

Table 4. Final Reachability Matrix

| S.no | Factors name | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Driving Power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | FMECA | 1 | 0 | 0 | 1 | 0 | 1* | 1 | 1 | 1 | 1 | 7 |
| 2 | Criticality analysis for subsystems/components | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1* | 1 | 8 |
| 3 | System description and functional block diagram | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 9 |
| 4 | Determinati0on of possible maintenance strategy | 0 | 0 | 0 | 1 | 0 | 1 | 1* | 1 | 1 | 1 | 6 |
| 5 | System selection and | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 10 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | information collection | | | | | | | | | | | |
| 6 | System reliability and comparison | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1* | 1 | 5 |
| 7 | Managerial review and judgment | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 4 |
| 8 | Make recommendation and package find maintenance program | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| 9 | Feedback-continuous revaluation and implementation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| 10 | Implementation | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 4 |
| | Dependence | 4 | 3 | 2 | 5 | 1 | 6 | 8 | 9 | 10 | 8 | 56 |

## 4.3 Level partitions

To determine the level partition, the reachability and antecedent set for each element is determined and presented in Table 5. Thereafter, the intersection set is determined for all elements. The element, for which the reachability set is same as the intersection set, comes at the bottom of the ISM hierarchy. It implies that this bottom-level element will not lead to achieving any other element. After the identification of the bottom-level element, it removed out from the other elements. Then the number of iteration of this process is done to get the level of each element. Table 6 represents the level of all the elements after the 8th iteration. The numbering of levels decided from bottom to top approach. Level 1 given to bottom element and level 8 given to top element of final ISM model of developed RCM framework.

Table 5. Partition of Reachability Matrix (1st Iteration)

| S.no | Element name | Reachability | Antecedent | Intersection | Level |
|---|---|---|---|---|---|
| 1 | FMECA | 1,4,6,7,8,9,10 | 1,2,3,5 | 1 | |
| 2 | Criticality analysis for subsystems/components | 1,2,4,6,7,8,9,10 | 2,3,5 | 2 | |
| 3 | System description and functional block diagram | 1,2,3,4,6,7,8,9,10 | 3,5 | 3 | |
| 4 | Determination of possible maintenance strategy | 4,6,7,8,9,10 | 1,2,3,4,5 | 4 | |
| 5 | System selection and information collection | 1,2,3,4,5,6,7,8,9,10 | 5 | 5 | |
| 6 | System reliability and comparison | 6,7,8,9,10 | 1,2,3,4,5,6 | 6 | |
| 7 | Managerial review and judgment | 7,8,9,10 | 1,2,3,4,5,6,7,10 | 7,10 | |
| 8 | Make recommendation and package find maintenance program | 8,9 | 1,2,3,4,5,6,7,8,10 | 8 | |

| | | | | | |
|---|---|---|---|---|---|
| 9 | Feedback-continuous revaluation and implementation | 9 | 1,2,3,4,5,6,7,8,9,10 | 9 | I |
| 10 | Implementation | 7,8,9,10 | 1,2,3,4,5,6,7,10 | 7,10 | |

Table 6. Final Level of elements in ISM model after 8th iteration

| Element No. | Name of element | Level |
|---|---|---|
| 9 | Feedback-continuous revaluation and implementation | First |
| 8 | Make recommendation and package find maintenance program | Second |
| 7,10 | Managerial review and judgment, Implementation | Third |
| 6 | System reliability and comparison | Fourth |
| 4 | Determination of possible maintenance strategy | Fifth |
| 1 | FMECA | Sixth |
| 2 | Criticality analysis for subsystems/components | Seventh |
| 3 | System description and functional block diagram | Eighth |
| 5 | System selection and information collection | Ninth |

## 4.4. MIC-MAC analysis

In MIC-MAC analysis, elements are segregated into following four categories based on their driving power and dependence and shown in Fig. 1: (I) autonomous elements (weak driving power, weak dependence), (II) dependent elements (weak driving power, strong dependence), (III) linkage elements (strong driving power and strong dependence) and (IV) independent elements (strong driving power weak dependence).

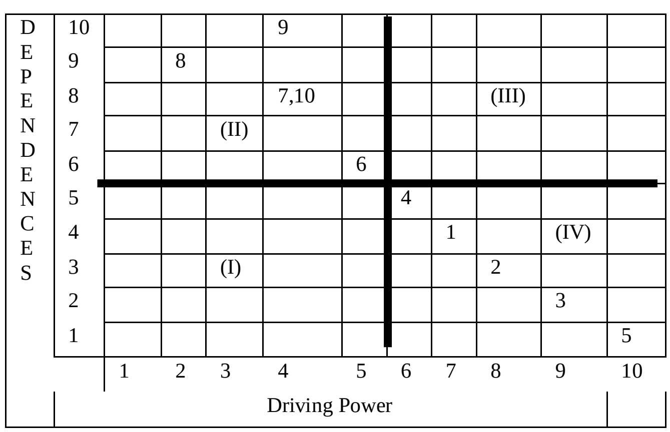


Figure 1. Micmac Analysis

## 5. Formation of ISM model and discussion

Level partitioning of each factor will lead to the formation of ISM model. Initially, a digraph is portrayed with the help of final reachability matrix. Diagraph used to represent the elements and their interdependencies in terms of nodes and edges or it is the visual representation of the elements and their interdependence. The final ISM model for RCM framework determined by removing the transitivity links from digraph and shown in Fig.2. It has found from MIC-MAC analysis that none of the factors comes under autonomous factor category, which indicates all factors identified from the literature review are essential for RCM framework and organizations should pay attention to all of them. System selection and information collection have the highest driving power and least dependence play a pivotal role in RCM implementation. This data collection will make the foundation of system description and functional block diagram. This leads to a criticality analysis of the subsystems/components effectively, which is the basis of FMECA. The FMECA helps in determining the best possible maintenance strategy for any organization. This maintenance strategy further assists implementation and management review phase followed by the final recommendation of managerial judgment. Based upon recommendation, the final maintenance program can be prepared, followed by the continuous revaluation after implementation of this. All these elements are essential for the development of RCM in various organizations. The main objective of this methodology is to create a clear structural view of contextual relationships of different elements, which will help the organizations to implement RCM successfully.

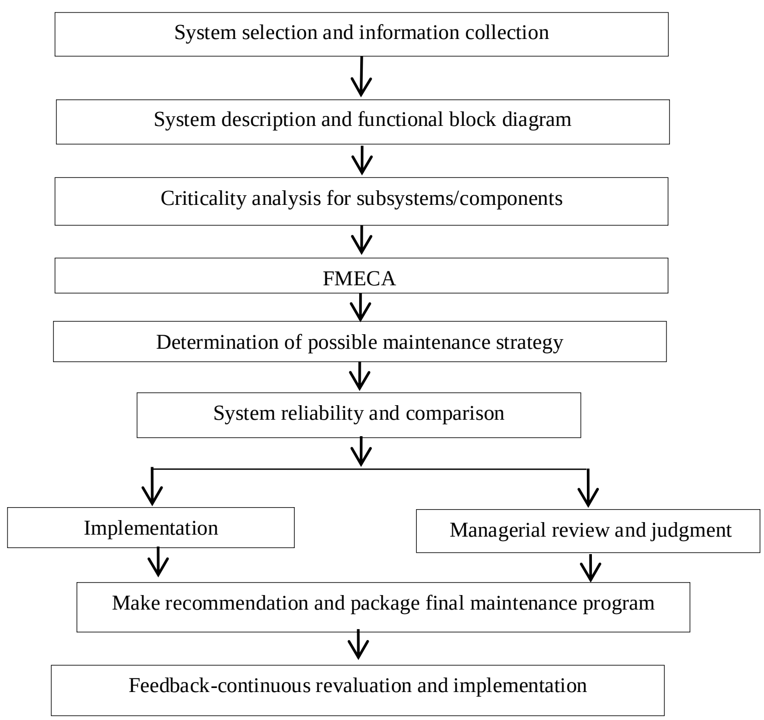


Figure 2. Final ISM Model of proposed framework for RCM

## 6. Conclusion:

The interpretive structural modelling (ISM) is used to determine the interrelationship of identified elements for RCM framework development. In addition, it is used to prioritized and categorized these elements based on their importance, preference, and causality over and among each other. The multilevel hierarchy framework model has developed from which, management/ managers who want to implement RCM, can easily visualize step by step procedure of RCM and can identify elements which required the highest attention and will pay stress accordingly.

This framework will help the organization to implement RCM successfully. However, the framework is not validated statistically. To validate it, Structural equation modeling (SEM) can be considered as a future work. The significance of this study is that, Proposed comprehensive framework for RCM process, can be implement including qualitative and quantitative analysis together at a time. However, in existing RCM procedure, the frameworks, which are available in literature, can implement either based on qualitative or quantitative analysis only.

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