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Development of a framework for implementation of World-class Maintenance Systems using Interpretive Structural Modeling approach

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Abstract

The purpose of this paper is to develop a framework for the implementation of World-class Maintenance Systems (WMS) with the help of Interpretive Structural Modeling (ISM) methodology. In our earlier work, the framework for WMS was proposed, which explained what constitutes WMS. As a follow up paper, an attempt has been made to present a detailed description about how an organization can implement WMS. To accomplish the same, a standard template is provided for describing the implementation of each and every element and their contextual relationships are also described by ISM methodology which shows driving power and dependence of each element. It is believed that such a normative presentation of the framework would benefit the managers in providing proper guidance and direction during implementation of WMS.

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Keywords: World class Maintenance Systems; Total Productive Maintenance; Interpretive Structural Modeling; Driving power; Dependence.

1. Introduction

With the increasing demand on productivity, quality and availability, machines have become more complex and capital intensive. Labib [1] noted that developing and implementing a maintenance program is a difficult process as it often suffers from lack of a systematic and a consistent methodology. The reason being that no two organizations are similar and each organization follows its own methodology of dealing with maintenance problems. Similarly, maintenance consultants from different countries have proposed different best practices, which were implemented in their client's organization and claim that such practices constitute world-class maintenance systems. However, Mishra et al. [2] proposed a framework earlier, describing the best practices in maintenance as elements of WMS as a solution to overcome the shortcomings of Total Productive Maintenance (TPM). The framework of WMS is built based on the underlying concepts of TPM, but incorporated the best practices within each element of it.

One of the drawbacks of TPM is that a proper implementation model is not available. Nakajima [3] has proposed a 12 step implementation methodology; however what tools and techniques to be implemented in each stage has not been explained properly. Furthermore, different implementation frameworks proposed by various consultants are complicated and confusing, making the organization to fail in their attempt to adopt TPM. Hence, the purpose of this paper is to develop a systematic framework for implementation of WMS. To accomplish this, Interpretive Structural Modeling (ISM) approach is adopted. ISM is an advanced interactive planning methodology that allows a group of people, working as a team, to develop a structure that imposes order and

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direction on the complex relationships among elements in a set [4].

2. Elements of framework for implementation of World-class Maintenance System

The framework for implementation of WMS is developed by ISM, based on literature review, discussions with experts and domain knowledge about the maintenance systems all elements are identified. As mentioned earlier, it is built on the basics of TPM; however this framework provides the practitioners with a number of best practices, drawn mainly from the experiences of organization in general and the failures and problems the organizations/consultants faced in particular, which were obtained from the case studies and literature. A definition of best practices adapted to the maintenance process can be referred as "maintenance practices that enable an organization to achieve a competitive advantage over its competitors and thereby achieve a status of world-class." Similar to any other function in an organization, maintenance too has different sub functions/activities/practices such as: spares parts management, inventory and procurement, operational involvement, etc. A complete list of elements and their associated practices/activities has been identified in the proposed framework for implementation of WMS. These elements/practices/activities are derived based on existing TPM knowledge and the implementation of best maintenance practices in various organizations as reported in the literature. Such information may assist or encourage organization to use these practices to improve the maintenance efforts and overall production performance. It should be noted that each WMS elements and its sub elements/practices/activities, tools and techniques are described briefly in Table 1.

Table 1: Elements under each stage of implementation of WMS

S.NO	Elements/Practices/Activities
1	Productivity
2	Ownership maintenance
	○ Autonomous inspection
	○ Operator involvement
	○ Initial cleanup/ adjustments/ lubrication/ tightening
	○ Participative management
	○ Troubleshooting
3	Policies and objectives /goals
	○ Training and development
	○ Manpower planning and staffing
	○ Cross-functional co-operation / co-ordination
	○ Incentive plans and benefits
	○ Performance management
	○ Enhancing employee relations
4	Long term commitment of top management and employee
5	Quality
6	Process quality maintenance
	○ Variation reduction in work processes
	○ Quality assurance
	○ Standardization of materials, methods and tools.
	○ Continuous improvement
7	Design of master plan
8	Self analysis
9	Delivery
10	Safety, health and environmental systems
	○ Regulatory compliance
	○ Environmental systems
	○ Safety systems
	○ 5S philosophy
	○ Occupational health systems
11	Flexibility
12	Leadership and change management
	○ Organization culture
	○ Maintenance strategy and policy deployment
	○ Cost distribution and financial control
	○ Participative management
	○ Empowerment
	○ Operator involvement
	○ Management support/commitment
13	Maintenance systems / practices / procedures
	○ Preventive maintenance
	○ Predictive maintenance
	○ Reliability centered maintenance
	○ Corrective maintenance
	○ Pro-active maintenance
	○ Planned/routine maintenance
	○ Maintenance standardization and documentation
14	Human resource development
	○ Training and development
	○ Manpower planning and staffing
	○ Cross-functional co-operation / co-ordination
	○ Incentive plans and benefits
	○ Performance management
	○ Enhancing employee relations
15	Cost
16	Eliminative maintenance
	○ Research and development of new process/ equipment
	○ Life cycle analysis
	○ Supporting / common facilities
	○ Initial control for process / equipment / product
17	Support systems improvement
	○ Work flow management
	○ Spares management
	○ Supporting / common facilities
	○ Contract /outsourcing management
	○ Supply chain management

S.NO	Elements/Practices/Activities
18	Morale
19	Improvement of process/equipment
	o Continuous improvement
	o Productivity
	o Process / equipment reliability
	o Process / equipment classification and standardization
20	Promotional organization
21	Effectiveness
22	Computer integrated maintenance management systems
	o Maintenance planning and scheduling
	o Knowledge management
	o Resource management
	o Support systems management
	o Process / equipment management
	o Material management
	o Work order planning and scheduling
	o Performance measurements and reports
	o Contract / outsourcing management
	o Financial control management
23	World class maintenance
24	Safety and work environment

3. ISM methodology and model development

Interpretive Structural Modeling (ISM) is a methodology for identifying and summarizing relationships among specific items, which define an issue or problem [5]. ISM is interpretive because the relation among the elements is given by group of members. It is structural also as based on the relationship; an overall structure is extracted from the complex set of variables. It is a modeling technique also as the specific relationships and overall structure is portrayed in a graphical model [6]. Following are the steps involved in the ISM technique:

3.1 Structural self-interaction matrix (SSIM)

The type of contextual relationships among the elements is indentified by Group of experts, from industries and the academics. For developing the SSIM, following four symbols are used to show the direction of relationship between elements (i and j):
V – Element j will be achieved by element i;
A – Element i will be achieved by element j;
X – Element i and j will help to achieve each other; and
O –both elements i and j are unrelated. (See Table 2)

3.2 Reachability matrix

After the SSIM, initial reachability matrix has been developed by replacing V, A, X and O by 1 and 0 as per given by Jharkharia and Shankar [7]:

- 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.

For final reachability matrix transitivity is checked. Transitivity is if element one is related to 2 and 2 is related to 3; element 1 must be related to 3 (See Table 3). The driving power for each element is the total number of element (including itself), which it may assist to achieve. Dependence is the total number of elements (including itself), which may assist to achieve it.

3.3 Level partitions

After the final reachability matrix, level partition takes place. For this reachability and antecedent set for each element is obtained (shown in Table 4).The reachability set consists of the element itself and the other elements which it may help achieve, whereas the antecedent set consists of the element itself and the other elements which may help in achieving it [6]. After that, the intersection set is obtained for all elements. The element, for which the reachability set is same as the intersection set, comes at the top of the ISM hierarchy. It implies that this top-level element will not lead to achieve any other element. After the identification of the top-level element it is removed out from the other elements. Then the number of iteration of this process is done to get the level of each element.

3.4 Classification of elements: MIC-MAC analysis

Based on driving power and dependence, all elements have been categorized, into four categories: autonomous elements (weak driving power, weak dependence) dependent elements (weak driving power, strong dependence) linkage elements (strong driving power and strong dependence) and independent elements (strong driving power weak dependence).

Figure 1: Driving power v/s dependence diagram for elements

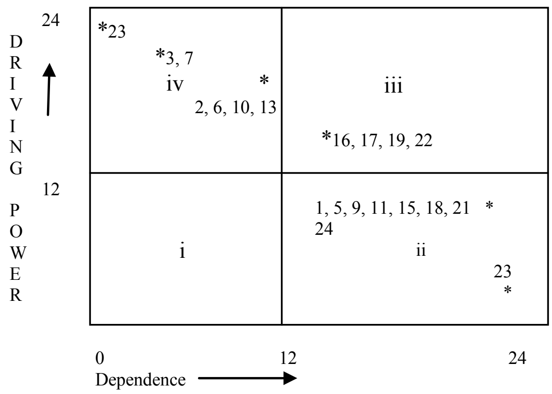


Table 2: Structural self-interaction matrix (SSIM)

S. N.	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	X	V	A	X	A	A	X	O	A	X	A	A	A	X	A	X	A	A	A	X	A	A	A	
2	V	V	V	V	A	V	V	V	V	V	A	X	A	V	X	V	A	A	X	V	A	A		
3	V	V	V	V	A	V	V	V	V	V	A	V	A	V	V	O	A	X	V	V	A			
4	V	V	V	V	X	V	V	V	V	V	X	V	X	V	V	V	X	V	V	V				
5	O	V	A	X	A	A	O	O	A	X	A	A	A	X	O	X	A	A	A					
6	V	V	V	V	A	V	V	V	V	V	A	X	A	V	X	V	A	A						
7	V	V	O	V	A	V	V	V	V	V	A	V	A	V	V	V	A							
8	O	V	V	V	X	V	V	V	V	V	X	V	X	V	O	V								
9	A	V	O	X	A	A	X	O	A	X	O	A	A	O	A									
10	V	V	V	O	A	V	V	O	O	V	A	V	A	O										
11	O	V	A	X	A	A	X	O	O	X	O	A	A											
12	V	V	V	V	X	V	V	V	V	V	X	V												
13	O	V	V	V	A	V	A	V	V	V	A													
14	V	V	V	V	X	V	V	V	V	V														
15	O	V	A	X	A	A	O	V	A															
16	V	V	X	V	A	X	V	X																
17	V	V	X	V	A	X	V																	
18	X	V	O	X	A	A																		
19	A	V	X	V	A																			
20	O	V	V	V																				
21	X	V	A																					
22	V	V																						
23	A																							
24																								

Table 3: Final reachability matrix

S.N.	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	Driving power
1	1	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	9
2	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	0	0	1	1	0	0	1	1	17
3	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1*	0	1	1	1	0	1	1	1	19
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
5	1	1	0	1	0	0	1*	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	9
6	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	0	0	1	1	0	0	1	1	17
7	1	1	1*	1	0	1	1	1	1	1	0	1	0	1	1	1	0	1	1	1	0	1	1	1	19
8	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1*	1	1	1	1	1	1	1	1	1	24
9	1*	1	0	1	0	0	1	0	0	1	0	0	0	1*	0	1	0	0	0	1	0	0	0	1	9
10	1	1	1	1*	0	1	1	1	1	1	0	1	0	1*	1	1	0	0	1	1	0	0	1	1	17
11	1*	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1*	0	0	0	1	0	0	0	1	9
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24
13	1*	1	1	1	0	1*	1	1	1	1	0	1	0	1	1	1	0	0	1	1	0	0	1	1	17
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1*	1	1*	1	1	1	1	1	1	1	1	24
15	1*	1	0	1	0	0	1*	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	9
16	1	1	1	1	0	1	1	1	1	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	13
17	1	1	1	1	0	1	1	1	1	1	0	0	0	1	0	1*	0	0	0	1*	0	0	0	1	13
18	1	1	0	1	0	0	1	0	0	1*	0	0	0	1	0	1	0	0	0	1*	0	0	0	1	9
19	1	1	1	1	0	1	1*	1	1	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	13
20	1*	1	1	1	1	1	1	1	1	1	1	1	1	1*	1	1	1	1	1	1	1	1	1	1	24
21	1	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	9
22	1	1	1	1	0	1	1*	1	1	1	0	0	0	1	0	1*	0	0	0	1	0	0	0	1	13
23	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
24	1	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	9
Dependence	23	24	15	23	5	15	23	15	15	23	5	11	5	23	11	23	5	7	11	23	5	7	11	23	351/351

Table 4: Level partition first iteration

S.N.	Reachability set	Antecedent set	Intersection set	level
1	1,5,9,11,15,18,21,23,24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24	1,5,9,11,15,18,21,24	
2	1,2,5,6,9,10,11,13,15,16,17,18,19,21,22,23,24	2,3,4,6,7,8,10,12,13,14,20	2,6,10,13	
3	1,2,3,5,6,7,9,10,11,13,15,16,17,18,19,21,22,23,24	3,4,3,8,12,14,20	3,7	
4	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24	4,8,12,14,20	4,8,12,14,20	
5	1,5,9,11,15,18,21,23,24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24	1,5,9,11,15,18,21,24	
6	1,2,5,6,9,10,11,13,15,16,17,18,19,21,22,23,24	2,3,4,6,7,8,10,12,13,14,20	2,6,10,13	
7	1,2,3,5,6,7,9,10,11,13,15,16,17,18,19,21,22,23,24	3,4,3,8,12,14,20	3,7	
8	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24	4,8,12,14,20	4,8,12,14,20	
9	1,5,9,11,15,18,21,23,24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24	1,5,9,11,15,18,21,24	
10	1,2,5,6,9,10,11,13,15,16,17,18,19,21,22,23,24	2,3,4,6,7,8,10,12,13,14,20	2,6,10,13	
11	1,5,9,11,15,18,21,23,24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24	1,5,9,11,15,18,21,24	
12	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24	4,8,12,14,20	4,8,12,14,20	
13	1,2,5,6,9,10,11,13,15,16,17,18,19,21,22,23,24	2,3,4,6,7,8,10,12,13,14,20	2,6,10,13	
14	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24	4,8,12,14,20	4,8,12,14,20	
15	1,5,9,11,15,18,21,23,24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24	1,5,9,11,15,18,21,24	
16	1,5,9,11,15,16,17,18,19,21,22,24	2,3,4,6,7,8,10,12,13,14,16,17,19,22	16,17,19,22	
17	1,5,9,11,15,16,17,18,19,21,22,24	2,3,4,6,7,8,10,12,13,14,16,17,19,22	16,17,19,22	
18	1,5,9,11,15,18,21,23,24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24	1,5,9,11,15,18,21,24	
19	1,5,9,11,15,16,17,18,19,21,22,24	2,3,4,6,7,8,10,12,13,14,16,17,19,22	16,17,19,22	
20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24	4,8,12,14,20	4,8,12,14,20	
21	1,5,9,11,15,18,21,23,24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24	1,5,9,11,15,18,21,24	
22	1,5,9,11,15,16,17,18,19,21,22,24	2,3,4,6,7,8,10,12,13,14,16,17,19,22	16,17,19,22	
23	23	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24	23	First
24	1,5,9,11,15,18,21,23,24	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,24	1,5,9,11,15,18,21,24	

4. Formation of ISM model and discussion

Levels of each element have been obtained (see Table 5) which will help in formation of ISM model. A digraph is created from the final reachability matrix and after eliminating the transitivities from digraph final ISM model for WMS has been developed as shown in Figure 2.

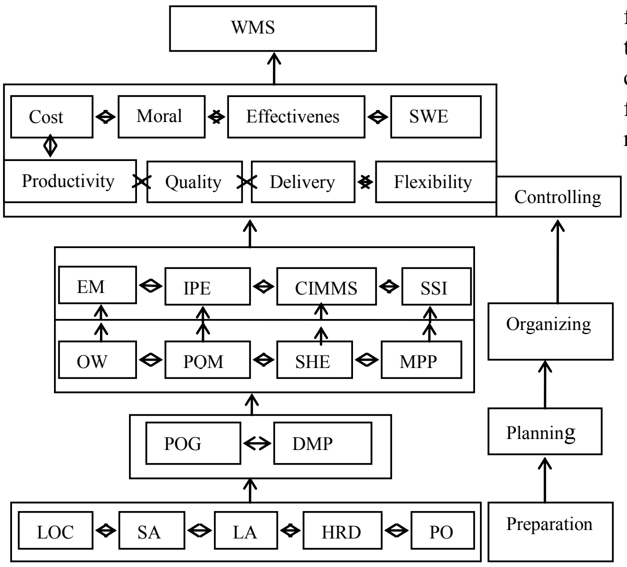
Table 5: Level partition of each element

S.N.	Elements	Level No.
1	23	First
2	1,5,9,11,15,18,21,24	Second
3	16,17,19,22	Third
4	2,6,10,13	Fourth
5	3,7	Fifth
6	4,8,12,14,20	Sixth

From the MIC-MAC analysis, it has been found that none of the element falls under autonomous element category, which means all elements found from the literature review are necessary and organizations have to give attention to all. Elements' long term commitment of top management and employee, self analysis leadership and change management, human resource development and promotional organization have the highest driving power and least dependence, so these are key elements and fall under preparation phase of WMS. Effective implementation of these elements will improve planning phase of organization. A further improvement in design of master plan, policies objectives/goals will lead to improve ownership of maintenance, process quality of maintenance safety, health and environmental systems, maintenance systems/practices/procedures. Improvements in above elements will support systems improvement,

improvement of process/equipment, eliminative maintenance and computer integrated maintenance systems.

Figure 2: Framework for implementation of world-class maintenance system



LOC: Long term Commitment of Top Management and Employees
LAC: Leadership and Change Management SA: Self Analysis
HRD: Human resource development PO: Promotional Organization
POG: Polices and Objectives/Goals DMP: Design of Master Plan
OW: Ownership Maintenance EM: Eliminative Maintenance
PQM: Process Quality Maintenance IPE: Improvement of Process/Equipment
SHE: Safety, Health and Environmental systems CIMMS: Computer Integrated Maintenance Management Systems
MPP: Maintenance systems/Practices/Procedure SSI: Support Systems Improvement
SWE: Safety Work and Environment WMS: World-class Maintenance System

All these elements fall under organizing phase. Effective implementation of organizing phase raises the productivity, quality, flexibility, safety and work environment and morale of organization, also reduces the cost and improves delivery. Now further improvement of this controlling phase will finally achieve the WMS. All these elements play a pivotal role for the implementation of WMS in several organizations. So this paper gives a clear understanding of contextual relationships among these elements with the help of ISM approach.

5. Conclusion

Implementation of WMS is a never-ending process and investing in WMS implementation does pay off, though it often implies a choice for a long-term effort that requires a great deal of energy, management attention, money, patience, and tenacity. This paper gives a clear understanding of contextual relationships among various elements of WMS. It should be noted that organizations are different in terms of their people, culture, history, goals, structure, products, services, technologies, processes, and operating environments. Therefore, they should combine their own uniqueness and knowledge with this framework and consequently develop their own ways to reach excellence. Thus, organization can optimize the use of this framework by blending it with and applying it to its own situations, allowing their own methods to better suit their situations. However it is worth to note that this framework has not been statistically validated. So to validate this WMS framework Structural equation modelling (SEM) can be seen as a future work. However the implementation of framework will lead to the application of best practices in maintenance, and hence can lead to following benefits:

- Constructs competitive capacities for production by means of best practices in maintenance.
- Maintains the highest standards of productivity.
- Reduces overall equipment emergencies.
- Reduces maintenance purchasing.
- Provides a systematic approach for improving the efficiency of the production system by eliminating all losses.
- Helps to develop equipment, which is designed for maintainability and reliability to realize reduced life cycle cost.
- Assures a good product quality through investigation, analysis and improvement of process, material and equipment conditions.
- Aids in achieving of zero accidents in a healthy and clean work environment and protect the natural environment.
- Develops a flexible, multi-skilled organization with internal experts.
- Ensures the investments that are made in the assets are highly profitable as it can be used to obtain better levels of reliability. Helps to optimize the maintenance cost and
- Provides better services to operations through Computer Integrated Maintenance Management Systems (CIMMS), teamwork, use of latest tools and technologies.

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