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A Practical Self-Assessment Framework for Evaluation of Maintenance Management System based on RAMS Model and Maintenance Standards

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Abstract

A set of technical, administrative and management activities done during the life cycle of equipment in order to improve its condition and functioning to a proper and expected level is called maintenance management system (MMS). The framework and models of assessment in order to enhance effectiveness of a MMS could be proposed in two categories: qualitative and quantitative. In this research, the self-assessment's dimensions of MMS which affect the successful implementation of this system in companies have been established and examined. This research uses a case study and review methodology (second hand material such as TPM, ISO 14224 and IEC 60300-3-14 and RAMS model) to extract dimensions, related indices and issues about how MMS must be measured and self-assessed these dimensions and indices. According to surveys and studies done by the authors the common dimensions of frameworks and models for evaluating MMS have been determined which includes; maintenance organization, training programs in maintenance, maintenance reporting, reliability engineering, maintenance – general practices, financial optimization, asset care continuous improvement, maintenance contracting, document management, the safety level of work environment, maintenance inventory and purchasing, predictive maintenance (PdM), maintenance work orders, maintenance planning and scheduling, maintenance automation(CMMS), operations/ facilities involvement on running of maintenance programs, preventive maintenance (PM) and maintenance quality management (MQM). Additionally, this paper presented a self-assessment framework based on the above mentioned topics for evaluation and placement of the MMS according to the total score obtained in a Wireman pyramid. Then, according to the review of the literature, the appropriate indicators for each dimension of evaluation have been extracted and the framework has been tested in a petrochemical company.

Keywords: maintenance management system; self-assessment framework; evaluation, total preventive maintenance (TPM); IEC 60300-3-14 standard; RAMS model

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1- Introduction

On the one hand, the increase in investment on industrial machinery and automation, and the increasing financial and economic value of machinery, on the other hand, made managers and industry owners think of logical solutions that enable them maximize useful lifetime of manufacturing equipment and extend their economic life cycle. In industrial plants, machinery is constantly being eroded, so one of the most significant issues is maintenance of machinery. The necessity of designing and implementing maintenance systems in factories is one of the critical and vital issues in today's industry. Saving the nation's funds and the high expenses of purchasing machinery and equipment warrant a rational and planned use of machinery and demands a timely maintenance of machinery and equipment. Strengths and weaknesses of this sector directly affect productivity and profitability of production (Tabatabaei *et al.*, 2007) Maintenance is a pervasive issue in an organization / company that involves sense and operational incentives and decision-making at different levels of organization from operators to managers of the organization. Maintenance is an administrative and managerial process and maintenance decisions made must be based on management maturity and engineering / technical sophistication in order to meet universality and overall acceptability of the whole organization. Thus, maintenance should be planned, implemented, and controlled in the form of a planning or engineering system from the very beginning of a project investment (for example, expanding the capacity of production or building a complex / refinery) to continuous productivity so as to ensure the performance and efficiency of equipment as well as constant production. Therefore, the components and processes of maintenance system in an organization must be clearly defined in a standardized form and the processes involved in maintenance must be designed from the very beginning (Márquez, 2007).

Self-assessment models and frameworks of maintenance management system are presented in two categories: qualitative and quantitative. Most quantitative assessment models proposed in previous studies are based on TPM concepts or related standards such as ISO 14224 and IEC 60300-3-14 standard while quantitative models are based on indicators such as reliability, availability and maintainability. Recently, the RAMS system including the above-mentioned indicators along with safety issues has been increasingly utilized.

1-1- Common framework for improving maintenance

Different frameworks and techniques have been used for assessment of maintenance management systems. For example, Wireman proposed a set of consecutive steps for the implementation of maintenance in order to ensure that all of the maintenance management functions are carried out. He believes that there should be a preventive maintenance in the first stage before moving on to the next step. The second step is the establishment and implementation of CMMS. He states that before taking reliability-centered maintenance (RCM) and predictive maintenance programs, a well-disciplined system to do tasks (for the right timing and implementation of the activities in order of priority) and a system for the management of maintenance resources are required. The operator also must be aware of the importance of their role in the maintenance general functioning. In this case, in addition to their role as a regular employee of the organization, the operator is assigned to perform and implement the maintenance processes in the next stage. It should be noted that TPM, which is an initiative of 1980, is composed of management initiatives and interventions (like TQM) that can help an operator play their role and can help promotion of the use of optimization techniques. TPM can also prove beneficial in creating the necessary structure for the maintenance in the organization and will facilitate continuous improvement in maintenance activities. See the overall picture of Wireman model in Figure 1 (Márquez, 2007).

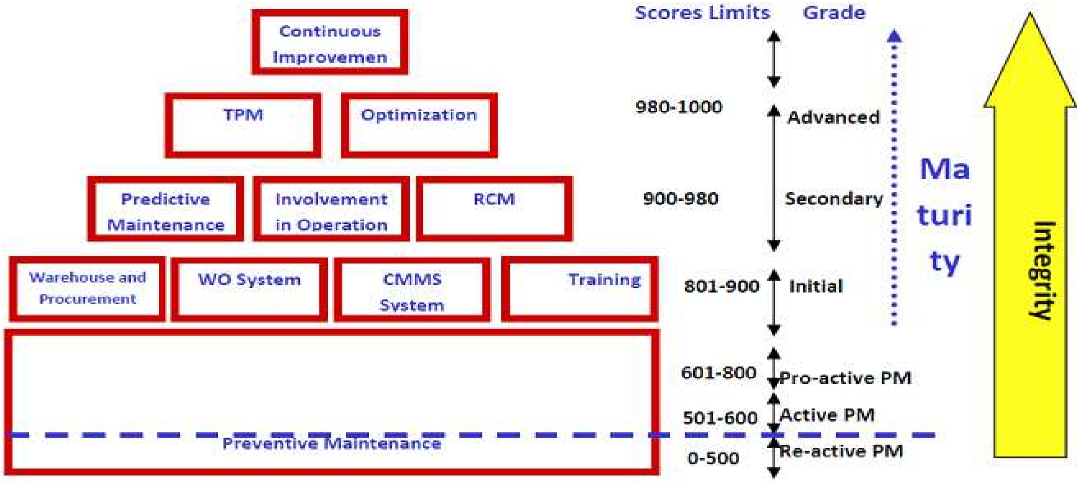

Figure 1. Framework and maturity level of maintenance management system based on Wireman (Márquez, 2007)

Campbell & Jardine (2001) also suggests a formal structure for the effective management of maintenance (see Figure 2). This process begins with developing a strategy for each asset and is closely related to the business plan. Aspects related to human resources that are needed to create cultural change have been considered in this model. Next, the organization gains control to ensure the proper function of each asset's life cycle. This is carried out by the implementation of a CMMS, a maintenance function measurement system, and planning and scheduling the maintenance activities. In this regard, a different set of tactics are employed based on the selection of the value and risk of the asset to the organization. Among these tactics, Campbell & Jardine (2001) will consider the following:

- Operating a machine until failure occurs,
- Duplication,
- Scheduled replacement,
- Scheduled overhauls,
- Ad-hoc maintenance,
- Preventive maintenance,
- Age or use based maintenance,
- Condition based maintenance, and
- Redesign.

Finally, Campbell & Jardine (2001) proposes the implementation of RCM and TPM as two highly successful methods for continuous improvement. He also recommends that process reengineering method (activity-based process mapping techniques, techniques for analysis of the process value, and innovative and visual techniques for the process) to make a dramatic and noticeable improvement, if used step by step.

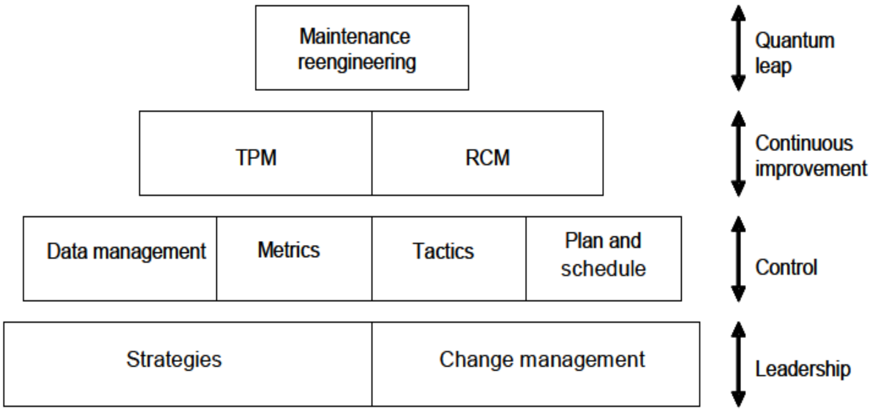

Figure 2. Maintenance framework based on Campbell (Campbell & Jardine, 2001)

Pintelon and Puyvelde (1997) provide an instrument for evaluating the performance of maintenance. The instrument consists of a control board and a set of reports to analyze specific ratios. This instrument is used in various areas under the maintenance management control: budget / cost of equipment, personnel performance, materials management and controlling work priority. For each of these areas, the control board displays the ratios in different ways as actual or expected data, goals, necessities, and requirements. Waeyenbergh and Pintelon (2002) discuss the framework that involves the main aspects of maintenance management. This framework is made up of two blocks:

- Activities related to system design, operations management/ maintenance management: This aspect associates maintenance management with broader business concepts and contexts; business in which marketing concepts, operational and financial issues are interacting with each other not the type of business in which each operation is confined to pursuing its own limited goals. In this study, maintenance management has been considered as a secondary function of operation.
- The second block concerns decision making about maintenance management is control and planning which includes decisions that maintenance manager within the main three functions of (marketing, finance and operations), resource management and performance reporting. Maintenance theories and methods are technically more complex (e.g., maintenance technology, the study of technical content materials that can improve maintenance like method of repair or new monitoring techniques to improve maintenance design) and they have not been directly discussed here.

1-2- Measurement and Control of maintenance management activities

A complete set of indicators for monitoring and improving maintenance management can be found in references Wireman (2005) and Campbell & Jardine (2001). For example Wireman defines a set of criteria which are divided into cooperative, financial, efficiency, technical, and functional groups in the source (Wireman, 2005). He asserts that people should use the indicators that are correctly linked with cooperative indicators. Objectives of performance indicators are as follow:

- Identifying the strategic objectives
- linking core business processes with the objectives
- Focusing on significant success factors and pursuing performance processes
- Identifying possible solutions to the problems

To assess the various instruments of maintenance management, a group of indicators are shown in the Wireman’s book. Table 1 displays a summary of a various functions related to maintenance engineering unit.

Table 1. Classification of functions within the ME methods (Márquez, 2007)

Functions of the ME Methods pillar	Design of the maintenance plan and its process of continuous improvement	Failure analysis, reliability analysis and risk analysis of the system's operation
		Design of the maintenance plan
		Ensure the total employees involvement in maintenance, to pursue continuous improvement
		Management of maintenance resources
	Optimization of the maintenance policy	Analysis and preparation of reliability and availability data of the system
		Analysis and preparation of maintenance financial data of the system
		Modeling systems for their maintenance policy optimization
	Measurement and control of maintenance engineering activities	

1-3- Maintenance assessment frameworks and models

With the emergence of various methods and techniques to improve work, we are increasingly seeing progress in many aspects of our industry. The purpose of these methods is to provide strategies on which we can rely in order to identify the work details and stages correctly and select the best method to carry out each and every stage. In the present era, measuring the performance is the best ways to obtain information for decision-making in organizations and plays a vital role in their success. However, majority of organizations have not developed and employed proper formal processes for evaluating their performance (Tabatabaei *et al*., 2007). The most important issue in the implementation of optimal maintenance in industry is having sufficient data and information to identify the gap between the existing conditions of the organization and the ideal situation and finally take the steps needed to fill the current gap between the two situations (Jalali & Mahpeykar, 2009). To this end, several models have been developed to measure the performance in organizations though each has its own advantages and disadvantages. If we develop a unified approach including a uniform set of criteria for the evaluation of their performance among organizations, it will, then, enable us to relatively compare organizations in terms of their performance. Evaluating the performance of organizations includes defining appropriate set of criteria, taking into account the entire input, procedures, output, and the whole consequences of the organization activities. Such evaluation would enable managers to compare the performance of the organization not only with other organizations but also with the performance of their own organization over the past years (Tabatabaei *et al*., 2007). Various methods have been used to assess the maintenance system both qualitatively and quantitatively. Azadeh *et al*. (2010) improved the maintenance process by using a method called fuzzy inference for evaluating the failure of pumps in the petrochemical industry. Tabatabai *et al*. (2007) provided a practical model of BSC to enhance the performance of maintenance system in a manufacturing plant and utilized appropriate criteria for reporting of the system for each of the aspects mentioned in the strategy map (Tabatabaei *et al*., 2007. Jalali & Mahpeykar, 2009) provided a check list for audit of maintenance activities. Ostadi *et al*. (2005) used a preventive maintenance in cement rotary furnace considering the availability of components in a system, Davoodi and Ghahramani (2010) employed a reliable method for maintenance management of rail. (Avestakhan *et al*., 2012) assessed the level of safety in production environments using fuzzy method. One of the most significant issues affecting the effectiveness of a maintenance system is frameworks and models used for the evaluation of maintenance system. Earlier research studies indicated that such frameworks and models have been offered in two categories: qualitative and quantitative. Most qualitative evaluation models are based either on TPM concepts or on the audit of the management system standards such as IEC 60300-3-14 (reliable management system), the standard ISO 14224 (principles for collecting reliable data and maintenance), etc. In some cases, however, assessments based on RAMS model have been proposed. In effect, in such a model of maintenance evaluation, the quantitative approach is mainly adopted. Quantitative models are based on indicators of reliability, maintainability, and availability. In recent years, RAMS system (including safety parameters in addition to the above-mentioned indicators) has been utilized as one of the most widely used systems among quantitative models.

2- Research Methodology

2-1- Completion status of the proposed framework

By reviewing earlier research studies, we found out that various dimensions influencing maintenance were identified and dealt with by researchers. These dimensions are presented in the table below.

Table 2. Frameworks and models have been studied by various authors

Main topics	Reference	Year
Reliability analysis to study the PM influence	Shankar & Sahani	2003
Provide an implementation check list for a TPM system	Jalali & Mahpeykar	2009
Provide a mechanism of fault finding, pumps by a fuzzy inference system	Azadeh *et al.*	2010
Provide PM policy considering the optimal availability of system	Ostadi *et al.*	2005
Using the relations of dependability in order to assess the reliability of rail failure and its growth rate	Davoodi , Ghahramani	2010
Provide functional model of BSC to enhance maintenance system performance of a manufacturing plant	tabatabai *et al.*	2007
Develop a comprehensive approach to evaluating manufacturing systems based on the dependability indices	Rezaie *et al.*	2009
Using TPM to improve status in Babacan textile company	Tavakoli-Moghaddam *et al.*	2013
Use of maintenance quality management and presented PMO techniques (optimization PM) as an efficient approach to eliminate unnecessary maintenance activities	Ramezani & Barzegar	2011
Risk assessment to determine safe levels of production environments by fuzzy method	Avestakhan *et al.*	2012

Table 2. Continued

Main topics	Reference	Year
Provide a framework for evaluating and improving the performance of shipboard equipment based on the dependability	Ebrahimipour & Suzuki	2006
Presentation the approaches for predictive analysis of potential human error	Kim & Park	2010
Presentation PSO[1] models and offer maintenance programming to establish units based on the optimization of the components using probabilistic risk optimization method	Suresh & Kumarappan	2010
Evaluation of CBM[2] in multi component systems with the economic relationship between the various components and provide a CBM procedure for them based on PHM model and develop a numerical algorithm for the accurate assessment of the cost of PHM based on a multi-component CBM approach	Tian & Liao	2011
Presentation a new application of virtual maintenance to maintenance safety evaluation	Geng *et al.*	2013
Improve the efficiency, reliability and safety associated with rail maintenance tasks using FMECA and provide new maintenance activity based on the evaluation results of preventive maintenance tasks	Jaehoon & Jeong	2013

2-2- The proposed framework for the evaluation of maintenance management system

In Table 2, the Frameworks and models studied by various authors are presented. Each of these researchers focuses on particular aspects of evaluation of maintenance management system. Upon classifying these scales as well as the required dimensions for maintenance of this system, the following pivots have been suggested. To validate these pivots, the authors of this article reviewed the related research studies to provide the corresponding studies to each pivot (table 3.).

Table 3. The authors focus on different aspects

Main topics	References
The safety level of work environment	(Avestakhan *et al*., 2012), (Geng *et al*.,2013), (Jie,Wensheng, 2012), (Zahara, Mushalia, 2012) (Hinze Thurman, Wehle, 2013), (Brown, 2000), (Schrörs, 2010)
Preventive Maintenance	(Ostadi *et al*., 2005), (Jalali, Mahpeykar, 2009), (Shankar, Sahani, 2003), (Wireman,2004), (Kolahan,Doostparast,2014), (Mercier,Pham,2012), (Garcia *et al*., 2014), (Selvik,Aven, 2011), (Dehayem,Gharbi, 2011)

[1] particle swarm optimization
[2] Condition based maintenance

Table 3. Continued

Main topics	References
Maintenance inventory and purchasing	(Zheng,Xu, 2004), (Wireman, 2004), (Van Horenbeek *et al*.,2013), (Smith,Hawkins, 2004)
Maintenance work orders	(Wireman, 2004), (Palma *et al*., 2010)
Maintenance planning and scheduling	(Márquez, 2007), (Wireman, 2004),(Commission I.E, 2004), (Siener, Aurich, 2011),(Patankar *et al*.,2009), (Fattahi *et al*.,2014), (Ming, Raghava ,2008)
Maintenance automation (CMMS)	(Wireman, 2004), (Durán, 2011), (Jalali,Gholaamzade, 2012), (Mädera,Gotelb, 2012) ,(Bertolini *et al*., 2009),(Waeyenbergh, Pintelon, 2002)
Operations/ facilities involvement on running of maintenance programs	(Jalali, Mahpeykar, 2009),(Kim & Park, 2012), (Wireman, 2004)
Predictive Maintenance (PdM)	(Márquez, 2007), (Ming, Raghava , 2008), (Beebe,2004),(Efthymioua *et al*., 2012), (Carnero, 2006), (Carnero Moya, 2004), (You *et al*., 2010), (Gilabert, Arnaiz, 2006)
Maintenance quality management (MQM)	(Kim & Park, 2012), (Siener,Aurich, 2011), (Wireman, 2004), (Dhillon, Liu, 2006), (Singh *et al*., 2013), (Bevilacqua *et al*., 2009), (Pandey, Vrat, 2011), (Leong *et al*., 2012), (Zawawi *et al*., 2011), (Lundteigen *et al*., 2009)
Maintenance organization	(Jalali, Mahpeykar, 2009) (Tavakoli-Moghaddam *et al*., 2013) ,(Wireman, 2004) ,(Hansson, Backlund, 2003), (Smith, Hawkins, 2004),(Reiman, Oedewald, 2006)
Training programs in maintenance	(Commission I.E, 2004),(Wireman,1992),(Smith, Hawkins, 2004)
Maintenance reporting	(Commission I.E, 2004), (ISO *14224,2006)* ,(Pintelon, Puyvelde, 1997) ,(Burgman, Roos, 2007)
Reliability Engineering (RCM)	(Carnero, 2006), (Wireman, 2004), (Zheng, Xu, 2004),(Azadeh *et al.* ,2010), (Deshpande, Modak, 2002) ,(Hansson, Backlund, 2003),(Chiodo *et al*., 2004) ,(Nilsson, Bertling, 2007), (Waeyenbergh, Pintelon, 2002) , (Kolahan, Doostparast, 2014), (Selvik, Aven, 2011)

Table 3. Continued

Main topics	References
Maintenance – general practices	(Commission I.E, 2004), (ISO *14224, 2006)*, (IEC 60300, 2004)
Financial optimization	(Komonen, 2002), (Wireman, 2004),(Wessels, 2003) ,(Khan, Haddara, 2003)
Asset care continuous improvement	(Wireman, 2004), (Wireman, 1992),(Azadeh *et al*., 2007), (Delgado *et al*., 2014),(Cachay, Abele, 2012)
Maintenance contracting	(Wireman, 2004), (ISO *14224, 2006)*, (Teixeira de Almeida, 2001),(Kumar *et al*., 2004), (Wu, 2012), (Jackson, Pascual, 2008), (Cavalieria *et al*., 2008)
Document management	(Commission I.E, 2004), (Wireman, 2004), (Durán, 2011)

2-3- Formula to calculate a system score and identify its placement in the Wireman pyramid

If M is the obtained score of a company in proportion to the evaluation pivots, and MAX is the total score for the proposed framework, then:

$$MMS\ Self - Assesment = R = \frac{1000 * \ M_i * \sum_j Ind(i,j)}{max} \qquad (1)$$

i=1, 2, …, *n*; *j*=1, 2, .., *m*; max shows the total score gained in the framework; M_i shows weight of *i*th dimension; (i, j) indicates the score of Index *i* at dimension *j* and *R* is the average score of self-assessment for a typical company.

The obtained score of a system for placement in the pyramid = (1000 * M) / MAX (2)

After calculating the scores, we can identify where in the pyramid the system fits and find out the placement of the system according to table (4).

Table 4. Determining a company's ranking Based on the scores and the Wireman Pyramid

Interval, the final score is calculated based on the proposed framework	Grade	No.
0-500	Re-active PM	1
501-600	active PM	2
601-800	Pro- active PM	3
801-900	initial	4
901-980	secondary	5
981-1000	advanced	6

3- Implementation the self-assessment framework in a case study

In this study, a company and its relevant parts of the maintenance management were observed and investigated in order to conduct a quantitative evaluation and audit of refinery maintenance management system based on the designed checklist.

During the assessment, the units and individuals were interviewed using questions included in the checklist in order to carry out the evaluation along with audits based on evidence of maintenance management system. Summary of assessment provided in table 5.

Table 5. Summary earned refinery maintenance management system

		Number of Criteria																				
	Dimension	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	W_i	$\sum$	$\bar{x}$
1	Maintenance organization	3	1	4	2	4	3	3	3	3	3	4	-	-	-	-	-	-	-	0.12	33	3
2	Training programs	4	4	4	4	4	4	4	4	3	3	2	-	-	-	-	-	-	-	0.04	40	3.64
3	Maintenance work orders	0	1	1	4	1	3	0	4	0	3	4	2	2	-	-	-	-	-	0.05	25	1.92
4	Maintenance planning and scheduling	4	4	4	3	4	1	4	4	0	4	2	2	-	-	-	-	-	-	0.06	36	3
5	Preventive Maintenance	4	4	4	4	4	4	4	0	4	4	4	4	2	4	2	-	-	-	0.04	52	3.47
6	Maintenance inventory and purchasing	3	1	0	2	4	4	4	4	4	4	2	4	4	-	-	-	-	-	0.06	40	3.08
7	Maintenance automation	3	2	0	0	0	0	4	4	2	0	2	1	2	2	2	3	2	-	0.04	29	1.71
8	Operations/ facilities involvement	4	0	2	2	4	2	4	4	4	4	0		-	-	-	-	-	-	0.04	30	2.73
9	Maintenance reporting	0	4	2	0	2	2	3			4	-	-	-	-	-	-	-	-	0.04	17	1.7
10	Predictive Maintenance	4	2	2	0	4	0	4	4	4	4	2	-	-	-	-	-	-	-	0.05	30	2.73
11	Reliability engineering	1	0	0	0	1	1	0	0	0	0	2	1	0	2	1	3	0	1	0.07	13	0.72
12	Maintenance – general practices	4	3	1	3	3	4	3	3	0	4	-	-	-	-	-	-	-	-	0.5	28	2.8
13	Financial optimization	0	0	2	4	4	4	0	4	4	1	2	1	1	2	1	2	-	-	0.07	32	2
14	Asset care continuous improvement	4	4		4	4	3	4		0	3	2	1	1	2	-	-	-	-	0.06	32	2.29
15	Maintenance contracting	3	3	3	4	4	1	3	0	3	3	2	3	-	-	-	-	-	-	0.05	32	2.67
16	Document management	2	0	4	4	4	4	4	4	4	4	2	-	-	-	-	-	-	-	0.07	36	3.27
17	The safety level of work environment	4	2	3	1	2	1	3	3	3	2	3	3	3	4	-	-	-	-	0.05	37	2.64
18	Maintenance quality management	3	3	2	4	3	2	2	2	3	4	3	4	-	-	-	-	-	-	0.04	35	2.92
Total score obtained																					577	2.57
The total possible score																					904	4
The percentage of compliance		Considering coefficient = 620.1 regardless coefficient = 638.2																				

In the above table, W_i is the corresponding weight (relative importance) of dimension i and $\sum$ is the corresponding total score dimension i obtained and $\bar{x}$ is the mean score dimension I obtained.

After calculating the above table for each company, we will have:

$$MMS\ Self - Assesment = R \quad (3)$$

The results indicated that issues such as performance training programs and RCM performance improvement seem necessary. According to the scores and wireman pyramid, the results of quantitative assessment showed that total percent of compliance refinery is equal to 624.5 and the ranking of maintenance management system is in the active preventive maintenance (PM pro- active). To reach the next level of the pyramid (initial), the system needs to improve in those cases when the company rating is low, especially in the training, CMMS, purchasing and inventory systems as well as agenda needed for fundamental improvement. RADAR charts (Figure 3) were used to show the results.

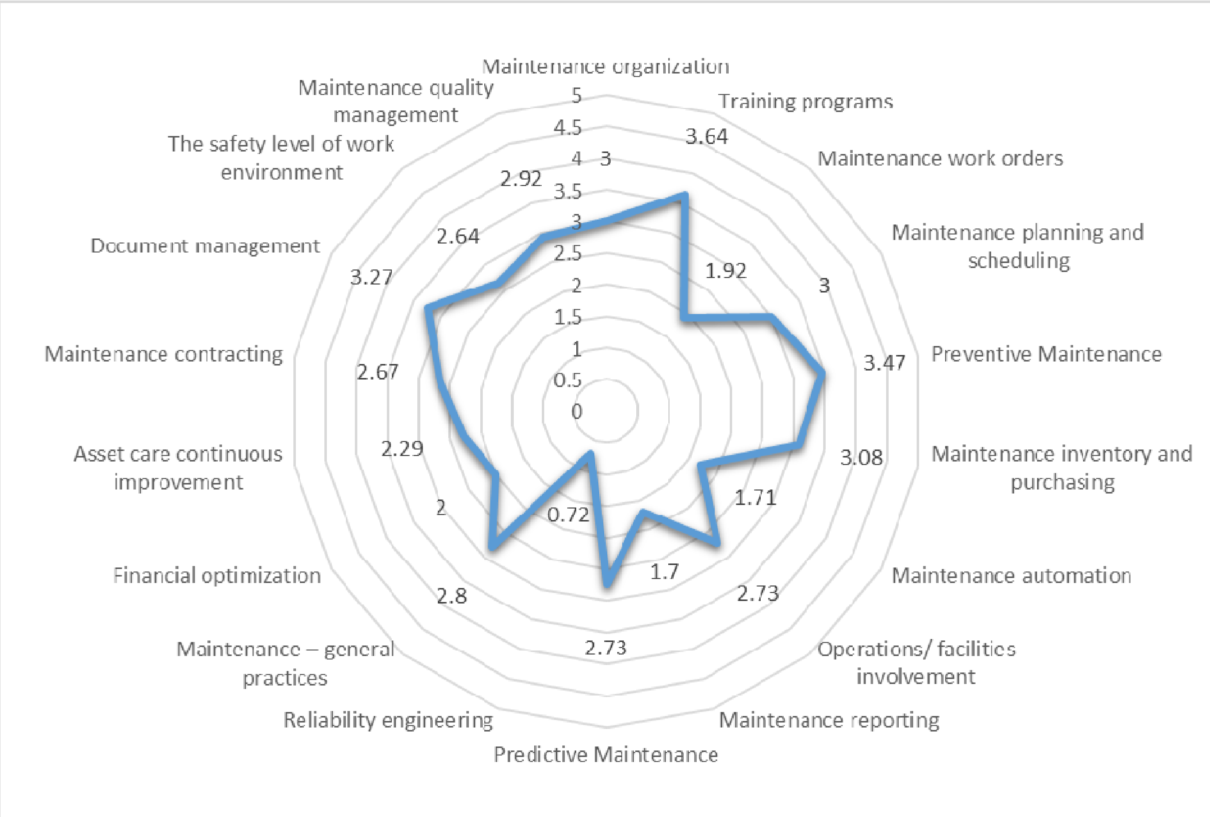

Figure 3. RADAR charts (finding from MMS self-assessment)

4- Results and Discussion

A set of technical, administrative and management activities are done in the life cycle of equipment to put it in good condition and let the equipment have proper and expected functioning. This procedure is referred to as maintenance management system (MMS). Given the importance of this system in the companies, the significance of frameworks required for the assessment becomes more obvious. Besides, by reviewing the literature, researchers have realized the importance and necessity of presenting a self-assessment framework for the maintenance management system. The framework and models of assessment in order to enhance effectiveness of a maintenance management system could be proposed in two categories: qualitative and quantitative. Most qualitative evaluation models proposed in previous research are based on total preventive maintenance (TPM) concepts and related standards such as ISO 14224 and IEC 60300-3-14. Quantitative models, on the other hand, are based on reliability, availability and maintainability measures. In recent years, measures relevant to safety issues have also been included in compliance with RAMS system. According to surveys and studies done by the authors, the common dimensions of frameworks and models for evaluating MMS have been determined, which include:

- Maintenance organization
- Training programs in maintenance
- Maintenance reporting
- Reliability engineering (such as RCM)
- Maintenance – general practices
- Financial optimization
- Asset care continuous improvement
- Maintenance contracting
- Document management
- The safety level of work environment
- Maintenance inventory and purchasing
- Predictive Maintenance (PdM)
- Maintenance work orders
- Maintenance planning and scheduling
- Maintenance automation (CMMS)
- Operations/ facilities involvement on running of maintenance programs
- Preventive Maintenance (PM)
- Maintenance quality management (MQM)

In this paper, first the eighteen dimensions and their indicators were reviewed and extracted. Then, a self-assessment framework was introduced to assess the value of these dimensions. Following the completion of a self-assessment questionnaire, improvement opportunities for MMS should be prioritized, providing an ongoing illustration of the company's MMS.

Therefore, this paper will present a self-assessment framework based on the above mentioned topics for evaluation and placement of the MMS according to the total points earned in a Wireman pyramid. Then, according to the review of the literature, the appropriate indicators for each dimension of evaluation have been extracted and the framework has been tested in a petrochemical company. Also, to identify and develop the assessment dimensions of MMS, several secondary data sources have been used by the authors that have been shown in Figure 4.

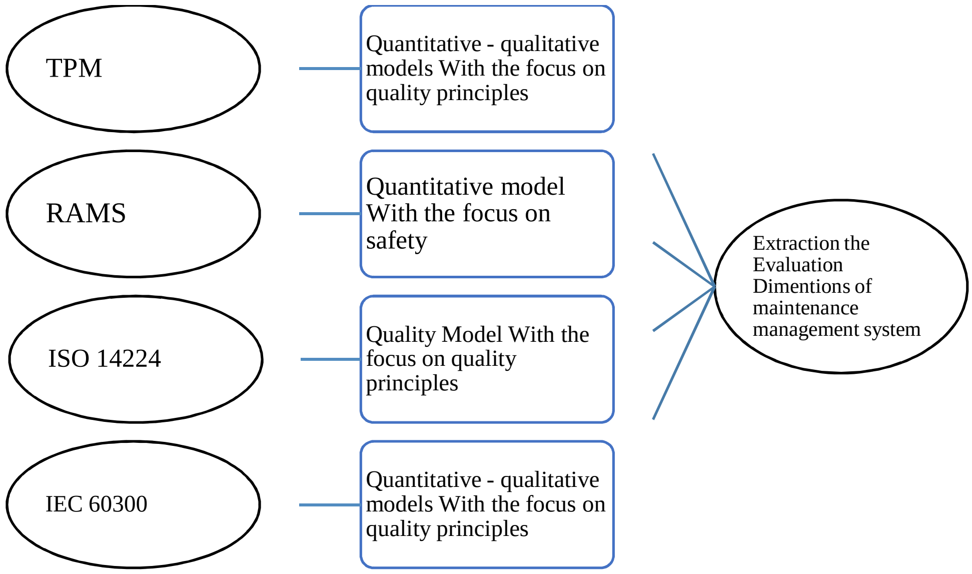

Figure 4. Methodology to identify and develop, Evaluation aspects of maintenance management systems

One of the applications of the designed framework based on the above topics is to identify the placement and location of a system, by using their results, in the Wireman pyramid of promotion (Figure 1.). In other words, if the proportion of points earned by a typical company and ranking of wireman, then the maturity level of maintenance system of a firm will be separable, according to Figure 1.

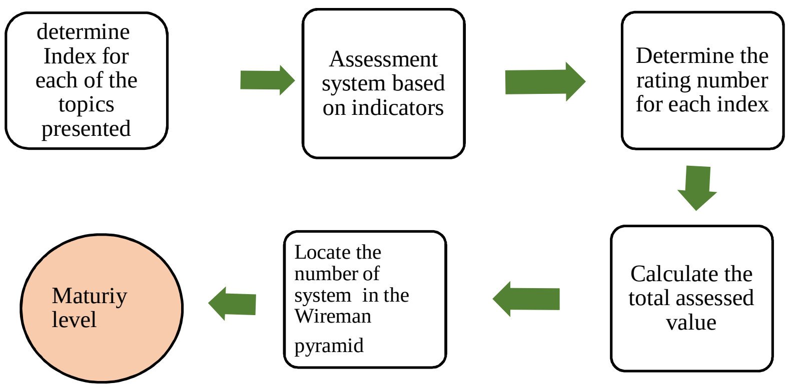

Figure 5. Procedures determine the maturity level maintenance management system based on the topics presented

Assessment result of this model will be based on the proposed framework. By using the average scores indicating the system points and Wireman pyramid, we can determine the ranking of the maintenance management system. In other words, the average scores of total points will be presented in a range of 0 to 1000. Then, the appropriate maturity level of the maintenance will be determined based on the maturity levels outlined by Wireman.

References

Azadeh, A., Ebrahimipour, V., & Bavar P. (2010). A fuzzy inference system for pump failure diagnosis to improve maintenance process: The case of a petrochemical industry. *Expert Systems with Applications*, 37(1), 627–639.

Azadeh, A., Ghaderi, S.F., Partovi Miran, Y., Ebrahimipour, V., Suzuki, K., (2007). An integrated framework for continuous assessment and improvement of manufacturing systems. *Applied Mathematics and Computation*, **186**(2), 1216-1233.

Avstakhan, M., Mofidi, A. A., & Meshkani, M. (2012). Safety level assessment in the production environment using Fuzzy logic. *Journal of Health and Safety at Work*, 2(1), 75-84.

Beebe, R., (2004). *Predicitive Maintenance of Pumps Using Condition Monitoring*. 1st Edition, Elsevier Science.

Bertolini, M., Bevilacqua, M., Ciarapica, F.E., Giacchetta, G., (2009). Development of Risk-Based Inspection and Maintenance procedures for an oil refinery. *Journal of Loss Prevention in the Process Industries*, **22**(2), 244-253.

Bevilacqua, M., Ciarapica, F.E.& Giacchetta, G., (2009). Critical chain and risk analysis applied to high-risk industry maintenance: A case study. *International Journal of Project Management,* **27**(4), 419-432.

Brown, S., (2000). Overview of IEC 61508: Design of electrical/electronic/programmable electronic safety-related systems. *Computing & Control Engineering Journal*, **11**(1), 6-12.

Burgman, R. & Roos, G., (2007). The importance of intellectual capital reporting: evidence and implications. *Journal of Intellectual capital*, **8**(1), 7-51.

Cachay, J. & Abele, E., (2012). Developing Competencies for Continuous Improvement Processes on the Shop Floor through Learning Factories–Conceptual Design and Empirical Validation. *Procedia CIRP*, **3**(0), 638-643.

Campbell, J. D., & Jardine, A. (2001). Maintenance excellence. New York: Marcel Dekker.

Carnero, M., (2006). An evaluation system of the setting up of predictive maintenance programmes. *Reliability Engineering and System Safety,* **91,** 945–963.

Carnero Moya, M.C., (2004). The control of the setting up of a predictive maintenance programme using a system of indicators. *Omega*, **32**(1), 57-75.

Cavalieria, S., Garettib, M., Macchib, M., & Pintob, R., (2008). A decision-making framework for managing maintenance spare parts, *Production Planning & Control: The Management of Operations*, **19** (4), 379-396.

Chiodo, E., Gagliardi, F. & Pagano, M., (2004). Human reliability analyses by random hazard rate approach. *The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, **23,** 65-78.

Commission, I.E (2004). Dependability management : Maintenance and maintenance support in IEC 60300-3-14., International Electrotechnical Commission. p. 50.

Davoodi, F., & Ghahramani, S. (2010). Rail maintenance management based on dependability. 1*2th International Conference and Exhibition Railway transport*, Tehran, Iran.

Dehayem Nodem, F., Kenné, J., & Gharbi, A., (2011). Simultaneous control of production, repair/replacement and preventive maintenance of deteriorating manufacturing systems. *International Journal of Production Economics*, **134**(1), 271-282.

Delgado, A., Weber, B., Ruiz, F., Garcia-Rodríguez De Guzmán, I., Piattini, M., (2014). An integrated approach based on execution measures for the continuous improvement of business processes realized by services. *Information and Software Technology*, **56**(2), 134-162.

Deshpande, V. & Modak, J., (2002). Application of RCM for safety considerations in a steel plant. *Reliability Engineering and System Safety*, **78**(3), 325–334.

Dhillon, B.S. & Liu, Y., (2006). Human error in maintenance: a review. *Journal of Quality in Maintenance Engineering*, **12,** 21-36.

Doostparast, M., Kolahan, F., & Doostparast, M. (2014). A reliability-based approach to optimize preventive maintenance scheduling for coherent systems. *Reliability Engineering & System Safety*, **126**, 98-106.

Durán, O., (2011). Computer-aided maintenance management systems selection based on a fuzzy AHP approach. *Advances in Engineering Software,* **42,** 821–829.

Ebrahimipour, V., & Suzuki, K. (2006). A synergetic approach for assessing and improving equipment performance in offshore industry based on dependability. *Reliability Engineering & System Safety*, 91(1), 10-19.

Efthymiou, K., Papakostas, N., Mourtzis, D., Chryssolouris, G., (2012). On a Predictive Maintenance Platform for Production Systems. *Procedia CIRP*, **3**(1), 221 – 226.

Fattahi, M., Mahootchi, M., Mosadegh, H., Fallahi, F., A new approach for maintenance scheduling of generating units in electrical power systems based on their operational hours. *Computers & Operations Research*, 2014. **50**, 61-79.

Garcia, V.J., *et al*. (2014). Reliability Assessment by Coordinating Maintenance Vehicles in Electric Power Distribution Systems. *Procedia - Social and Behavioral Sciences*, **111**, 1045-1053.

Geng, J., Zhou, D., Lv, C., & Wang, Z., (2013*)*. A modeling approach for maintenance safety evaluation in a virtual maintenance environment. *Computer-Aided Design,* **45**(5), 937–949.

Gilabert, E. & Arnaiz, A., (2006). Intelligent automation systems for predictive maintenance: A case study. *Robotics and Computer-Integrated Manufacturing*, **22**(5–6), 543-549.

Hansson, J. & Backlund, F., (2003). Managing commitment: increasing the odds for successful implementation of TQM, TPM or RCM. *International Journal of Quality & Reliability Management,* **20,** 993-1008.

Hinze, J., Thurman, S., & Wehle, A., (2013). Leading indicators of construction safety performance. *Safety Science,* **51,** 23–28.

IEC60300, (2004). *Dependability management : Maintenance and maintenance support* in *IEC 60300-3-14*, International Electrotechnical Commission. p. 50.

ISO *14224*, (2006). in *Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment*.

Jackson, C. & Pascual, R., (2008). Optimal maintenance service contract negotiation with aging equipment. *European Journal of Operational Research*, **189**(2), 387-398.

Jaehoon, K. & Jeong, H.-Y., (2013). Evaluation of the adequacy of maintenance tasks using the failure consequences of railroad vehicles. *Reliability Engineering and System Safety*, **117,** 30–39.

Jalali, N. M., & Mahpeykar, M. R. (2009). TPM. Soroush andisheh pouya.

Jalali, N.M. & Gholaamzade, B., (2012). *maintenance management system based on iso 14224 standard*. ed. 1. Sorush Andisheh Poia.

Jie, L., Peng, Y. & Wensheng, L., (2012). Safety Entropy Research of Working Environment Parameters in Plateau Non-coal Underground Mine. *Procedia Engineering*, **43,** 197 – 203.

Khan, F.I. & Haddara, M.M., (2003). Risk-based maintenance (RBM): a quantitative approach for maintenance/inspection scheduling and planning. *Journal of Loss Prevention in the Process Industries*, **16**(6), 561-573.

Kim, J., & Park, J., (2012). Reduction of test and maintenance human errors by analyzing task characteristics and work conditions. *Progress in Nuclear Energy*, **58,** 89-99.

Komonen, K., (2002). A cost model of industrial maintenance for profitability analysis and benchmarking. *International Journal of Production Economics*, **79**(1), 15–31.

Kumar, R., T. Markeset, & Kumar, U., (2004). Maintenance of machinery: negotiating service contracts in business-to-business marketing. *International Journal of Service Industry Management*, **15**(4), 400-413.

Leong, T.K., Zakuan, N. & Saman, M.Z.M., (2012). Quality Management Maintenance and Practices-Technical and Non-Technical Approaches. *Procedia - Social and Behavioral Sciences*, **65**, 688-696.

Lundteigen, M.A., Rausand, M.& Utne, I.B., (2009). Integrating RAMS engineering and management with the safety life cycle of IEC 61508. *Reliability Engineering & System Safety*, **94**(12), 1894-1903.

Mädera, P. & Gotelb, O., (2012). Towards automated traceability maintenance. *Journal of Systems and Software*, **85,** 2205–2227.

Márquez , A.C. (2007). The maintenance management framework: models and methods for complex systems maintenance. 2 ed. Springer-Verlag London.

Mercier, S., & Pham, H.H., (2012). A preventive maintenance policy for a continuously monitored system with correlated wear indicators. *European Journal of Operational Research*, **222**(2), 263-272.

Ming Tan, C. & Raghavan, N., (2008). A framework to practical predictive maintenance modeling for multi-state systems. *Reliability Engineering & System Safety*, **93**(8), 1138-1150.

Nilsson, J. & Bertling, L., (2007). Maintenance management of wind power systems using condition monitoring systems—life cycle cost analysis for two case studies. *Energy Conversion, IEEE Transactions on*, **22**(1), 223-229.

Ostadi, B., Pazand, K., & Panahi, M. S. (2005). Preventive maintenance with regard to the availability of components in a system: a case study in the state of rotary kiln cement. *4th International Industrial Engineering Conference*, Tehran, Iran.

Palma, J., Gómez de León Hijes, F.C., Campos Martínez, M., Guillén Cárceles, L., (2010). Scheduling of maintenance work: A constraint-based approach. *Expert Systems with Applications*, **37**(4), 2963-2973.

Pandey, D., Kulkarni, M.S. & Vrat, P., (2011). A methodology for joint optimization for maintenance planning, process quality and production scheduling. *Computers & Industrial Engineering*, **61**(4), 1098-1106.

Patankar, R., *et al* (2009). Global search algorithm for automated maintenance planning and scheduling of parts requests. *Computers & Operations Research*,. **36**(6), 1751-1757.

Pintelon, L.,& Puyvelde, F. V., (1997). Maintenance performance reporting systems: some experiences. *Journal of Quality in Maintenance Engineering*, 3(1), 4-15.

Ramezani, S. & Barzegar, A., (2011). maintenance Quality management (MQM) appraoch. *Journal of Supply Chain Management*. **33**, 66-73.

Reiman, T. & Oedewald, P., (2006). Assessing the maintenance unit of a nuclear power plant – identifying the cultural conceptions concerning the maintenance work and the maintenance organization. *Safety Science*, **44**(9), 821-850.

Rezaie, K., Dehghanbaghi, M., & Ebrahimipour, V. (2009). Performance evaluation of manufacturing systems based on dependability management indicators—case study: chemical industry. *International journal of advanced manufacturing technology*, 43, 608-619.

Schrӧrs, B., *(*2010). *Functional Safety: IEC 61511 and the industrial implementation*. in *Networked Sensing Systems (INSS), Seventh International Conference on*. IEEE.

Selvik, J.T. & Aven, T., (2011). A framework for reliability and risk centered maintenance. *Reliability Engineering & System Safety*, **96**(2), 324-331.

Shankar, G., & Sahani, V. (2003). Reliability analysis of a maintenance network with repair and preventive maintenance. *International Journal of Quality & Reliability Management*, 20**,** 268-280.

Siener, M. & Aurich, J.C., (2011). Quality oriented maintenance scheduling. *CIRP Journal of Manufacturing Science and Technology*, **4**(1), 15-23.

Singh, R., Gohil, A. M., Shah, D. B., & Desai, S., (2013). Total Productive Maintenance (TPM) Implementation in a Machine Shop: A Case Study. *Procedia Engineering*, **51**, 592-599.

Smith, R. & Hawkins, B., (2004). Lean maintenance: reduce costs, improve quality, and increase market share. *Butterworth-Heinemann*.

Smith, R. & Hawkins, B., (2004). *Total Productive Maintenance (TPM), in Lean Maintenance.*, Butterworth-Heinemann: Burlington, 55-104. Smith, R. & Hawkins, B., (2004). *Pre-Planning for Lean Maintenance,* in *Lean Maintenance,* R. Butterworth-Heinemann: Burlington, 105-124.

Suresh, K. & Kumarappan, N., (2012). Particle swarm optimization based generation maintenance scheduling using probabilistic approach. *Procedia Engineering*, **30,** 1146-1154.

Tabatabaei, S.A.N., M. Bagherzadeh, and M. Shabani (2007). *Designing an Application method of BSC for maintenance management system.*

Tavakoli Moghadam, R., Hasanli, N. & Balo, J., (2013). Designing & Implementation of Total Prevention Main tenance in Babakan textile company. Babakan textile Co., Available in: fornm.iien.ir/showthread. php?tid=66.

You, M.-Y., Liu, F., Wang, W., Meng, G., (2010). Statistically planned and individually improved predictive maintenance management for continuously monitored degrading systems. *IEEE Transactions on Reliability*, **59**(4), 744-753.

Teixeira de Almeida, A., (2001). Multicriteria decision making on maintenance: Spares and contracts planning. *European Journal of Operational Research*, **129**(2), 235-241.

Tian, Z. & Liao, H., (2011). Condition based maintenance optimization for multi-component systems using proportional hazards model. *Reliability Engineering and System Safety*, **96,** 581–589.

Van Horenbeek, A., Buré, J., Cattrysse, D., Pintelon, L., Vansteenwegen, P., (2013). Joint maintenance and inventory optimization systems: A review. *International Journal of Production Economics*, **143**(2), 499-508.

Waeyenbergh, G., & Pintelon, L. (2002). A framework for maintenance concept development. *International Journal of Production Economics*, 77(3), 299-313.

Wessels, W.R. (2003). *Cost-optimized scheduled maintenance interval for reliability-centered maintenance*. in *Reliability and Maintainability Symposium, Annual*. IEEE.

Wireman, T., (2004). *Benchmarking best practices in maintenance management*. Industrial Press Inc.

Wireman, T. (1994). *Computerized maintenance management systems*.Industrial Press Inc.

Wireman, T. (2005). Developing performance indicators for managing maintenance.Industrial Press Inc.

Wireman, T. (1992). *Inspection and Training for TPM*. Industrial Press Inc.

Wireman, T. (2004). *Total productive maintenance*. Industrial Press Inc.

Wu, S., (2012). Assessing maintenance contracts when preventive maintenance is outsourced. *Reliability Engineering & System Safety*, **98**(1), 66-72.

Zahara, H.S. & Mushalia, S., (2012). Industrial Hygiene Programs Design in The Oil & Gas Company. *Procedia - Social and Behavioral Sciences*, **65**(3), 468–472.

Zawawi, E.M.A., Kamaruzzaman, S.N., Ithnin, Z., Zulkarnain, S.H., (2011). A Conceptual Framework for Describing CSF of Building Maintenance Management. *Procedia Engineering*, **20**, 110-117.

Zheng, B., Cai, F., & Xu, J., (2004). Evaluation of system storage reliability. *Kybernetes*, **33,** 438-445.