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Functional Model of Integrated Maintenance in Petrochemical Industries

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ABSTRACT

The purpose of this research is to provide an integrated maintenance model in the petrochemical industry. The current research is applied in terms of purpose and descriptive survey in terms of data collection method. A mixed method (qualitative and quantitative) has been used to conduct the research. The tools used in this research are researcher-made questionnaires (36 Questions), dialog with domestic and foreign professors in the field of maintenance and production, the Delphi technique (41 Maintenance managers), Field investigations (20 internal and 7 overseas petrochemical companies), and experiences and evidence obtained from 12 overhauls during 30 years. The validity was determined through experts' opinions and reliability through Cronbach's alpha evaluation. The results showed that the questionnaire has high validity and reliability. The statistical population includes experts in the field of Maintenance in industry and university, among whom 110 people were selected by targeted sampling. To conduct the research in the first stage, first by using the documentary method and content analysis and interviews with experts, the indicators and dimensions of the strong integrated maintenance and repair model were extracted and given to the experts in the form of a Likert scale for scoring; After conducting the survey, 36 components were selected, and each component of management, manpower, equipment, and knowledge had 9 sub-components. In the next step, the components and sub-components were scored and ranked using the questionnaire and the Analytical hierarchy process method. In this research, the following three results have been obtained: 1. Four main roots (Human, Management, Knowledge, and Equipment) and thirty-six sub-roots of effective maintenance. 2. The essential elements of the formula for measuring the criticality index of equipment. 3. Five indicators for measuring integrated maintenance performance. According to the calculations, the inconsistency between the vectors of each matrix is less than 0.10. Therefore, the constituent vectors of each of the formed matrices are consistent with the three results of the research and the stability of the respective comparisons is acceptable.

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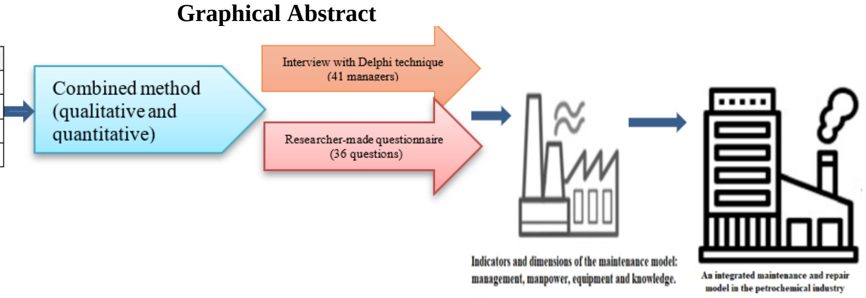
Graphical Abstract

Component	Cronbach's alpha
Management	0.781
Human	0.893
Equipment	0.832
Knowledge	0.754



1. INTRODUCTION

Maintenance is one of the basic concepts in advanced organizations and moving towards world-class and has a special position among industrial managers. Today, maintenanceare of particular importance with the demand for productivity, quality, and availability of equipment (1). Maintenance systems directly affect the

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budget and profitability of industries, and the lack of proper planning of maintenance in the organization reduces the useful life of the equipment (2). Great attention to science of maintenance is necessary to respond to the expectations of industries, which is due to the limited resources such as energy, manpower, and capital, with suitable planning and its principled implementation, can lead to an increase in productivity, efficiency. Finally, the goals will be achieved (3).

Petrochemical industries are among the sensitive and complex industries that require efficient and practical maintenance due to the high volume of production, high added value, technical and safety risks, the need to comply with international standards, and high competition (4). Maintenance in petrochemical industries can improve performance, reduce costs, increase equipment life, reduce breakdowns, increase reliability, increase productivity, reduce waste, preserve the environment, and improve employee safety (5).

As the holder of first place in the country's non-oil exports, the petrochemical industry plays an essential role in the direction of economic prosperity, sustainable development, localization of technology, development of downstream industries, job creation, etc. The main advantages of this industry in Iran are the variety of feed, access to water resources, young and expert manpower. The petrochemical industry is one of the industries in which oil and gas are processed form the oil field region (6).

Considering that currently, Iran is considered the second gas-producing country and the fourth country in the field of crude oil production in the world. Iran is susceptible to the growth and development of the petrochemical industry. Thus, the development of the petrochemical industry is considered one of the important and strategic categories of development of the country. The petrochemical sector produces a variety of products, and among the products produced, polyethylene is very important due to its large volume, as well as its use and importance in the production of various of plastic appliances and food industries. So far, the countries of India, China, the Middle East and Far East, Europe, and Southeast Asia have been among the importers of Iranian petrochemical products (7).

A petrochemical complex is a complex combination of advanced equipment, machinery, and arteries. All kinds of valves, heat exchangers, steam boilers, distillation towers, hydraulic and gas turbines, separators, pumps and compressors, industrial valves, precision instruments, dryers, and blowers can be seen in a petrochemical complex. It takes years and sometimes decades to engineer and build a petrochemical complex, time, energy, and capital. In this complex, right after the start of operation, an important part of the costs is the maintenance of the refinery. Stopping production in a petrochemical complex can bring irreparable costs to the complex (5). Access to specialized manpower, identification system for maintenance, and planning of these matters, along with issues related to the supply of required parts and consumables, is one of the challenges of this field (7).

To better use and increase the useful life of equipment and optimal use of resources, it is necessary to have a proper system of planning, analysis, control, and applying correct management methods (8).

Therefore, developing an effective and dynamic maintenance and repair system is very important. Neglecting the maintenance and repair of equipment, especially complex, sensitive, and expensive devices, imposes a lot of costs on the petrochemical industry and causes many problems for that organization. The environmental conditions of the studied industry, expensive equipment, and the problems of its replacement have increased the importance of this issue and the need to pay attention to maintenance and increase the effectiveness of the equipment (9). Therefore, considering the importance of Maintenance in the current research, we present a functional model of integrated maintenance in the petrochemical industry. Building upon the foundation established, we will delve into the definitions, categorizations, and models of maintenance and repairs, exploring their diverse applications. We will also outline the methodology and tools employed for data collection, introduce the research community involved in this field, and then embark on a comprehensive data analysis process. The culmination of this endeavor will be a presentation of the research outcomes and a proposed model that encapsulates the findings.

2. LITERATURE REVIEW

The continuous growth of industrial operations and the increasing complexity of production processes have fueled the development of maintenance and repair practices. Traditionally, maintenance has been associated with preserving and restoring capital assets to ensure their ability to perform desired tasks. The term "maintenance and repair" is defined in the EN 13306 standard as the combination of technical, administrative, and managerial actions throughout the lifecycle of an item to maintain or restore it to an optimal state for performing its intended function. The EN 13306 standard also defines maintenance management as the set of all activities that prioritize maintenance goals, set basic goals for the maintenance and repair department, determine the maintenance and repair strategies, and implement them through planning, control, support, and continuous improvement (10). In today's advanced and dynamic organizations, maintenance and repair strategies play a crucial role in optimizing asset utilization, enhancing productivity, and achieving organizational objectives. Effective maintenance practices can lead to significant cost savings, improved product quality, and reduced downtime (11).

The management system of maintenance and repairs encompasses the comprehensive management of all physical assets within an organization, aiming to maximize capital utilization efficiency. By effectively managing inputs such as human resources, equipment, tools, and associated costs, and outputs such as the performance of devices and equipment during planned operations, maintenance management techniques like preventive inspections, schedule maintenance, and performance monitoring play a vital role in achieving desired performance levels (12). The maintenance and repair management process can be divided into two key phases: strategy definition and its implementation. Strategy definition involves establishing clear maintenance and repair goals, which serve as the foundation for other activities in the process, such as planning, scheduling, progress control, and indirect cost reduction. The correct implementation of maintenance and repair strategies effectively minimizes direct costs associated with labor and resources, aligning with the concept of efficiency (13).

Orrù et al. (14), Labib (15) and Mowbray (16) emphasized the complexity involved in developing and implementing effective maintenance and repair programs. They highlight that organizations often lack a systematic approach, leading to the adoption of various maintenance models, even among similar organizations. Similarly, consultants from different countries may present different maintenance models to their clients. To address these challenges and optimize asset utilization, a comprehensive system integrating planning, analysis, control, and sound management principles is essential. Neglecting maintenance and repair, especially for complex, sensitive, and expensive equipment, can incur significant costs and operational disruptions. The harsh environmental conditions in petrochemical industries, the high cost of equipment, and the challenges associated with replacement further underscore the importance of prioritizing maintenance and enhancing equipment effectiveness (17). In summary, maintenance and repair management encompasses activities aimed at maintaining or restoring production systems to ensure their efficient and economic operation. Key objectives include:

1. Ensuring system performance (availability, efficiency, and product quality)
2. Prolonging system life (asset management)
3. Maintaining safety
4. Promoting worker well-being (18).

In the world of manufacturing, the importance of efficient production planning is undeniable, particularly in the face of increasing competition. The high cost of equipment and the associated expenses of replacing damaged machinery necessitate effective maintenance and repair strategis (19). As industries rapidly transition towards automation, the need for skilled personnel to manage and maintain equipment intensifies. Additionally, rising investment levels, production speeds, and spare part costs underscore the significance of integrating maintenance and repair processes into production systems (20). This approach aims to minimize repair costs and overall production expenses by employing techniques like regular inspections, scheduling maintenance tasks, and utilizing advanced monitoring systems (21). The strategies adopted in the petrochemical industry for maintenance and repairs have undergone significant transformations, particularly in terms of mindset and management style (22). However, a notable segment of experts, managers, and operations and maintenance executives still view production, maintenance, and repair processes as separate entities. This perspective fails to recognize the interconnectedness of these aspects and the potential benefits of adopting a holistic approach. In advanced industries worldwide, the concept of breakdown maintenance has gradually faded, replaced by a combination of preventive, predictive, and condition monitoring strategies (23). Experts strive to minimize or eliminate process disruptions, leading to the development of comprehensive maintenance and repair frameworks that optimize unit performance while minimizing costs and maximizing added value (24).

Reliability-centered maintenance (RCM) has emerged as a leading approach in the industry, providing a systematic method for determining the most appropriate maintenance strategy for equipment (systems). By analyzing factors like equipment criticality, failure modes, and potential consequences, RCM helps organizations make informed decisions about maintenance activities, ensuring optimal performance and minimizing disruptions (25). In summary, effective maintenance and repair strategies are crucial for manufacturing industries to thrive in the competitive landscape. By adopting a holistic approach that integrates maintenance and repair processes into production systems, organizations can achieve significant cost savings, enhance productivity, and safeguard their equipment's longevity. Reliability-centered maintenance (RCM) provides a valuable framework for making informed decisions about maintenance activities, ensuring that equipment is maintained in a condition that maximizes its availability, efficiency, and overall performance (21).

The maintenance and repair management system seeks to minimize repair costs and overall production expenses by implementing strategies such as regular inspections, scheduled maintenance, and advanced monitoring techniques. These measures contribute to reducing the financial burden associated with equipment breakdowns and enhancing overall operational efficiency.

In parallel, environmental concerns have gained prominence in recent years, recognized as a critical aspect of sustainable development. The escalating issues of air pollution and climate change have propelled governments worldwide to formulate policies aimed at curbing greenhouse gas emissions. These initiatives include imposing limits on carbon emissions and levying penalties for exceeding these thresholds (25, 26).

In summary, both economic and environmental considerations necessitate effective maintenance and repair practices. By optimizing equipment performance, organizations can reduce repair costs, minimize environmental impact, and contribute to sustainable development goals.

3. METHODOLOGY

The current research is applied in terms of fundamental purpose and descriptive survey in terms of the data collection method. A mixed method (qualitative and quantitative) was used to conduct the research. In the qualitative stage, the indicators and dimensions of the model were extracted using library studies, and a questionnaire was designed for the survey in the form of four areas human resources, equipment, knowledge, and management. Using the Delphi technique, the dimensions and components were approved by experts. The statistical population is experts in the field of maintenance industry and university, and 110 of them were selected as a sample by simple random sampling. The indicators extracted from the qualitative stage were provided to the sample in the form of a questionnaire. The validity of the questionnaire was confirmed by experts in the qualitative stage and its reliability was determined through Cronbach's alpha.

The method used in this research, which is based on the arithmetic mean of experts' opinions, is carried out in the following steps:

The arithmetic mean of the opinions of decision-makers was calculated in the form of a matrix and the relationship was calculated.

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & (1,1,1) \end{bmatrix}$$

$$\alpha_{ij} = \sum_{K=1}^{P_{ij}} a_{ijk} \qquad i,j = 1,2,\ldots,n$$

Calculate the sum of row elements

$$S_i = \sum_{i=1}^{n} a_{ij} \qquad i = 1,2,\ldots,n$$

to normalize

$$M_i = s_i \otimes [\sum_{i=1}^{n} s_i] - 1 \qquad i = 1,2,\ldots,n$$

Determining the degree of probability of being larger

$$V(M_2 > M_1) = \mathrm{Sub}_{y\geq x}[\min(\mu_{M_1}(x), \mu_{M_2}(y))]$$

This relationship can be expressed synonymously as follows:

$$V(M_2 > M_1) = \mathrm{hgt}\,(M_2 \cap M_1) = \mu_{M_2}(d)$$

$$m_2 \geq m_1$$

$$l_2 \geq u_1$$

Normalized weights are obtained by normalizing the vector of weights.

$$W = \left[\frac{d(A_1)}{\sum_{i=1}^{n} d(A_i)}, \frac{d(A_2)}{\sum_{i=1}^{n} d(A_i)}, \ldots \frac{d(A_n)}{\sum_{i=1}^{n} d(A_n)}\right] t$$

By combining the weights of the option and the criteria, the final weights are obtained.

$$U_i = \sum_{j=1}^{n} w_i\, r_{ij}$$

Finally, the inconsistency rate should be calculated. If the inconsistency rate is less than 0.10, the consistency of the comparisons is acceptable, and otherwise, the comparisons should be revised.

The results of Table 1 and Figure 1 shows that among the experts in the research community, 2 of them are experts, 3 are masters, 5 are deputy directors, 12 are maintenance managers, 4 are operations managers, 3 are Deputy complex, and 1 person has also been the manager of the petrochemical complex.

TABLE 1. Related to the organizational post of the respondents

The organizational post	Absolute abundance	Abundance percentage
Expert	2	6.7
Master expert	3	10
Deputy Director	5	10
Maintenance Manager	12	40
Operation Manager	4	13
Deputy complex	3	10
Complex Manager	1	3.3
Sum	30	100

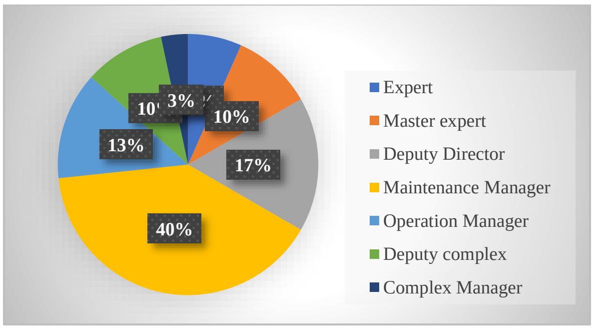

Figure 1. Related to the organizational post of the respondents

3. 2. Confirmatory Factor Analysis The most important goal of confirmatory factor analysis is to determine the power of the predefined factor model with a set of observed data. In other words, confirmatory factor analysis tries to determine whether the number of factors and variable loadings measured on these factors are consistent with what was expected based on the theory and theoretical model. In other words, this type of factor analysis tests the degree of conformity between the theoretical construct and the empirical construct of the research. In this method, the relevant variables and indicators were first selected based on the primary theory and after factor analysis, they were used to check whether these variables and indicators were loaded on the predicted factors as expected. Or that their composition has been changed and loaded on other factors. The second-order confirmatory factor analysis of management, knowledge, equipment and human variables were reported in Tables 2 to 5, respectively.

In the following, we will examine the statistical indicators to confirm the research data, which is given in Table 6.

TABLE 2. Second-order confirmatory factor analysis of the management variable

Component	Dimensions	Factor load	Estimation error	T statistic	The result of the path analysis
Management	MA1	0.7891	0.0113	36.9816	meaningful
	MA2	0.8145	0.0190	43.0050	meaningful
	MA3	0.8070	0.0219	39.1956	meaningful
	MA4	0.7801	0.0293	26.3816	meaningful
	MA5	0.8445	0.0186	22.7059	meaningful
	MA6	0.8333	0.0209	32.1956	meaningful
	MA7	0.7991	0.0222	35.9516	meaningful
	MA8	0.8145	0.0196	40.5059	meaningful
	MA9	0.8270	0.0198	41.0621	meaningful

TABLE 3. Second-order confirmatory factor analysis of the knowledge variable

Component	Dimensions	Factor load	Estimation error	T statistic	The result of the path analysis
Knowledge	KN1	0.8391	0.0213	29.3816	meaningful
	KN2	0.8944	0.0293	12.0330	meaningful
	KN3	0.8022	0.0119	19.4946	meaningful
	KN4	0.8801	0.0283	26.3416	meaningful
	KN5	0.8441	0.0196	21.7559	meaningful
	KN6	0.8535	0.0229	22.1226	meaningful
	KN7	0.8996	0.0233	34.9661	meaningful
	KN8	0.8445	0.0177	30.0059	meaningful
	KN9	0.8362	0.0244	29.5463	meaningful

TABLE 4. Second-order confirmatory factor analysis of the equipment variable

Component	Dimensions	Factor load	Estimation error	T statistic	The result of the path analysis
Equipment	EQ1	0.8032	0.0139	36.9816	meaningful
	EQ2	0.8801	0.0163	43.0050	meaningful
	EQ3	0.8241	0.0226	39.1956	meaningful
	EQ4	0.8323	0.0219	26.3816	meaningful
	EQ5	0.8801	0.0283	22.7059	meaningful
	EQ6	0.8311	0.0200	32.1956	meaningful
	EQ7	0.8981	0.0222	35.9516	meaningful
	EQ8	0.8845	0.0206	40.5059	meaningful
	EQ9	0.8181	0.0022	15.1511	meaningful

TABLE 5. Second-order confirmatory factor analysis of the human variable

Component	Dimensions	Factor load	Estimation error	T statistic	The result of the path analysis
Human	HU1	0.7899	0.0213	16.1816	meaningful
	HU2	0.8143	0.0290	13.0350	meaningful
	HU3	0.8323	0.0259	29.1056	meaningful
	HU4	0.8801	0.0243	26.3006	meaningful
	HU5	0.8313	0.0201	20.7012	meaningful
	HU6	0.8335	0.0219	22.1922	meaningful
	HU7	0.7999	0.0112	15.9916	meaningful
	HU8	0.8145	0.0096	10.5779	meaningful
	HU9	0.7960	0.0206	20.5510	meaningful

TABLE 6. Indicators and Current Situation

Indicator	Measurement criteria	Current situation
2X (k squared)	The smaller the better	178.15

(Degree of freedom)	Greater than Zero	29
(The significance level) P- Value	-	0.0000
(Squared error) RMSEA	Smaller than 0.8	0.138
GFI (Fitness index)	Greater than 0.9	0.98
(adjusted fitness index) AGFI	Greater than 0.9	0.93

According to the results of Table 6 and the level of significance and the degree of freedom, it can be concluded that the research data is normal, and since the significance level is less than 5%. It can be concluded that the chance of this difference or relationship is very low. It was concluded that the difference or relationship in question is significant. When the results of structural equations are presented, the resulting reports include several indicators to show the degree of model fit, usually the distribution of these indicators is X2. In the current research, the degree of freedom is equal to 178.15, which indicates the fit of the current research model.

In this research, Cronbach's alpha was used to check the reliability of the research questions. As shown in Table 7, considering that Cronbach's alpha of all the questions of the upper components is 0.7, it can be concluded that all the questions are valid.

After fitting the structural model (SEM), the reliability of the structure (conceptual variables) can be calculated. Construct reliability can be calculated based on composite reliability (CR) and variance extracted (AVE). Whenever one or more characteristics are measured through two or more methods, the correlation between these measurements provides two important indicators of reliability. If the correlation between the scores of tests that measure a single trait is high, the questionnaire has convergent validity. The existence of this correlation is necessary to ensure that the test measures what it is supposed to measure. According to the obtained results, it can be concluded that the existing sub-components have convergent validity, divergent validity, and reliable construct validity.

4. FINDINGS

In this part of the research, we will present the findings of the research considering that the four main components of management, knowledge, equipment, and manpower have been used in this research to examine the importance of evaluation indicators. Therefore, in the first place, we will introduce the main components of the research in the structural model of the research.

In this step, the dimensions and components of management and knowledge were extracted by studying the models and studies presented in the subject of research. The results show that each of the four main components of management, knowledge, equipment, and manpower under investigation has 9 sub-axis which are mentioned in the table above. In the continuation of the research, each of the sub-components was examined to check their weight and importance from the point of view of experts, and the results are shown in Tables 8 and 9.

The sub-components of income and cost, mission and strategy, risk and change, human resources and energy, planning and scheduling, efficiency and effectiveness, condition monitoring and foresight, corrective action and continuous improvement, control, and evaluation were selected. Regarding the knowledge component, the following components of standards and regulations, software, books and articles, research and development, less and practice, procedures, work orders, technical data and maintenance, and inherent knowledge of the expert were selected.

To determine the sub-component of equipment and manpower, by studying the models and studies conducted in the field of research, their dimensions and sub-

TABLE 7. Reliability of the first questionnaire

Component	Number of Questions	Cronbach's alpha
Management	9	0.781
Human	9	0.893
Equipment	9	0.832
Knowledge	9	0.754

TABLE 8. Introducing management and knowledge sub-components in the strong integrated Maintenance model

Management	Income & Cost	MA1
	Mission & Strategy	MA2
	Risk & Change	MA3
	Human & Energy Resources	MA4
	Planning & Scheduling	MA5
	Efficiency & Effectiveness	MA6
	Condition Monitoring & Foresight	MA7
	Corrective action and continuous improvement	MA8
	Control & Evaluation	MA9
Knowledge	Standards & Regulation	KN1
	Software	KN2
	Books & Articles	KN3
	Research & Development	KN4
	Lessens & Practices	KN5
	Procedures	KN6
	Work orders	KN7
	Technical & Maintenance Data	KN8
	Expert’s inherent knowledge	KN9

TABLE 9. Introducing the sub-components of equipment and manpower in the strong integrated Maintenance model

Equipment	Criticality Analysis	EQ1
	Condition Monitoring	EQ2
	Life Cycle Cost	EQ3
	Risk Based Inspection	EQ4
	Optimized Risk & Cost	EQ5
	Overall Equipment Effectiveness	EQ6
	Root cause failure Analysis	EQ7
	Reliability Centered Maintenance	EQ8
	Availability and Maintainability	EQ9
Human	Motivation & Effort	HU1
	Commitment & Ethical	HU2
	Education & Learning	HU3
	Expertise & Experience	HU4
	Flexibility & Creativity	HU5
	Responsibility & Loyalty	HU6
	Mental Model & Behavior	HU7
	Encouragement & Appreciation	HU8
	Culture & Teamwork	HU9

components were determined, as shown in Table 3, the sub-components of equipment include critical analysis, condition monitoring, cycle cost life, risk-based inspection, optimized risk and cost, the overall effectiveness of equipment, root cause analysis of failure, maintenance based on reliability and availability and maintenance, and the sub-components of human resources include motivation and effort, commitment and ethics, education and learning, expertise and experience, flexibility and creativity, responsibility and loyalty, mental model and behavior, encouragement and appreciation, and culture and teamwork.

The results of the investigations in Table 10 show that the sig (significance level) of all variables is greater than 0.05. Therefore, at the 95% confidence level, it can be said that the distribution of all data is normal.

In Table 11 and Figure 2 the ranking of the criteria for evaluating the quality of maintenance and production

TABLE 10. Checking the normality of population distribution

Variables	Average	The significance level
Human	4.41	**0.22**
Equipment	3.33	**0.41**
Management	3.87	**0.08**
Knowledge	4.95	**0.90**
The whole questionnaire	4.12	**0.20**

TABLE 11. Friedman's test ranks the importance of each of the quality evaluation criteria of the new model

Evaluation criteria	Average rank	Statistics $\chi 2$
Cost	6.97	**47.773**
Production	6.54	
Reliability	6.79	
Availability	6.70	
Operational Risk	6.52	
Safety	6.72	
Quality	6.49	
Environment	6.43	
Maintainability	6.52	
Energy	6.12	

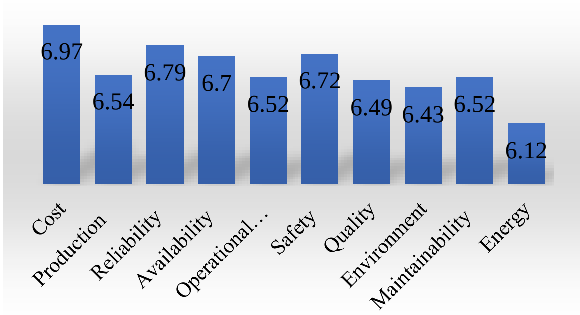

Figure 2. Friedman's test ranks the importance of each of the quality evaluation criteria of the new model

from the point of view of experts was discussed, among which the cost component is the first important criterion with an average of 6.97. The energy component with an average of 6.12 ranks last in service quality evaluation criteria. The important features and sub-features should be considered in choosing a Maintenance strategy. including determining the criteria that are involved in the decision-making process for choosing maintenance and repair strategies. The analysis should be done in such a way that the maintenance and repair strategy that is chosen will achieve the desired goals, improve the availability, and reduce the number of failures.

The top and most important according to a survey conducted in the field of maintenance and repair of the petrochemical industry, from the point of view of experts, the most important factors are cost, reliability, and availability, respectively, with coefficients of 6.97, 6.79, and 6.70. The repair of machinery in the petrochemical field has been selected.

To obtain the equipment criticality index and coefficients of its essential elements, we used the Likert preferences of 75 experts using the AHP method. Equation 1 and Table 13 present the results.

$$\boldsymbol{ECI}=0.116Q+0.105P+0.117S+0.099E+0.089OR+0.104R+0.089A+0.105M+0.077ES+0.105C \quad (1)$$

Pairwise comparison scale for AHP preferences by 64 judges are stated in Table 14.

The matrix for the calculation of the inconsistency rate is reported in Table 15. Weight Coefficients of Integrated Maintenance obtained from geometric mean is stated in Table 16.

TABLE 12. The judgment of 75 experts on the coefficients of the 10 elements of determining the sensitivity of equipment its calculations based on Satya's (AHP)

No.	Judgment by	Quality	Capacity	Safety	Environment	Operation Risk	Reliability	Availability	Maintainability	Energy	Cost	No.	Judgment by	Quality	Capacity	Safety	Environment	Operation Risk	Reliability	Availability	Maintainability	Energy	Cost
1	Main. Manag.*7	12	9	12	10	9	10	8	11	8	11	38	MR-2	10	5	10	22	5	10	10	10	10	20
2	Planning	12	10	12	9	6	12	10	10	7	12	39	Jam-DOPM	13	10	10	9	10	12	10	10	7	10
3	Mechanical	12	11	11	10	9	10	7	11	8	12	40	JPC	11	8	12	9	8	13	10	11	8	11
4	R&D	12	9	10	11	9	11	9	10	10	10	41	PPC	10	10	14	12	8	11	12	5	6	12
5	HRM	12	10	11	9	11	9	10	10	9	9	42	MR-4	14	10	13	9	10	11	9	10	9	10
6	DOCM	11	12	8	10	13	11	8	12	8	9	43	Razak MD	12	10	10	10	10	10	9	10	9	10
7	Percurment	12	11	13	7	11	10	8	9	8	11	44	DOCM-Jam	8	15	10	8	8	10	10	8	8	15
8	Shift head	12	10	11	8	10	10	9	12	10	9	45	MM1	8	8	15	10	15	10	9	15	10	15
9	Feed head	9	12	12	10	12	9	7	10	7	12	46	MM2	12	8	12	10	10	10	8	12	9	12
10	CM	10	10	12	11	9	10	8	10	10	10	47	MM3	10	10	14	8	8	10	10	12	8	10
11	IT	11	8	14	13	9	8	12	11	8	7	48	-MOTS KHPC	15	7	12	8	8	10	10	8	8	10
12	Electrical	12	10	12	10	9	10	8	11	8	11	49	MOP-AKPC	12	9	11	10	10	9	10	10	9	10
13	SSD	12	11	11	9	10	11	8	11	9	9	50	MM4	10	10	14	10	6	10	8	12	7	11
14	DOM	11	10	12	11	9	10	8	11	9	10	51	MM5	12	9	11	9	9	10	9	8	10	13
15	Shift maneger	15	8	11	12	8	9	9	10	8	11	52	MM6	12	9	12	10	9	12	6	11	8	11
16	Security	11	10	11	9	10	11	9	10	8	11	53	MM7	12	9	13	9	9	10	8	11	9	10
17	Exc &IT	10	12	12	8	10	12	11	10	6	10	54	MM8	12	10	13	10	9	10	10	12	7	12
18	Planning	12	12	8	6	10	12	12	11	8	12	55	MM9	10	11	12	8	9	12	10	11	8	11
19	Supervisour1	12	14	10	12	12	9	9	9	13	12	56	-MOM	10	10	13	11	10	10	10	10	8	10
20	Supervisour2	12	11	10	8	9	11	9	10	10	13	57	-DOMM	12	10	12	11	9	9	8	12	8	11
21	Supervisour3	15	15	8	12	10	8	8	8	6	12	58	MM10	10	9	15	9	12	10	10	9	8	11
22	Supervisour4	10	10	15	15	11	15	1	10	10	5	59	MM11	12	8	14	9	10	12	10	10	8	9
23	M.S.S1	12	10	14	10	10	10	6	10	9	10	60	MM12	12	9	15	7	9	10	10	11	8	11
24	M.S.S2	12	9	12	9	9	10	11	10	8	11	61	MM13	11	9	15	12	9	10	7	11	7	10
25	M.S.S3	18	9	12	10	4	10	8	11	7	11	62	MM14	13	9	11	8	9	10	8	11	1	12
26	M.S.S4	12	9	12	8	8	10	10	11	10	11	63	-MOM	10	9	10	11	10	9	8	12	10	11
27	M.S.S5	14	12	10	7	7	12	9	12	7	10	64	BIPC	11	8	15	12	8	10	8	10	8	10
28	M.S.S6	14	8	10	10	10	10	10	12	5	10	65	MOM-REPC	12	8	12	12	7	10	8	10	10	11
29	M.S.S7	12	9	12	11	8	10	8	11	9	9	66	-MOM	12	11	12	10	10	11	9	11	6	10
30	M.S.S8	12	8	12	10	8	10	9	10	10	11	67	Pars MM	12	9	12	10	9	10	8	11	7	12
31	M.S.S9	12	10	12	10	8	10	7	11	11	9	68	ARYA_S_MM	10	13	13	10	9	8	8	10	8	10
32	M.S.S10	12	11	12	10	10	11	8	8	8	9	69	MM15	12	9	12	10	9	10	8	12	7	11
33	M.S.S11	12	11	12	10	10	11	8	10	8	8	70	MM16	11	9	13	11	8	10	9	11	7	11
34	M.S.S12	12	8	12	10	8	11	9	11	8	11	71	MS.S.A	10	10	13	11	9	9	10	11	8	10
35	M.S.S13	13	9	12	10	9	10	9	12	8	11	72	TRC-MM	10	10	12	10	10	10	8	13	7	10
36	M.S.S14	10	10	12	10	9	10	9	12	8	11	73	TRC-S-1	12	10	11	10	10	10	8	10	9	10
37	MR-1	9	12	10	12	9	10	11	8	11	8	74	TRC-S-2	12	9	12	9	10	9	9	13	8	10
												75	TRC-S-3	11	9	12	10	9	10	9	10	9	11

TABLE 13. Equipment criticality elements and related coefficients

Item	Quality	Production	Safety	Environment	Operational Risk
Coefficient	0.116 - Q	0.105 - P	0.117 - S	0.099 - E	0.089 - OR
Item	Reliability	Availability	Maintainability	Energy Saving	Cost
Coefficient	0.104 - R	0.089 - A	0.105 - M	0.077 - ES	0.105 - C

TABLE 14. Pairwise comparison scale for AHP preferences by 64 judges (OEE, OLE, EEE, HSE, and OCE)

	Pairwise comparison scale for AHP prefe							**64 Judgers**					
	Judgment By	OEE	OLE	EEE	HSE	OCE		Judgment By	OEE	OLE	EEE	HSE	OCE
J1	Inspection Head	7	5	4	7	9	J33	Instrument Engnieer	3	5	7	5	9
J2	Deputy of Complex M	8	6	7	7	6	J34	Inspection Engineer	7	4	6	4	4
J3	Reliability Engineer	7	9	9	6	8	J35	Workshop Manager	3	5	7	5	8
J4	Planning engineer	8	8	9	7	7	J36	Instrument Manager	4	4	6	5	4
J5	Planning Manager	9	7	5	7	9	J37	Professor	9	4	6	5	9
J6	O/H Head	8	9	8	7	6	J38	Professor	3	4	7	3	3
J7	CM Head	7	8	6	6	9	J39	Professor	5	3	6	4	8
J8	Instrument Head	5	9	8	5	5	J40	Professor	9	4	6	5	5
J9	Service	8	9	7	5	5	J41	Professor	3	4	7	4	3
J10	Planning Head	9	8	7	6	5	J42	Deputy of Complex M-J	4	4	6	5	5
J11	Electrical Head	7	9	8	5	6	J43	Professor	3	4	6	4	4
J12	Packaging Head	9	8	8	5	7	J44	Professor	4	8	6	4	4
J13	Maint. Manager	8	8	7	7	7	J45	Project Manager	7	5	4	7	9
J14	Machinery Head	9	8	8	9	7	J46	PHD-Student	8	6	7	7	6
J15	Electrical Manager	8	9	5	6	7	J47	Mechanical. Eng.	7	9	9	6	8
J16	Coplex Manager	4	4	6	5	4	J48	Mechanical. Eng.	8	8	8	7	7
J17	IT manager	4	5	6	5	4	J49	electrical eng.	9	7	5	7	9
J18	DOMM	4	4	6	9	3	J50	electrical eng.	8	9	8	7	7
J19	R&D Maneger	5	6	8	7	6	J51	Project eng.	7	8	6	6	8
J20	Process	4	4	6	4	3	J52	Human Resource Manager	5	9	8	5	5
J21	Planning	4	4	6	5	5	J53	Contractor Manager	8	9	7	5	6
J22	Inspection Manager	5	4	6	5	5	J54	Master.S .Student	9	8	7	6	5
J23	Production Manager	4	3	5	4	4	J55	Energy control head	7	9	8	5	6
J24	Technical Ser. Mang.	3	4	6	4	9	J56	Maint. Manager-PPC	9	8	8	5	7
J25	Maintenance shift Head	3	8	9	5	5	J57	Maint. Manager-OPC	8	8	7	7	6
J26	Maintenance shift Head	5	6	9	7	9	J58	Maint. Manager-BIPC	9	8	8	9	7
J27	Manitenance Ser. Manage	4	4	6	5	4	J59	Plan. Manager-AKPC	8	9	5	6	7
J28	CM. Engineer	3	5	6	3	3	J60	DOMM-ARPC	5	4	6	3	3
J29	Electrical Engineer	4	4	6	4	4	J61	Eng.Manager-NPC	4	4	6	4	4
J30	Civil Engineer	2	7	9	3	3	J62	Maint. Manager-TPC	4	4	6	4	3
J31	Engeneering Head	3	4	6	5	5	J63	Maint. Manager-Arya	4	4	7	5	4
J32	Machinery Engineer	3	5	6	3	3	J64	Maint. Manager-KHPC	8	8	7	7	9

OEE: Overall Equipment Effectiveness;
OLE: Overall Labor Effectiveness;
EEE: Endogeneity, Extroversion, and Exogenous;
HSE: Health, Safety, and Environment;
OCE: Overall Cost Effectiveness

TABLE 15. The matrix for the calculation of the inconsistency rate

		A1	A2	A3	A4	A5
	WF	0. 190	0. 202	0. 232	0. 182	0. 194
A1	0. 190	1. 000	0.941	0.819	1.044	0.979
A2	0. 202	1.063	1. 000	0.871	1.110	1.041
A3	0. 232	1.221	1.149	1.000	1.275	1.196
A4	0. 182	0.958	0.901	0.785	1.000	0.938
A5	0.194	1.021	0.960	0.836	1.066	1.000

II= (λmax-n)/4=(5.255-5)/4=0.6375

Ci =II / (Cr or R.I) , n=5 → Cr or R.I = 1.12 ⇨ Ci = 0.057 ′0.1

TABLE 16. Weight Coefficients of Integrated. Maintenance obtained from geometric mean

Coefficient	Item	AHP
A1	OEE	0.190
A2	OLE	0.202
A3	EEE	0.232
A4	HSE	0.182
A5	OCE	0.194

Considering the results, the inconsistency rate is less than 0.10, as a result, the matrix is compatible and the stability of the comparisons is acceptable.

5. RESULT

The findings showed that the establishment of an integrated net system can lead to the improvement of related indicators. One of the most important reasons for this is to design and provide written implementation methods for each step of the hierarchy of stopping. Because the stoppage is not a routine operation and the probability of problems related to process safety is higher in these situations than in normal operation times.

Another reason is that the system created to prevent the wear and tear of machine components can reduce unplanned breakdowns and, as a result, machines being out of reach. On the other hand, in the implemented system, the failure times of the parts are predicted. Therefore, these parts are purchased in advance, which leads to a reduction in procurement time and an improvement in the average repair time after the installation of the system compared to before.

Considering that petrochemical industries usually use old equipment and machinery that are usually at least 15 years old in their upstream, middle, and downstream operations. Therefore, an integrated system of maintenance is necessary to keep this relatively old equipment operational. In such a situation, adopting a reactive maintenance and repair tactic does not provide any guarantee that sudden and unplanned outages will not occur. The working nature of these complexes is vital and at the same time very dangerous. For this reason, it needs double care and supervision. In the petrochemical industry, many accidents such as fire and explosion or even the stoppage of some equipment lead to huge damages, which is generally due to the failure of the parts used in the equipment and processes. It is vital to know and how these failures occur to prevent them from increasing system reliability, optimizing process performance and profitability.

6. CONCLUSION

In today's competitive industrial landscape, organizations must prioritize maintenance and repair strategies to safeguard their performance, efficiency, and productivity. These strategies play a crucial role in maintaining equipment reliability, availability, and product quality while mitigating risks and reducing downtime. As investments in industries surge, the efficient utilization of resources and raw materials becomes paramount for industrial owners and responsible managers. This is particularly critical in the face of intense competition in both domestic and global markets.

A growing number of engineers and managers are recognizing the significance of maintenance and repair engineering, often referred to as 'Net' in technical and engineering terms. Modern net engineering departments in industrial units have adopted statistical and mathematical methods to enhance their planning capabilities, transforming net into a knowledge-based discipline. Numerous companies have employed various net strategies, including corrective net, preventive net, comprehensive productive net, reliability-based net, and status-based net. However, the primary challenge faced by those involved in maintenance and repair lies not only in applying these techniques but also in making informed decisions regarding the selection of the most suitable and effective maintenance and repair strategies for their organization's specific needs. This research delves into the development of an integrated maintenance and repair management model tailored to the unique needs of the petrochemical industry. The study's initial phase involved identifying the key components of the maintenance management model through theoretical discussions and expert interviews. By analyzing the findings, the dimensions, components, and sub-components of the model were extracted, yielding a four-component structure .

The research focused on four key components: management, manpower, equipment, and knowledge. The results indicated that knowledge is the most critical component (importance coefficient of 0.90), followed by equipment (0.41), manpower (0.22), and management (0.08) in terms of their impact on implementing an integrated maintenance and repair system.

The subsequent stage involved evaluating maintenance and repair quality using expert opinions. The cost component emerged as the most significant criterion (average score of 6.97), while the energy component ranked lowest (average score of 6.12). These rankings highlight the importance of prioritizing cost-effectiveness and energy efficiency in establishing a robust maintenance and repair system.

The study identifies human incentives, management, equipment, and knowledge as the key components for establishing an integrated maintenance model in the petrochemical industry. Based on these findings, the following suggestions are proposed :Formulate comprehensive guidelines and regulations for integrated maintenance in Iranian petrochemical companies to shift the mindset of senior, middle management, and employees from traditional maintenance to integrated maintenance practices .Provide comprehensive training programs for managers and employees to cultivate integrated maintenance thinking and instill a long-term vision of the benefits of integrated maintenance, recognizing its potential to enhance petrochemical industries' economic, social, and environmental performance, leading to increased competitiveness and market success.

Develop maintenance sustainability strategies based on a thorough assessment of internal and external environmental factors, including opportunities, threats, strengths, and weaknesses .Prioritize product quality and quantity by closely monitoring key indicators such as OEE (Overall Equipment Effectiveness), OCE (Overall Cycle Effectiveness), OLE (Overall Logistics Effectiveness), HSE (Health, Safety, and Environment), and EEE (Energy Efficiency).

Implement industry-standardized maintenance procedures that encompass safety, health, environment, energy, production, quality, cost, revenue, export, stress, risk, maintainability, reliability, availability, replacement cost, motivation, and satisfaction .Embrace appropriate maintenance tools like Total Productive Maintenance (TPM), Reliability-Centered Maintenance (RCM), Risk-Based Inspection (RBI), Industry 4.0 technologies, Artificial Intelligence (AI), and the Internet to enhance maintenance efficiency and effectiveness. For future research, the following areas are recommended :Explore the intricate relationship between maintenance, the Internet, business environment, Industry 4.0, and Artificial Intelligence (AI) to optimize maintenance strategies .Develop effective mechanisms for managing conflicts, interactions, and the impact of various organizational units' activities (e.g., top management, operations, maintenance, safety, procurement, finance, human resources, and education) to ensure seamless and coordinated maintenance operations.

Investigate the potential of Internet-based failure detection and artificial intelligence-based condition monitoring systems to enhance maintenance proactiveness and reduce downtime.

Conduct research on the application of integrated maintenance practices in the context of pandemics (such as COVID-19), warfare, embargos, and uncertainty to develop resilient and adaptable maintenance strategies.

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Persian Abstract

چکیده

هدف از پژوهش حاضر ارائه یک مدل نگهداری و تعمیرات یکپارچه در صنعت پتروشیمی می باشد. تحقیق حاضر از نظر هدف، کاربردی و از نظر روش گردآوری داده ها، توصیفی- پیمایشی است. برای انجام پژوهش از روش ترکیبی (کیفی و کمی) استفاده شده است. ابزار مورد استفاده در این تحقیق، پرسشنامه محقق ساخته (۳٦ سوال)، گفتگو با اساتید داخلی و خارجی در زمینه نگهداری و تولید، تکنیک دلفی (٤١ مدیر تعمیر و نگهداری)، تحقیقات میدانی (۲۰ شرکت پتروشیمی داخلی و ۷ شرکت پتروشیمی خارج از کشور) ، تجربیات و شواهد به دست آمده از ۱۲ تعمیرات اساسی در طول ۳۰ سال است. که روایی پرسشنامه از طریق نظرات خبرگان و پایایی آن از طریق ارزیابی آلفای کرونباخ تعیین شده است. نتایج نشان می دهد که پرسشنامه دارای روایی و پایایی بالا می باشد. جامعه آماری شامل، متخصصان حوزه نگهداری و تعمیرات در صنعت و دانشگاه می باشد که از بین آنها ۱۱۰ نفر به روش نمونه گیری هدفمند انتخاب شده اند. جهت انجام تحقیق در مرحله اول، ابتدا با استفاده از روش اسنادی ، تحلیل محتوا و مصاحبه با خبرگان ، شاخص‌ها و ابعاد مدل نگهداری و تعمیرات یکپارچه قوی استخراج گردید و به صورت طیف لیکرت جهت امتیاز دهی در اختیار خبرگان قرار گرفت؛ بعد از انجام بررسی تعداد ۳٦ زیر مولفه انتخاب گردید که هر یک از مولفه های اصلی: مدیریت، نیروی انسانی، تجهیزات و دانش دارای ۹ زیر مولفه بودند. در مرحله بعد با استفاده از پرسشنامه و به روش فرآیند تحلیل سلسله مراتبی به امتیاز دهی و رتبه بندی مولفه ها و زیر مولفه ها پرداخته شد. در این تحقیق سه نتیجه زیر به دست آمده است: ۱- چهار ریشه اصلی (انسان، مدیریت، دانش و تجهیزات) و سی و شش ریشه فرعی نگهداشت اثر بخش. ۲- عناصرضروری فرمول اندازه گیری شاخص بحرانی تجهیزات.۳- پنج شاخص برای اندازه گیری عملکرد تعمیر و نگهداری یکپارچه. با توجه به محاسبات، مقدار ناسازگاری بین بردارهای هر ماتریس کمتر از ۰.۱۰ است. بنابراین، بردارهای تشکیل دهنده هر یک از ماتریس های تشکیل شده برای نتایج سه گانه تحقیق سازگار بوده و همچنین پایداری مقایسه های مربوطه قابل قبول هستند.