Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/01/jls.htm
2015 Vol.5 (S1), pp. 4780-4793/Jamshidi and Razavi
Research Article

SELECTING MAINTENANCE STRATEGY USING AHP AND FUZZY TOPSIS TECHNIQUES CASE STUDY: KAROON PHOSPHATE COMPLEX

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ABSTRACT
The aim of this study was id to select the appropriate maintenance strategy using AHP and fuzzy TOPSIS techniques in Karoon Phosphate Complex. Respondents were asked to identify the importance of each case from 55 criteria using a questionnaire with 55 questions in order to determine factors that affect the optimal maintenance strategy in Karoon Phosphate Complex by analytic hierarchy process and fuzzy TOPSIS. Respondents used numbers of 1, 2, 3, 4 and 5 in order to determine the importance of parameters that represent very low, low, medium, high and very high, respectively. According to the findings of study, factors affecting the selection of optimal maintenance strategy of Karoon Phosphate Complex were 26 parameters which are classified into six categories including operation efficiency, cost aspect, resources aspect, failure type and pattern aspect, knowledge and skills aspect and security aspect. It was also known that operational efficiency aspect is the most important aspect and then, cost and knowledge and skill aspects have the highest weight and importance.

Keywords: *Maintenance, AHP and TOPSIS*

INTRODUCTION
Industrial maintenance has been converted from unimportant into significant issue over the past decade. There are several administrative areas that have experienced many changes over past half-century; in this course, maintenance role in organization has been dramatically changed. At the beginning, maintenance was inevitable part, but now, it is a crucial factor in order to achieve strategic business objectives (Pintelon, 2010).

Organizations are active in a highly competitive environment and there is no chance for error and a slightest mistake will lead to a lot of damages to organization. Hence, in this environment where organizations are compelled to use the capital equipment and assets with exorbitant prices, maintaining them is more important (Aghayi and Fazli, 2012).

Many organizations are looking for more production with less consumption resources at shorter time under increasingly competitive pressure. Physical assets have central role in order to meet the urgent needs (Pintelon, 2010).

Managers of successful organization try to act in all fields of production, information, shopping, marketing, engineering systems and high level quality. One of the distinctive characteristics of outstanding manufacturing organization is to have efficient and effective maintenance organization.

Maintenance is the most important and fundamental issue that will lead to survival and continuity of production lines and will provide cost savings. Over time, the economic and efficient use of equipment and facilities and maintenance procedures will be further considered. Strategies and methods are compared using various indicators. The proposed research aims to provide a model for selecting optimal maintenance strategy in Karoon phosphate Complex using hierarchy analysis and fuzzy TOPSIS.

Literature
Definition of Maintenance

Maintenance is the most important and fundamental issue that will lead to survival and continuity of production lines and will provide cost savings. The economic and efficient use of equipment and facilities is further considered due to more sophisticated equipment and facilities in order to meet growing needs of people (Seyyed, 1997).

In another definition, maintenance is a set of different activities that is used for preservation of parts, equipment, capital and assets in order to prevent the occurrence of events leading to failure of machines and interruption of production process or equipment operation (Chen *et al.*, 2009).

In other words, the mission of maintenance system can be expressed as follows:

"Providing the desired product fields (production targets) through maintaining supplies, equipment, machinery, necessary facilities and requirements in short and long-term with less cost"(Nazmi, 2002).

The Objectives of Maintenance Systems

Various manufacturing companies have different objectives of implementing maintenance. These objectives can be divided into several major categories:

Added Value

A good maintenance program can promote added value that includes reduced costs for spare parts, low waste production and production quality.

Product Quality

Equipment failures can affect product quality. In fact, when machine has the best situation and more reliability for work, product quality will be increased (Bevilacqua and Braglia, 2000).

The Production Waste

The main machine downtime in production line leads to more production waste costs. Selecting an appropriate maintenance strategy for this machine can reduce production waste.

Significant factors of production waste include:

- The spare parts cost: corrective maintenance typically needs more spare parts compared to other strategies.
- Functionality: it refers to favorable conditions for implementation of strategy.
- Access to equipment and technology: It is one of the most influential factors in selecting an access strategy to equipment and technology of implementation.

Reliability of Techniques: Since both contingency and predictive maintenance strategies are still being developed, they do not seem appropriate for some complex production facilities (Bevilacqua and Braglia, 2000).

Security

A high level of security is required in many of manufacturing plants, especially in industrial sectors. Associated factors can be concluded in the following way.

- Facilities: for example, a sudden stop of pump can lead to serious damages to power plant.
- Personnel: Breakdown of machinery can damage staff severely in sites.

Environment: failure of equipment that contains toxic gases and liquids damage to environment (Bevilacqua and Braglia, 2000).

Costs

Different strategies of maintenance need different budgets on software, hardware and personnel groups.

- Hardware: the presence of sensors and computers is unavoidable for contingency and predictive maintenance.
- Required experts: they are needed in order to implement each strategy, depending on its type. They can be absorbed or supplied by teaching staff members.
- Software: we need monitoring software in order to analyze the data when we use predictive and contingency maintenance (Wang *et al.*, 2006).

Barriers to Maintenance Systems

The main challenges that managers face in different organizations include:

- Selecting the most appropriate maintenance technique
- The way of dealing with any failures and downtime
- Combining all expectations of industry owners and special users

- Selecting the best method based on minimum cost for enterprises in order to overcome the drawbacks (Selih *et al.*, 2008).

According to Wireman (2004), the main objective of establishing a proper maintenance is as follow:

• Preventing the development of defects and deficiencies
• The removal of minor defects and disadvantages before need for general repairs
• Avoiding interruptions in production operations through replacing worn parts before fracture and decommissioning the machine
• Reducing production stops and preventing losses resulting from interruption of work
• Manpower savings due to reduced maintenance operations
• Better use of installation and maintenance personnel
• Reducing overall maintenance and replication
• Reducing the consumption of spare parts and related costs
• Reducing the amount of poor quality products and increasing product quality
• Increasing the lifetime of machinery and savings in purchasing new machines
• Identifying and evaluating the performance of machinery and maintenance costs in order to make decisions on selecting new machines
• Increasing production efficiency of machinery and reducing production costs (Wireman, 2004).

Research Questions

1. What are effective parameters in selecting maintenance strategy of Karoon Phosphate Complex and how important is each one?
2. What are proper maintenance strategies for Karoon Phosphate Complex?

MATERIALS AND METHODS

Since this study is conducted in an objective and real organization, and its results can be used practically, it is an applied research.

Given that this study seeks to select the appropriate maintenance strategy for Karoon Phosphate Complex, then it is a descriptive – functional

The statistical population of this study consists of 2,300 managers, professionals, technicians and staff of Karoon Phosphate Complex and industries maintenance professionals.

Sample size was obtained 93 people using Cochran formula.

In this study, a questionnaire was distributed among 152 people and finally 117 questionnaires were collected and were used in data analysis.

Data collection tool of this study includes two questionnaires. The first questionnaire will identify parameters.

The second questionnaire is designed based on fuzzy AHP technique concept and measures the importance of parameters using paired comparisons.

One-sample T-test was used after collecting the first questionnaires in order to determine the presence or absence of each parameter in final list of parameters.

When effective parameters were finalized, and literature was reviewed, hierarchical structure of problem will be defined based on expert opinions on parameters contained in second questionnaire.

Second questionnaire is designed based on fuzzy AHP technique concept and the importance of parameters is measured using paired comparisons.

Verbal expressions and fuzzy numbers listed in (Table 1) are response base of this questionnaire. Decision makers must record preferred value according to (Table 1) between any two elements of numbers $\tilde{1}$ to $\tilde{9}$.

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Table 1: Verbal expression and fuzzy numbers in order to compare criteria priorities (Semih *et al.*, 2009)

Linguistic variable	Fuzzy numbers	Triangular fuzzy number
Equal importance	$\tilde{1}$	(1,1,3)
A little important	$\tilde{3}$	(1,3,5)
More important	$\tilde{5}$	(3,5,7)
Very important	$\tilde{7}$	(5,7,9)
Fully important	$\tilde{9}$	(7,7,9)
Preferred values of underlying values	$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	(6,8,9) (4,6,8) (2,4,6) (1,2,4)

As it is determined from (Table 1), all triangular fuzzy numbers that are used in this study, except initial and final numbers, are symmetrical numbers.

Data Analysis

Respondents were asked to identify the importance of each case from 55 criteria using a questionnaire with 55 questions in order to determine factors that affect the optimal maintenance strategy in Karoon Phosphate Complex by analytic hierarchy process and fuzzy TOPSIS.

Table 2: Factors influencing the optimal maintenance strategy in Karoon Phosphate Complex and their hierarchical classification

Aspects	Effective Parameters	Sign
Operating efficiency	Response rate	d1
	Overall equipment efficiency	d2
	Equipment installation and implementation time	d3
	Process optimization in order to maximize the effectiveness of equipment	d4
	Flexibility of production variety	d5
	production lines stoppage and forced unemployment of personnel costs	d6
Costs	Mean monthly maintenance costs	d7
	Equipment purchase cost	d8
	Over- consumed spare parts price	d9
	Mean cost of downtime	d10
	Storage costs	d11
	Personnel wages	d12
Resources	Availability of Maintenance Equipment	d13
	Public access level to repair technology	d14
	Spare parts delivery time	d15
	Quality of spare Parts	d16
Failure pattern and type	Depreciation rate	d17
	Traceability of failure field	d18
	Calculating the exact replacement period of parts used in machinery	d19
Knowledge and skills	Upgradeability and optimization of maintenance techniques	d20
	The level of training personnel	d21
	The mean time of repairs parameter	d22
	Knowledge related to strategy implementation	d23
	Advanced training needed for maintenance	d24
security	System and Computer Security	d25
	Maintaining hierarchy of access to classified information	d26

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Respondents used numbers of 1, 2, 3, 4 and 5 in order to determine the importance of parameters that represent very low, low, medium, high and very high, respectively.
Only 26 cases of 55 parameters are maintained on the list of factors affecting optimal maintenance strategy of Karoon Phosphate Complex after calculating the mean and standard deviation of responses and conducting single-sample t test (one- sequence right test at 95% confidence level).

Calculating Preference Weights of Fuzzy Paired Comparison Matrices using Fuzzy Hierarchy Analytic Process

1. Calculating preference weights of six parameters related to operational efficiency aspect

The first step: integration of paired comparison matrices

As it is known from Table (2), the following six parameters effect on operational efficiency aspect:
- Response rate
- Overall equipment efficiency
- Equipment installation and implementation time
- Process optimization in order to maximize the effectiveness of equipment
- Flexibility of production variety
- Production lines stoppage and forced unemployment of personnel costs

Comparing these six parameters is shown relative to each other in the following matrix. Here, the way of calculating matrix elements is discussed.

(4-1) $\tilde{r}i=(\tilde{a}i_1 \otimes \tilde{a}i_2 \otimes ... \otimes \tilde{a}i_n)^{\frac{1}{n}}$

Decision makers, comparing second parameter and first parameter, have mentioned 3 times the verbal statement of equal, 2 times the verbal statement of a little important, 2 times the verbal statement of rather important and 2 times the verbal statement of a little more important.
Therefore, the element in the second row and the first column can be calculated as follows, in accordance with rules of fuzzy numbers multiplication:

$(\sqrt[9]{1^3 \times 1^2 \times 1^2 \times 2^2}, \sqrt[9]{1^3 \times 3^2 \times 2^2 \times 4^2}, \sqrt[9]{3^3 \times 5^2 \times 4^2 \times 6^2}) = (1.66, 2.026, 4.179)$

Table (3) shows the results of merging paired comparisons matrixes related to six parameters affecting organizational factors aspect.

Table 3: Comparison of six parameters affecting operation efficacy to each other

	S1			S2			S3			S4			S5			S6		
S1	1.00	1.00	1.00	0.24	0.50	0.86	1.10	2.95	4.97	0.15	0.22	0.40	1.35	2.85	4.91	0.20	0.33	0.82
S2	1.17	2.03	4.18	1.00	1.00	1.00	0.19	0.30	0.61	0.11	0.12	0.16	0.30	0.49	1.20	0.15	0.18	0.26
S3	0.20	0.34	0.91	1.64	3.28	5.35	1.00	1.00	1.00	0.16	0.24	0.45	1.10	2.95	4.97	0.14	0.21	0.37
S4	2.52	4.62	6.66	6.14	8.14	9.00	2.25	4.16	6.26	1.00	1.00	1.00	5.13	7.53	8.14	1.10	2.95	4.97
S5	0.20	0.35	0.74	0.84	2.04	3.38	0.20	0.34	0.91	0.12	0.13	0.19	1.00	1.00	1.00	0.16	0.24	0.47
S6	1.22	3.07	5.10	3.87	5.45	6.58	2.74	4.87	6.92	0.20	0.34	0.91	2.12	4.20	6.33	1.00	1.00	1.00

As it is necessary and conventional at all methods based on paired comparisons, examining the validity and accuracy of comments and paired comparisons related to calculating compatibility rate is implemented in this study. So, compatibility rate calculation is done after de-fuzzy the numbers on main diagonal of matrix and inserting their reverse on lower diagonal of matrix in accordance with conventional hierarchy analytic process method. Here details are not mentioned for summary.

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Second step: calculating $\left[\sum_{i=1}^{m}\sum_{i=1}^{n} M_{ij}\right]^{-1}$

For this purpose, we must calculate the sum of all Ls, Ms and Us along with all rows and columns of table for all triangular fuzzy numbers that are defined as (L, M, U), for example:
1+0.24+...+0.20+2.12+1=43.01
As it is indicated above, these numbers have been extracted from paired comparisons matrix and their L number. Having the same calculation for M and U values, we will have:
$\sum_{i=1}^{m}\sum_{i=1}^{n} M_{ij}$ = (43.01, 71.420, 102.98)
If M = (l, m, u), then, equation (4-2) is used in order to calculate the inverse of fuzzy number.

(4-2) $M^{-1} = (\frac{1}{u}, \frac{1}{m}, \frac{1}{l})$

Then we have,
$\left[\sum_{i=1}^{m}\sum_{i=1}^{n} M_{ij}\right]^{-1} = (\frac{1}{102.98}, \frac{1}{71.42}, \frac{1}{43.01})$=*(0.009 , 0.014 , 0.023)*

Third step: Calculating $\sum_{j=1}^{n} M_{kj}$ for each row

For each row, fuzzy numbers of each row are calculated according to sum of fuzzy numbers.
For example, for the first row:
(0.20, 0.33, 0.82)+…+(0.24,0.50,0.86)+(1,1,1)=(4.04, 7.85, 12.96)
Step Four: calculating S_k for each member of matrix
For example, S_1 is calculated in the following way:
S-1=(14.04,7.85,12.96)×(0.009, 0.014, 0.023)=(0.039, 0.110, 0.0301)
Similarly, other S_k are calculated.

Table 4: S_K calculated values according to Table (3)

S_1	**(0.039 ,0.110 , 0.301)**
S_2	(0.017 ,0.029 , 0.074)
S_3	(0.038 ,0.104 , 0.277)
S_4	(0.165 ,0.362 , 0.756)
S_5	(0.026 ,0.065 , 0.176)
S_6	(0. 122 ,0.277 , 0.614)

Fifth step: Calculating magnitude degree of S_k and final weights

At this point, magnitude degree of all S_k is calculated.
For example, magnitude degree of S-1 to S-2 is equal to 1, because m_2 ≤ m_1
But, magnitude degree of S_1 to S_4 is calculated as follows:

$$V(S_1 \geq S_4) = \frac{(0.301-0.165)}{(0.301-0.165)+(0.362-0.110)}$$

Similarly, the magnitude degree of all S_k is calculated relative to each other and then, the magnitude degree of each of them is obtained compared to other numbers from the minimum amount. This is equal to non-normalized weights of paired comparisons matrix.

Table 5: Non-normalized and normalized weights of parameters affecting operation efficiency

Parameter	Non-normalized weights		Normalized weights	
Response rate	W_1'	0.434	W_1	0.167
Overall equipment efficiency	W_2'	0.115	W_2	0.044
Equipment installation and implementation time	W_3'	0.097	W_3	0.037
Process optimization in order to maximize the effectiveness of equipment	W_4'	1.000	W_4	0.386
Flexibility of production variety	W_5'	0.178	W_5	0.069
production lines stoppage and forced unemployment of personnel costs	W_6'	0.769	W_6	0.297

The final normalized weights are given in fourth column of above table. Each of these numbers has been obtained through dividing each number of second columns sum by sum of column numbers. Equation (4-3) shows the way of normalization:

$$Wj = \frac{w_j'}{\Sigma w_j'}$$

4-3

For other factors, the weight of factors affecting each of them has been calculated. In this section, we will provide the results in order to avoid the longevity.

2. Calculate the weight of factors affecting cost aspect

As it is known from Table (3), the following six parameters effect on cost aspect:

- Mean monthly maintenance costs
- Equipment purchase cost
- Over- consumed spare parts price
- Mean cost of downtime
- Storage costs
- Personnel wages

Table 6: Six parameters affecting cost aspect

Parameter	Relative weight
Mean monthly maintenance costs	0.238
Equipment purchase cost	0.219
Over- consumed spare parts price	0.094
Mean cost of downtime	0.204
Storage costs	0.073
Personnel wages	0.172

3. Calculating the weight of factors affecting resource aspect

As it is known from Table (3), the following four parameters effect on resource aspect:

-Availability of Maintenance Equipment
-Public access level to repair technology
-Spare parts delivery time
-Quality of spare Parts

Table 7: Weight of four parameters affecting resources

Parameter	Relative weight
Availability of Maintenance Equipment	0.274
Public access level to repair technology	0.258
Spare parts delivery time	0.191
Quality of spare Parts	0.277

4. Calculating the weight of factors affecting failure pattern and type aspect
As it is known from Table (3), the following three parameters effect on failure pattern and type aspect:
-Depreciation rate
-Traceability of failure field
-Calculating the exact replacement period of parts used in machinery

Table 8: Weight of three parameters affecting failure pattern and type

Parameter	**Relative weight**
Depreciation rate	0.388
Traceability of failure field	0.341
Calculating the exact replacement period of parts used in machinery	0.271

5. Calculating the weight of factors affecting knowledge and skills aspect
As it is known from Table (3), the following five parameters effect on knowledge and skills aspect:
-Upgradeability and optimization of maintenance techniques
-The level of training personnel
-The mean time of repair parameter
-Knowledge related to strategy implementation
-Advanced training needed for maintenance

Table 9: Weight of five parameters affecting knowledge and skills

Parameter	**Weight**
Upgradeability and optimization of maintenance techniques	0.177
The level of training personnel	0.264
The mean time of repair parameter	0.314
Knowledge related to strategy implementation	0.127
Advanced training needed for maintenance	0.118

6. Calculating the weight of factors affecting security aspect
As it is known from Table (3), the following three parameters effect on security aspect:
-System and Computer Security
-Maintaining hierarchy of access to classified information

Table 10: Weight of parameters affecting security aspect

Parameter	**Weight**
System and Computer Security	0.5
Maintaining hierarchy of access to classified information	0.5

4.4.7. Calculating the preference weights of five main aspects
As it is known from Table (3), the following six parameters effect on implementing information security system:
-Operation efficiency
-Costs
-Resources
-Failure pattern and type
-Knowledge and skills

Table 11: Weight of problem main six aspects

Weight of aspects	Aspects
0.314	Operation efficiency
0.257	Costs
0.122	Resources
0.105	Failure pattern and type
0.131	Knowledge and skills
0.071	Security

5. Calculating the final weights of parameters
The calculated weight of parameters is multiplied by calculated weight of parameters for the same aspect and in peer to peer way in order to calculate the final weight of parameters.

Table 12: Weights of parameters affecting the selection of maintenance strategy in Karoon Phosphate Complex

Aspects	Final weight of aspects	Effective parameters	Relative weight of parameters	Final weight of parameters
Operating efficiency	0.314	Response rate	0.167	0.052
		Overall equipment efficiency	0.044	0.014
		Equipment installation and implementation time	0.037	0.012
		Process optimization in order to maximize the effectiveness of equipment	0.386	0.121
		Flexibility of production variety	0.069	0.022
		production lines stoppage and forced unemployment of personnel costs	0.297	0.093
Costs	0.257	Mean monthly maintenance costs	0.238	0.061
		Equipment purchase cost	0.219	0.056
		Over- consumed spare parts price	0.094	0.024
		Mean cost of downtime	0.204	0.052
		Storage costs	0.073	0.019
		Personnel wages	0.172	0.044
Resources	0.122	Availability of Maintenance Equipment	0.274	0.033
		Public access level to repair technology	0.258	0.031
		Spare parts delivery time	0.191	0.023
		Quality of spare Parts	0.277	0.034
Failure pattern and type	0.150	Depreciation rate	0.388	0.041
		Traceability of failure field	0.341	0.036
		Calculating the exact replacement period of parts used in machinery	0.271	0.028
Knowledge and skills	0.131	Upgradeability and optimization of maintenance techniques	0.177	0.023
		The level of training personnel	0.264	0.035
		The mean time of repair parameter	0.314	0.041
		Knowledge related to strategy implementation	0.127	0.017
		Advanced training needed for maintenance	0.118	0.015
security	0.071	System and Computer Security	0.5	0.036
		Maintaining hierarchy of access to classified information	0.5	0.036

6. Selecting maintenance strategies of Karoon Phosphate Complex by fuzzy TOPSIS:
The following four maintenance strategies were introduced as solutions of Karoon Phosphate Complex after evaluations that were carried out:

Es1: Focused corrective maintenance strategy

Es2: Focused preventive maintenance strategy

Es3:Non-focused corrective maintenance strategy

Es4:Non-focused preventive maintenance strategy

After determining the final weight of each 26 parameters affecting selection of maintenance strategies in Karoon Phosphate Complex, decision makers were asked to estimate the positive effect (utility) of each four strategies using with verbal expressions and fuzzy numbers based on each 26 parameters that are mentioned.

Having gathered the views of respondents to questions, we convert verbal expressions into triangular fuzzy numbers, and then we multiply aforementioned fuzzy numbers using fuzzy relations. Then, we convert final fuzzy numbers into exact number using de-fuzzy equation.

Table 13: Definite number of evaluating four strategies from 26 parameters

Strategy	s1	s2	s3	s4	s5	s6	...	...	s24	s25	s26
Focused corrective maintenance strategy	3.674	1.705	5.175	7.294	7.192	7.709			4.262	3.983	3.127
Focused preventive maintenance strategy	7.830	6.647	7.939	7.159	7.662	6.159			5.159	4.189	7.483
Non-focused corrective maintenance strategy	1.702	2.797	6.430	5.758	6.664	6.070			7.067	1.804	1.417
Non-focused preventive maintenance strategy	5.159	6.169	7.904	4.111	7.327	4.815			6.615	5.873	3.987

Then, Euclidian non- scaling step is implemented.

Table14: Euclidian non-scaling matrix

Strategy	s1	s2	s3	s4	s5	s6	...	...	s24	s25	s26
Focused corrective maintenance strategy	0.36	0.18	0.37	0.59	0.50	0.61			0.36	0.47	0.34
Focused preventive maintenance strategy	0.77	0.69	0.57	0.58	0.53	0.49			0.44	0.50	0.82
Non-focused corrective maintenance strategy	0.17	0.29	0.46	0.46	0.46	0.48			0.60	0.21	0.15
Non-focused preventive maintenance strategy	0.51	0.64	0.57	0.33	0.51	0.38			0.56	0.70	0.44

In the next step, we multiply the above matrix by weight matrix in order to obtain the harmonic non-scaled matrix.

Table 15: Harmonic non-scale matrix

Strategy	**s1**	**s2**	**s3**	**s4**	**s5**	**s6**	**...**	**...**	**s24**	**s25**	**s26**
Focused corrective maintenance strategy	0.019	0.002	0.004	0.071	0.011	0.057			0.0054	0.017	0.0123
Focused preventive maintenance strategy	0.040	0.010	0.007	0.070	0.012	0.046			0.0066	0.0179	0.0294
Non-focused corrective maintenance strategy	0.009	0.004	0.006	0.056	0.010	0.045			0.009	0.0077	0.0056
Non-focused preventive maintenance strategy	0.026	0.009	0.007	0.040	0.011	0.036			0.0084	0.0251	0.0157

In the next step, we calculate the positive and negative ideal solution.

Table 16: Positive and negative ideal solution matrix

	s1	**s2**	**s3**	**s4**	**s5**	**s6**	**...**	**...**	**s24**	**s25**	**s26**
Positive ideal	0.040	0.010	0.007	0.071	0.012	0.057			0.009	0.025	0.029
Negative ideal	0.0087	0.0025	0.0045	0.04	0.0102	0.0357			0.0054	0.0077	0.0056

In this step, the distance of each option from positive and negative ideal is measured.

Table 17: Positive and negative ideal distance of each option

Strategy	**Distance from positive ideal**	**Distance from negative ideal**
Focused corrective maintenance strategy	0.075	0.043
Focused preventive maintenance strategy	0.028	0.083
Non-focused corrective maintenance strategy	0.072	0.042
Non-focused preventive maintenance strategy	0.051	0.064

In the next step, we calculate the proximity factor of Ci.

Table 18: Proximity factor of four strategies

Strategy	C_i
Focused corrective maintenance strategy	0.368
Focused preventive maintenance strategy	0.748
Non-focused corrective maintenance strategy	0.367
Non-focused preventive maintenance strategy	0.556

It shows the final rank of four strategies based on proximity factor (Ci).

Table 19: The final ranking of four strategies

Strategy	**Rank**
Focused corrective maintenance strategy	First
Focused preventive maintenance strategy	Second
Non-focused corrective maintenance strategy	Third
Non-focused preventive maintenance strategy	Forth

Conclusion

First Question

What are effective parameters in selecting maintenance strategy of Karoon Phosphate Complex and how important is each one?

According to the findings of study, we can consider 26 below factors affecting the selection of optimum maintenance strategy in Karoon phosphate Complex that are classified in six categories.

A: Operati efficiency aspect:

- Response rate
- Overall equipment efficiency
- Equipment installation and implementation time
- Process optimization in order to maximize the effectiveness of equipment
- Flexibility of production variety
- Production lines stoppage and forced unemployment of personnel costs

B: Costs aspect

- Mean monthly maintenance costs
- Equipment purchase cost
- Over- consumed spare parts price
- Mean cost of downtime
- Storage costs
- Personnel wages

C: Resource aspect:

-Availability of Maintenance Equipment

-Public access level to repair technology

-Spare parts delivery time

-Quality of spare Parts

D: Failure pattern and type aspect

-Depreciation rate

-Traceability of failure field

-Calculating the exact replacement period of parts used in machinery

H: Knowledge and skills aspect

-Upgradeability and optimization of maintenance techniques

-The level of training personnel

-The mean time of repair parameter

-Knowledge related to strategy implementation

-Advanced training needed for maintenance

V: Security aspect

-System and Computer Security

-Maintaining hierarchy of access to classified information

Second Question

Table (20) shows the weight and rank of each factor affecting the selection of optimal maintenance strategy in Karoon Phosphate Complex.

Table 20: The weight and rank of each factor affecting the selection of optimal maintenance strategy of Karoon Phosphate Complex

Rank	Parameter weight	Parameter
1	0.121	Process optimization in order to maximize the effectiveness of equipment
2	0.093	production lines stoppage and forced unemployment of personnel costs
3	0.061	Mean monthly maintenance costs
4	0.056	Equipment purchase cost
5	0.052	Response rate
6	0.052	Mean cost of downtime
7	0.044	Personnel wages
8	0.041	Depreciation rate
9	0.041	The mean time of repairs parameter
10	0.036	Traceability of failure field
11	0.036	System and Computer Security
12	0.036	Maintaining hierarchy of access to classified information
13	0.035	The level of training personnel
14	0.034	Quality of spare Parts
15	0.033	Availability of Maintenance Equipment
16	0.031	Public access level to repair technology
17	0.028	Calculating the exact replacement period of parts used in machinery
18	0.024	Over- consumed spare parts price
19	0.023	Spare parts delivery time
20	0.023	Upgradeability and optimization of maintenance techniques
21	0.022	Flexibility of production variety
22	0.019	Storage costs
23	0.017	Knowledge related to strategy implementation
24	0.015	Advanced training needed for maintenance
25	0.014	Overall equipment efficiency
26	0.012	Equipment installation and implementation time

As it is determined from Table (20), operational efficiency aspect is the most important aspect. Then, cost and knowledge and skill aspects have the highest weight and importance. Table (21) shows the prioritization of maintenance strategies in Karoon Phosphate Complex.

Table 21: Prioritizing maintenance strategies of Karoon Phosphate Complex

Strategy	Rank
Focused corrective maintenance strategy	First
Focused preventive maintenance strategy	Second
Non-focused corrective maintenance strategy	Third
Non-focused preventive maintenance strategy	Forth

As it is determined preventive maintenance strategies have priority over corrective strategies. Also, focused corrective maintenance strategies have priority over non- focused strategies.
This is due to the kind of company production that is mainly based on type of production process.

ACKNOWLEDGEMENT
We are grateful to Islamic Azad University, Marvdasht branch authorities, for their useful collaboration.

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