

PROPOSING A MODEL FOR THE SELECTION OF REPAIR & MAINTENANCE STRATEGY FOR IT SYSTEMS WITH THE HELP OF DEMATEL & ANP FUZZY PROCESS

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Abstract

Repair & maintenance are the integral parts of using any technology which can affect the competitive priorities of organizations. Some changes have been made in dominant paradigms of production and in some other factors such as the progress of societies towards an information society and various strategies of repair and maintenance. In order to select a repair & maintenance strategy for IT systems in this research, an attempt was made to present a comprehensive and scientific perspective as well as introducing an applied model on the selection of repair & maintenance strategy for IT systems in Tehran Cement Factory. In order to identify the effective parameters on research problems of the present descriptive functional study, a questionnaire with 51 indicators was developed and a population of 86 people answered it. Among these indicators, 21 of them were identified as effective factors on the selection of repair & maintenance strategy for IT systems in Tehran Cement Co. In the next step, the weight of each indicator and the dimensions of other questionnaires were determined on the basis of DEMATEL method and the technique of fuzzy analytic network process (FANP) and had been sent along with a letter for every member. After measuring the weight of each using DEMATEL method and fuzzy analytic network process, it was found that the time for equipments installation and commissioning, the amount of investments in information technology systems and the cost of buying equipments are of the maximum value and importance respectively.

Keywords: Repairs & maintenance, DEMATEL process, fuzzy analytic network process (FANP)

Introduction

Today, the cost of repair & maintenance is constantly an important part of every company's production budget. This cost, depending on the variety of industry type, may embrace 15 to 70 percent of the company's production costs. In this regard, considering the increasing role of new technologies in human life and the necessity of using a proper repair & maintenance

strategy for performance increase and prevention from interruption or disruption of these networks, researchers decided to provide an appropriate model for the selection of repair & maintenance strategy for IT systems in order to reduce costs as well as making effective efforts in maximizing the shelf life, reliability and performance of equipments and machinery and minimizing the costs of production lines stoppages due to a device failure.

Nowadays, the use of information technology along with a variety of information systems which are designed for different needs has been increased. Information technology enables managers to make more and better relationships with organization, environment and each other. More participation in decision-making, speed increase of decision-making, speed increase of issue identification, reduction of the height of organization pyramid, coordination improvement and the increase of professional staff are just some of the impacts that information technology and information systems have on some organizations (Mehrinezhad, 2002).

Repair & maintenance play an important role in preserving the reliability, availability, risk reduction, increase of efficiency; equipments safety etc; thus repair & maintenance and their strategies are of a special position in industry. Decision-making process and judgment about the selection of repair & maintenance strategy are often fragmented, complex and unstructured (Hajshir. mohammadi et al, 2004) and requires the consideration of many characteristics and factors some of which are also unavailable (Bevilacqua et al, 2000). Evaluation of these strategies is a decision-making process in a multi-criteria condition and many factors affect its selection.

Some of these most important strategies are: preventive maintenance, predictive maintenance, condition-based maintenance, reliability-based maintenance, lean maintenance, total productive maintenance, lean total productive maintenance, risk-base maintenance, agile maintenance and virtual maintenance.

In the digital world of today and the age of communications, the application of new technologies such as IT and information systems is necessary for a proper response to current changes in the environment, because information technology has increasingly affected the function and performance of both public and private organizations.

The selection of maintenance & repair strategy for IT systems takes different forms according to the type and number of equipments and also their failure patterns in different organizations and should be selected according to the required features of organization and process and various expected characteristics.

However, for the review of maintenance policies, there are multiple criteria and different perspectives that must be considered in this decision-making. Many factors such as cost, reliability, security, etc are effective in the selection of maintenance & repair strategy. In many cases, these parameters are unknown in some various factories and industries and their weight and level of importance is also not clear. It seems that in many industries of the country, the dominant insight into the process of maintenance & repair strategies selection is not a holistic and scientific vision and is based more on simple perceptions and past experiences of managers.

Multi-criteria decision-making creates a good framework for the evaluation of multi-dimensional, paradoxical and incompatible issues, because this method consists of a series of decision-making techniques and quantitative and qualitative set of factors. Therefore, due to the presence of qualitative and subjective factors in the selection of maintenance & repair strategy for IT systems, the application of multi-criteria decision-making methods based on

paired comparisons such as analytic hierarchy process or analytic network process, is a logical solution and a more appropriate response in solving complex problems.

The process of network analysis is the extended form of analytic hierarchy process technique, but we cannot consider many of multi-criteria decision-makings as a hierarchical structure due to internal and external dependency and the relationships and interactions between the elements of clusters in decision-making levels. Therefore, the fuzzy analytic network process or FANP with a comprehensive framework, takes into consideration all interactions and relationships between the levels of decision-making which form a lattice structure (Saaty, 2004).

Since each problem has its own unique factors and indicators, the over-reliance on the opinion of decision-makers about the form of relationship between these factors, may not create an exact trend and because of the uniqueness of each issue the mode of relationship between indicators may not be clear, the application of DEMATEL method can help to enhance the reliability of issue framework design.

So it seems that the use of combined fuzzy analytic network process and DEMATEL method can be helpful in the selection of maintenance & repair strategies for IT systems. According to what was said, in this study the researcher tries to select maintenance & repair strategies for IT systems with the help of fuzzy analytic network process and DEMATEL.

Research Background

Maintenance & repair is defined as the combination of technical and managerial activities with the goal of maintaining a device or system or retrieving it, in a case that is able to perform its proper function. A proper maintenance requires technical skills, methods and techniques through which the assets like factories, power plants, machinery, equipments and machines are appropriately fitted. Key issues in repair & maintenance are ensuring the system performance (availability, efficiency and production quality), life of the system (asset management) and system security with the lowest energy consumption. A machine or device which has not been repaired or maintained well, will be faced with numerous stops and as a result will be frequently out of reach in a service or production cycle. In total, this would lead to less equipment, lower production or service reduction. Hence, repair & maintenance is directly connected with competitive advantage and profitability of an organization. [Akarte, 2012]

Deciding on the management of maintenance & repair for information technology (IT) systems where facilities are typically expensive resources, will have a great impact on organization performance; because a small defect in them can lead to great losses such as the loss of company. Although information technology (IT) has brought significant advantages to systems production, facilities of maintenance planning and operation, but it is recognized as a vulnerable spot and needs to take some measures for maintenance. [Muller et al, 2008]

In 2000, Bevilacqua used AHP in the selection of the best maintenance strategy for a major oil refinery in Italy. In his research, the five possible alternatives such as preventive, predictive, contingency, corrective and opportunistic maintenance were considered. [Bevilacqua, 2000]

In 2003 and in a different research, he used the combination of AHP and fuzzy method for the prediction of costs in an effective approach to maintenance strategy; however the author did not care about the significance of great conditions for maintenance time. [Al-najjara, 2003]

It is recommended to use AHP and fuzzy logic control in the preparation of fixed rules and flexible strategies for supporting decision makers in the determination of assets maintenance methods. Libib (2008) has suggested that these two methods be applied in determining the kind of maintenance strategy that should be chosen for the production system response to environmental changes and also its proper time. [Libib, 2008]

In other cases, additional tools are also used; for instance Dragan & Savic (1995) proposed genetic algorithm method in determining the minimal cost of parts replacement for different conditions. (Dragan A. Savic, 1995)

Jafari (2008) used Fuzzy Delphi in selecting the best method of maintenance. (Jafari, 2008)

Dragan et al (1995) selected an optimal maintenance policy in manufacturing factories using a genetic algorithm. (Dragan et al, 1995)

Almeida et al, have used decision-making theory and multi-criteria utility theory in order to deal with maintenance & repair issues. (Almeida, 1995)

Triantaphyllou et al. proposed using a hierarchical structure only with respect to the four criteria of cost, reliability, repair capability and availability. (Triantaphyllou, 1997)

Bevilacqua et al, have expressed the application of AHP technique for selecting maintenance & repair strategy in an oil refinery in Italy. (Bevilacqua, 2000)

In 2000, Bevilacqua was dealing with analytic hierarchical process and the selection of maintenance strategy. An interesting point in this research was the analysis of a detailed and complex sensitivity which was imposed on data resulted from paired comparison judgments. The results of this sensitivity analysis showed that the way of locating and the applied weights to different members of the decision group will have an impact on the outcome. (Bevilacqua, 2000)

Onoufriou et al (2009), have dealt with optimal maintenance strategies and preventive maintenance using genetic algorithms and Bayesian estimations. (Onoufriou et al, 2003)

Basim et al (2003), selected the most efficient maintenance method using fuzzy multi-criteria decision-making. The only flaw in this study was the applying of identical definitions of membership functions for fuzzy numbers and linguistic variables from the viewpoint of different people. (Basim et al, 2003)

In 2005 & 2006, two other researchers have mentioned in their investigations that the general development of IT in industries had been followed by the development of maintenance & repair systems. Due to these improvements, the scope of the basic features of CMMS has been increased. These functions are as follows:

- Equipment management & control;
- Factory management & control (purchase expenses, amortization plan, etc.);
- Predictive maintenance methods (interventions, planning, program);
- Designing & document management & control;
- Planned maintenance & unplanned management;
- The task of order management;
- Resource management (technical, staff);
- Data analysis;
- Costs & budget control;
- Stock management, and
- Purchase order management (Braglia et al., 2006; Huo et al., 2005)

Kumar et al (2005), selected a proper repair & maintenance strategy in industrial processes using a fuzzy modeling. (Kumar et al, 2005)

Bevilacqua et al (2006), have dealt with the issue of selection in repair & maintenance systems with the aim of its improvement, using a combined method of goal programming and AHP. (Bevilacqua et al, 2006)

Ling Wanga et al (2007), selected an optimal maintenance strategy based on a fuzzy analytic hierarchical process. (Wanga et al, 2007)

Pierre Dersin et al (2008), selected appropriate inspection and maintenance strategies with the aim of minimizing the costs throughout the product life cycle. (Dersin, 2008)

Maiti et al (2010), selected a risk-based maintenance policy using AHP method and goal-based programming. (Maiti et al, 2010)

Wang et al (2011), selected an optimal maintenance method according to the relative membership degree in fuzzy environments. (Anhua Peng et al, 2011)

Dutta et al (2011), selected an appropriate maintenance strategy for supporting transmission and vehicle transportation systems using a fuzzy method. (Sunil Dutta et al, 2011)

Research Methodology

The statistical population of this research consists of all managers, professionals, experts and employees of Tehran Cement Factory; in addition to above mentioned cases, the opinions of professors and authorities from outside the company will also be used in decision-making discussions about the selection and identification of decision parameters.

Since in this study the judgments of a group of experts have been used, we don't need a specific method for sampling; because we have applied the comments of all those who were experts or have been involved in this issue.

This research was conducted in response to the following questions:

- What are the evaluation parameters of technology systems maintenance strategies?
- What is the weight of each parameter with the help of fuzzy analytic network processes and DEMATEL method?

Due to the lack of literature on this topic, the formulation of hypothesis will be done according to interviews and initial surveys in statistical population. Therefore, the following hypothesis will be examined in this study:

First hypothesis: the type and model of equipment failure of IT system in the desired statistical population affect the selection of maintenance strategy.

Second hypothesis: the skill level and the training of maintenance staff in IT system of the desired statistical population affect the selection of maintenance strategy.

Third hypothesis: the amount of investment of IT systems in the desired statistical population affects the selection of maintenance strategy.

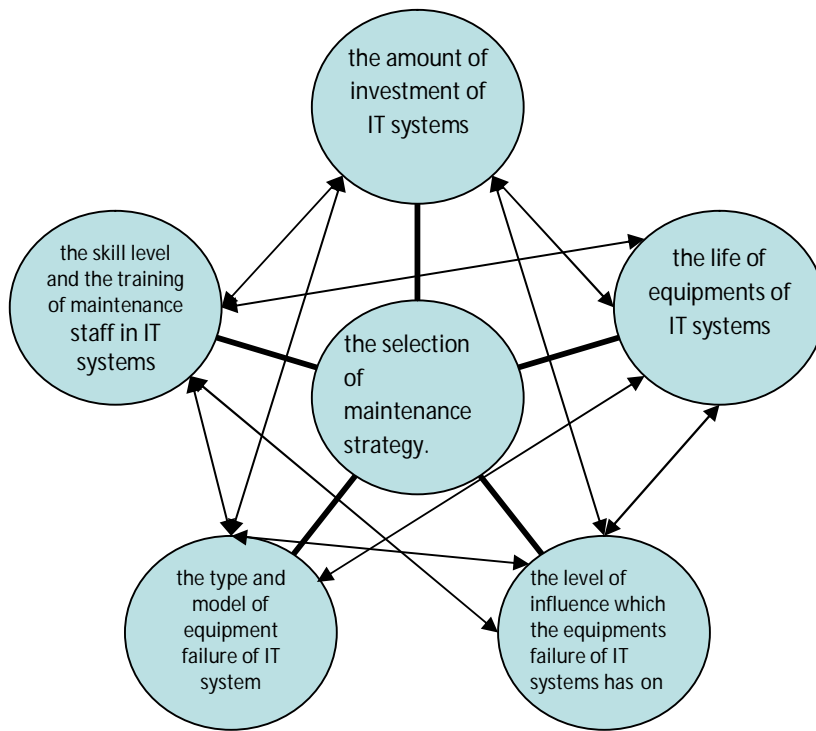
Fourth hypothesis: the life of equipments of IT systems in the desired statistical population affects the selection of maintenance strategy.

Fifth hypothesis: the level of influence which the equipments failure of IT systems has on the production schedule in the desired statistical population affects the selection of maintenance strategy.

Sixth hypothesis: the information security in the desired statistical population affects the selection of maintenance strategy.

With regard to raised issues, the conceptual model of this study is shown in figure 1.

Figure 1. The conceptual model of research



The instrument for data collection in this research is three questionnaires which have been designed in a closed format. The first questionnaire will be deal with identification of parameters. The second questionnaire has been formed for the evaluation of cause and effect relationships according to DEMATEL method. The third questionnaire has been designed according to the concept of fuzzy ANP technique which in addition to considering specified interactions in DEMATEL method through paired comparison, measures the importance of parameters relative to each other. To determine the validity of questionnaires in this research, a number of managers and experts were asked to comment in this field; they expressed their opinions after studying the questionnaires and the questionnaires were corrected again based on their viewpoints.

The third question has been designed according to the concept of fuzzy ANP technique which in addition to considering specified interactions in the results of DEMATEL method through paired comparison, measures the importance of parameters relative to each other.

The basis of responding to this questionnaire is verbal expressions and fuzzy numbers contained in table (1-3). Decision makers should have recorded a preferred value between the numbers $\tilde{1}$ to $\tilde{9}$ according to table (1).

Table 1. Verbal expressions and fuzzy numbers for comparing the preferences of standards

Linguistic variable	Fuzzy numbers	Triangular fuzzy numbers
Equally important	$\tilde{1}$	(1,1,3)

Slightly more important	$\tilde{3}$	(1,3,5)
More important	$\tilde{5}$	(3,5,7)
Much more important	$\tilde{7}$	(5,7,9)
Absolutely most important	$\tilde{9}$	(7,7,9)
Preferred values between above values	$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}$	(9,8,6)(8,6,4) (6,4,2)(4,2,1)

Also, the algorithms used in this study are fuzzy analytic hierarchy process and DEMATEL which are going to be introduced in this section.

The numbers used in this method are triangular fuzzy numbers. Here, we'll attempt to describe EA method steps.

In EA method, the value of S_k which is a triangular fuzzy number is calculated as equation 1 for each row of the matrix of paired comparisons:

$$S_k = \sum_{j=1}^n M_{kj} \times \left[\sum_{i=1}^m \sum_{j=1}^n M_{ij} \right]$$

In which K denotes the number of rows and i and j denote options and parameters respectively.

In this method, after the calculation of all S_k values we should measure their degree of largeness to each other. Generally, if M_1 & M_2 are two triangular fuzzy numbers, then the largeness degree of M_1 on M_2 will be defined as equation 2:

$$\mu_{max}(x) = \begin{cases} V(M_1 \geq M_2) = 1 \\ V(M_1 \geq M_2) = hgt(M_1 \cap M_2) \end{cases} \quad (2)$$

On the other hand, it can be proven by mathematical reasoning:

$$hgt(M_1 \cap M_2) = (u_1 - l_2) / [(u_1 - l_2) + (m_2 - m_1)]$$

The largeness degree of a triangular fuzzy number is obtained from K , which is another triangular fuzzy number and according to the following equation:

$$V(M_1 \geq M_2, \dots, M_k) = V(M_1 \geq M_2), \dots, V(M_1 \geq M_k)$$

Moreover, in order to calculate the weight of indexes in the matrix of paired comparisons, we act as follows:

$$W'(x_i) = \min\{V(S_i \geq S_k)\} \quad k = 1, 2, \dots, n, \quad k \neq i \quad (3)$$

Thus, the vector of indexes weight which is the same as the vector of fuzzy AHP non-normalized coefficients will be calculated as follows:

$$W' = [W'(x_1), W'(x_2), \dots, \dots] \quad (4)$$

The calculation of weights or the fuzzy non-normalized vector will be done by normalization relationships and also transformation of fuzzy numbers to a necessary weight vector for the goal of creating a super-matrix. (Momeni, 2008)

- 1- Stages of research conducting
 - a) Preparation of parameters initial list
 - b) Collection of decision group comments on the initial list
 - c) Preparation of parameters final list

In this questionnaire, respondents were asked to rate the importance level of each parameter by the numbers of a five-option Likert spectrum.

- d) Single-sample T- test
- e) Parameters layout in the lattice structure based on DEMATEL method
- f) Paired comparisons for determination of parameters weight
- g) Completion of paired comparison matrixes

The completion of paired comparison matrixes will be done according to decision group's responses.

h) Integration of paired comparison matrixes

Buckely has proposed the equations (1-3) in providing the groundwork for a group decision-making of paired comparison matrixes for fuzzy numbers:

$$i\check{r}=(\tilde{a}i_1 \otimes \tilde{a}i_2 \otimes \dots \otimes \tilde{a}i_n)^{\frac{1}{n}} \quad (5)$$

i) Calculation of parameters weight with the help of fuzzy analytic network process

At this point, we'll attempt to form a super-matrix for the issue after performing some paired comparisons; the weight of desired parameters will be obtained after frequent exponentiation of the mentioned super-matrix. In this part, we'll introduce two algorithms which are used in this study.

These stages will be reviewed in this part.

A, B & C: Identification of effective factors on the selection of repair & maintenance strategy for IT systems

For Identification of effective factors on the selection of repair & maintenance strategy for IT systems and also examination of research hypothesis, a questionnaire of 51 questions was given to respondents in which they were asked to specify the importance level of considering each 51 mentioned cases. Respondents must use one of the numbers 1,4,3,2 & 5 in determining the importance level of each index.

Table 2 represents the index list of the questionnaire.

Table 2.The inderxt list of questionnaire

Row	Factor	Row	Factor	Row	Factor
1	Information security and prevention from its disclosure	18	Existence of inexpensive spare parts	35	Purchase costs of equipments
2	Availability	19	Fast delivery of computer spare parts and servers accessories	36	Amortization speed
3	Integrity	20	Existence of personnel skills in emergency and urgent repairs of IT-based systems	37	The ability to calculate the exact replacement period of machinery consumable parts
4	Performance	21	Maximizing the reliability of machinery and equipments using IT	38	Traceability of failure causes for preventing emergency repairs
5	Effectiveness	22	Maximizing the useful life period of equipments and computers	39	Manpower efficiency
6	Security	23	Increasing the accessibility of equipments	40	Fast and easy access to manpower in emergencies
7	Wages of maintenance personnel	24	Improvement of morale and relationships between production and maintenance partners	41	The time of equipments installation and commissioning
8	Minimizing the incidental repairs of machinery and equipments	25	Maximizing the overall performance of system	42	Job enrichment & job satisfaction

9	Need for advanced training in maintenance & repair of IT systems	26	The average monthly cost of maintenance and repairs	43	Creation model of failures
10	Transmission and distribution of IT users level of knowledge	27	Traceability of failure source	44	Response time
11	Process optimization for maximizing the effectiveness of maintenance activities	28	Inventory costs of spare items	45	Experiences associated with strategies implementation
12	The level of basic trainings in the field of maintenance operations	29	Average losses due to per hour lost production for each failure	46	The monopoly level in the provision of used maintenance and repair equipments
13	Monitoring capability of the conditions of machinery and production equipments	30	The level of public access to repair technologies	47	The type and model of equipment failure of IT system
14	The quality of IT systems spare parts	31	The life of IT system current equipments	48	The skill level and the training of maintenance staff in IT system
15	Costs of regular and planned inspections in the company	32	The index of the median duration of repairs	49	The amount of investment of IT systems
16	Minimizing the costs of production line stoppages and mandatory unemployment of staff	33	The index of mean time between failures	50	The equipments life of IT systems
17	Maintaining a hierarchy of access to classified information	34	The level of primary investment	51	The level of influence which the equipments failure of IT systems has on the production schedule

D: single-sample T-test

After measuring the mean and standard deviation of responses and holding a single-sample T-test, only 21 of 51 reviewed indicators remains in the list of effective factors on the selection of maintenance strategy for IT systems. Table 3 presents the effective factors on the selection of maintenance strategy for IT systems.

Table 3. Effective factors on the selection of maintenance strategy for IT systems

Row	Sign	Parameters
1	S1	Information security and prevention from its disclosure
2	S2	Monitoring capability of the conditions of machinery and production equipments
3	S3	Maintaining a hierarchy of access to classified information
4	S4	The level of basic trainings in the field of maintenance operations
5	S5	The skill level and the training of maintenance staff in IT system
6	S6	Wages of maintenance personnel
7	S7	Existence of personnel skills in emergency and urgent repairs of IT-based systems

8	S8	Maximizing the reliability of machinery and equipments using IT
9	S9	Maximizing the useful life period of equipments and computers
10	S10	Increasing the accessibility of equipments
11	S11	Manpower efficiency
12	S12	Fast and easy access to manpower in emergencies
13	S13	Response time
14	S14	The average monthly cost of maintenance and repairs
15	S15	Purchase costs of equipments
16	S16	The time of equipments installation and commissioning
17	S17	The amount of investment of IT systems
18	S18	Minimizing the costs of production line stoppages and mandatory unemployment of staff
19	S19	The life of IT system equipments
20	S20	The level of influence which the equipments failure of IT systems has on the production schedule
21	S21	Average losses due to per hour lost production for each failure

Test results of the six research hypothesis are as follows:

First hypothesis: the type and model of equipment failure of IT system in the desired statistical population affect the selection of maintenance strategy.

For examining the first hypothesis, questions 27, 32, 37, 33, 38, 43 & 47 had been used.

Research findings show that in a 95% level, test statistic is equal to -5.342 and as a result the research hypothesis will be rejected. Therefore, the type and model of equipment failure of IT system in the desired statistical population don't affect the selection of maintenance strategy.

Second hypothesis: the skill level and the training of maintenance staff in IT system of the desired statistical population affect the selection of maintenance strategy.

For examining the second hypothesis, questions 3, 6, 7, 9, 10, 12, 20, 48, 46, 45, 42, 40, 39, 30 & 24 had been used.

Research findings show that in a 95% level, test statistic is equal to 4.096 and as a result the research hypothesis will be confirmed. Therefore, the skill level and the training of maintenance staff in IT system of the statistical population affect the selection of maintenance strategy.

Third hypothesis: the amount of investment of IT systems in the desired statistical population affects the selection of maintenance strategy.

For examining the third hypothesis, questions 14, 18, 19, 26, 34, 35, 41 & 49 had been used.

Research findings show that in a 95% level, test statistic is equal to 6.259 and as a result the research hypothesis will be confirmed. Therefore, the amount of investment of IT systems in the statistical population affects the selection of maintenance strategy.

Fourth hypothesis: the life of equipments of IT systems in the desired statistical population affects the selection of maintenance strategy.

For examining the fourth hypothesis, questions 22, 31, 36 & 50 had been used.

Research findings show that in a 95% level, test statistic is equal to 5.143 and as a result the research hypothesis will be confirmed. Therefore, the life of equipments of IT systems in the desired statistical population affects the selection of maintenance strategy.

Fifth hypothesis: the level of influence which the equipments failure of IT systems has on the production schedule in the desired statistical population affects the selection of maintenance strategy.

For examining the fifth hypothesis, questions 4, 5, 8, 11, 51, 44, 29, 28, 25, 23, 21, 16 & 15 had been used.

Research findings show that in a 95% level, test statistic is equal to 7.248 and as a result the research hypothesis will be confirmed. Therefore, the level of influence which the equipments failure of IT systems has on the production schedule in the statistical population affects the selection of maintenance strategy.

Sixth hypothesis: the information security in the desired statistical population affects the selection of maintenance strategy.

For examining the sixth hypothesis, questions 17, 13, 2 & 1 had been used.

Research findings show that in a 95% level, test statistic is equal to 9.965 and as a result the research hypothesis will be confirmed. Therefore, the information security in the desired statistical population affects the selection of maintenance strategy.

E: Determining a cause and effect network of the issue using DEMATEL method

After determining the effective factors on the issue, an attempt should be made to locate the parameters into a network structure. This will be done by the application of DEMATEL technique.

Step 1: Providing the matrix of direct relations

In this part of study, we need a four-level comparative scale to evaluate the relationships among factors by the help of expert opinions. These four applied scales in description of the extent of relationships among factors are, respectively: 0 (no impact), 1 (low impact), 2 (high impact) and 3 (extremely high impact). We represent the outcome of this step and its components with a Z symbol and Z_{ij} respectively. Each member of Z indicates the degree of influence which i criterion has on j criterion.

Since in the previous section, the number of factors was found to be 21, we will have a square matrix of paired comparisons with 21 rows and columns. Moreover, since the decision group members were 7, we will sum up the results from different people comments and then take an arithmetic mean from them.

Step 2: Normalization of direct relations matrix

Z can be converted into normal matrix of direct relations through the formulas 5 & 6 of direct relations matrix.

$$X = s \cdot Z,$$

(5)

$$s = \min \{ 1/\max_{1 \leq i \leq n} \sum_{j=1}^n z_{ij}, 1/\max_{1 \leq j \leq n} \sum_{i=1}^n z_{ij} \}, \quad i, j = 1, 2, \dots, n$$

(6)

It means that we calculate the maximum for all rows and columns and then apply the above equation.

Step 3: Formation of a general relationship matrix

The normalized matrix of the previous step was named X ; the general relationship matrix is calculated by equation 7:

$$T = X(I - X)^{-1} \quad (7)$$

Step 4: Providing a casual graph

The total elements of matrix T rows and columns are respectively named as vectors D & R . Then, the value of graph's horizontal axis which has been called "the axis of importance" and indicates the importance degree of related criterion, will be measured by the addition of vectors R & D , ($D+R$). The vertical axis of the graph called "the axis of dependency" is also calculated by ($D-R$) equation. When ($D-R$) is positive, the related criterion belongs to the cause group; otherwise it

belongs to the effect group. Thus, a casual graph is obtainable by plotting some points with the coordinate **(D+R, D-R)**.

Table 4, represents the values of R, D, D+R & D-R for the 21 mentioned factors.

Table 4. Calculation results of R, D, D+R & D-R

Row	Factor	D	R	D+R	D-R
1	Information security and prevention from its disclosure	3.894	4.174	8.068	-0.280
2	Monitoring capability of the conditions of machinery and production equipments	4.208	4.534	8.742	-0.326
3	Maintaining a hierarchy of access to classified information	4.044	4.661	8.705	-0.617
4	The level of basic trainings in the field of maintenance operations	5.190	5.070	10.260	0.121
5	The skill level and the training of maintenance staff in IT system	4.994	4.913	9.908	0.081
6	Wages of maintenance personnel	4.722	5.165	9.887	-0.443
7	Existence of personnel skills in emergency and urgent repairs of IT-based systems	4.950	5.538	10.488	-0.587
8	Maximizing the reliability of machinery and equipments using IT	3.635	5.461	9.096	-1.826
9	Maximizing the useful life period of equipments and computers	3.906	5.448	9.354	-1.542
10	Increasing the accessibility of equipments	4.044	5.574	9.617	-1.530
11	Manpower efficiency	5.487	5.538	11.025	-0.051
12	Fast and easy access to manpower in emergencies	5.665	5.415	11.081	0.250
13	Response time	5.017	5.611	10.628	-0.594
14	The average monthly cost of maintenance and repairs	6.383	6.496	12.878	-0.113
15	Purchase costs of equipments	6.292	6.712	13.004	-0.420
16	The time of equipments installation and commissioning	6.829	6.044	12.873	0.784
17	The amount of investment of IT systems	6.467	6.757	13.223	-0.290
18	Minimizing the costs of production line stoppages and mandatory unemployment of staff	6.415	6.596	13.012	-0.181
19	The life of IT system equipments	5.449	5.457	10.906	-0.009
20	The level of influence which the equipments failure of IT systems has on the production schedule	4.827	5.575	10.402	-0.748
21	Average losses due to per hour lost production for each failure	4.829	4.985	9.814	-0.157

Table 5 represents the cause and effect network governing issue parameters. In this table, dark squares represent the influence of the row element on the column element.

For example, S1 index has an impact on both S2 & S3 indexes.

Table 5. Cause and effect relationships governing research issue factors

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21
S1																					
S2																					
S3																					
S4																					

S5																				
S6																				
S7																				
S8																				
S9																				
S10																				
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S14																				

S15																				
S16																				
S17																				
S18																				
S19																				
S20																				
S21																				

F: Measuring the priority weights of fuzzy paired comparisons matrix

The calculation procedure for paired comparison matrixes to measure priority weights is done according to the following equations:

- Step 1: Integration of paired comparison matrixes
- Step 2: Calculation of inconsistency rate for each matrix
- Step 3: Measuring the largeness degree of all S_k
- Step 4: Calculation of priority weights for each matrix
- Step 5: Formation of a super-matrix and its frequent exponentiation

For integration of fuzzy paired comparison matrixes, equation (8) is used:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \dots \otimes \tilde{a}_{in})^{\frac{1}{n}} \tag{8}$$

Second step- calculation of $[\sum_{i=1}^m \sum_{j=1}^n M_{ij}]^{-1}$:

For this purpose, we first need to calculate the sum of all L, U & T ones for all fuzzy triangular numbers which are defined as (l, m, u) throughout the entire rows and columns of the above table.

If $M = (l, m, u)$, then for measuring the reverse of this fuzzy number, equation (9) will be used:

$$M^{-1} = (\frac{1}{u}, \frac{1}{m}, \frac{1}{l}) \tag{9}$$

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

In each column, the fuzzy numbers of each row is calculated according to the equation of fuzzy numbers addition.

Fourth step- calculation of S_k for each member of matrix:

As mentioned in chapter 3, S_k will be calculated by equation (10):

$$S_k = \sum_{j=1}^n M_{kj} \times [\sum_{i=1}^m \sum_{j=1}^n M_{ij}] \tag{10}$$

Fifth step- measuring the largeness degree of all S_k and final weights:

In this step, the largeness degree of all S_k relative to each other should be measured according to equations (4-7). If M_1 and M_2 are two fuzzy triangular numbers, the largeness degree of M_1 over M_2 will be defined as equation 11:

$$\mu_{max}(x) = \begin{cases} V(M_1 \geq M_2) = 1 \\ V(M_1 \geq M_2) = gt(M_1 \cap M_2) \end{cases} \quad (11)$$

Similarly, the largeness degree of all S_k relative to each other is calculated and the largeness degree of each relative to other numbers will be obtained from the minimum value of largeness which is equal to non-normalized weights obtained from the matrix of paired comparisons.

Sixth step- creation of a super-matrix and its frequent exponentiation

In this section, an attempt is made to create a super-matrix of the issue according to the results of previous section.

Table 5 represents parameters weights obtained from the super-matrix of the issue after 92 times of exponentiation.

Table 5. The weight of effective parameters on the selection of repair & maintenance strategies for IT systems

Row	Parameter	Weight from a super-matrix
1	The time of equipments installation and commissioning	0.207
2	The amount of investment of IT systems	0.166
3	Purchase costs of equipments	0.147
4	The average monthly cost of maintenance and repairs	0.126
5	The life of IT system equipments	0.076
6	Minimizing the costs of production line stoppages and mandatory unemployment of staff	0.054
7	Manpower efficiency	0.04
8	Fast and easy access to manpower in emergencies	0.039
9	Average losses due to per hour lost production for each failure	0.031
10	Response time	0.029
11	Existence of personnel skills in emergency and urgent repairs of IT-based systems	0.015
12	Maximizing the reliability of machinery and equipments using IT	0.011
13	Monitoring capability of the conditions of machinery and production equipments	0.008
14	Maintaining a hierarchy of access to classified information	0.007
15	Maximizing the useful life period of equipments and computers	0.007
16	The level of influence which the equipments failure of IT systems has on the production schedule	0.007
17	Increasing the accessibility of equipments	0.003

These parameters affect each other in a non-linear network and finally the resultant of them will lead to calculation of weights and the unique importance degree for each of these parameters.

As can be seen, the maximum weight has been allocated to the time of equipments installation and commissioning from among other parameters with the value of 0.207.

After that, the amount of investment of IT systems & purchase costs of equipments will be placed in next rankings. These two parameters along with the average cost of maintenance and repairs index are the most important economic factors.

Conclusion and suggestions:

With regard to obtained results, it was found that a number of sub-factors in the selection of maintenance strategy for IT systems of Tehran Cement Factory are dependent on the time of equipments installation and commissioning; in fact the application of smart equipments at a proper time will lead to an identification in the field of equipments repair in a more optimized and effective time and with lower repair costs.

The importance of this factor is due to essentiality of a non-stop production line. Stops in the process of cement production will incur a lot of costs.

The amount of investment of IT system is the second effective factor in repair & maintenance. It is recommended to those involved in the field of repair & maintenance to make an attempt in the establishment of suitable and sufficient funds for commissioning maintenance system of information technology by understanding the system and avoid additional spending of costs or the actions that incur substantial costs and damages to the control of maintenance process. In addition to proper investment in the field of IT system, the adoption of a suitable cost for the purchase of proper high quality equipments is also an essential factor; so it is suggested to reduce the costs of repair & maintenance and system control with a reasonable accuracy in the purchase of equipments and increase the efficiency of company's performance. The other recommendation for Tehran Cement Company practitioners and decision-makers is paying attention to the life of IT system equipment. Due to advances in the world of IT and a modern and more efficient knowledge, more efforts should be made to update these equipments and increase system accuracy and information reliability. Another recommendation is that specialist force must be considered as another factor. Employing specialists who are suited relevantly to the area of activity and IT systems, familiar with the basics of maintenance & repair and are of a high sense of responsibility and accuracy in systems control, failure reduction and timely notification for avoiding the closure of production line, is very crucial.

The following items are also recommended for further research trends:

- Determining the effective risks on maintenance and repairs of IT systems
- Providing a model based on queuing theory in maintenance management of IT systems in Cement Factory
- Selecting a maintenance & repair strategy of IT systems with the help of TOPSIS
- Providing a model for assessing the performance of maintenance projects management with the help of data envelopment analysis.
- Providing a model for correct estimation of cost and time in the companies using maintenance systems with the help of neural networks

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