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Optimizing Maintenance in Project Management by Considering Health, Safety, Environment and Resilience Engineering

Behnam Einabadi
School of Industrial Engineering
University of Tehran
Tehran, Iran
behnam.einabadi@ut.ac.ir

Pedram Memari
School of Industrial Engineering
University of Tehran
Tehran, Iran
memari.pedram@ut.ac.ir

Seyed Farid Ghaderi
School of Industrial Engineering
University of Tehran
Tehran, Iran
ghaderi@ut.ac.ir

***Abstract*—** One of the most important objectives of project management is to complete the project within the specified completion date of the project. Another important objective of project is to terminate the project by minimum rate of injuries and damage to the environment. One of the important factors which affect the time objective of the project is the failures or breakdowns of the project Machines and Equipment. Also, Health, Safety, Environment (HSE) factors are crucial in the efficient execution of the project. Resilience engineering is a new concept that will improve the safety and reliability of a high-risk system such as power plant construction project. Previous studies didn't consider the resilience engineering (RE) factors which could help the project to achieve its goals. Related data was collected from a power plant construction project and fuzzy DEA and Z-number DEA were utilized to analyze the Data and Best DEA model is selected according to maximum average efficiency and also for identifying most effective factors sensitivity analysis was done, and we found that flexibility, and project percent progress, system downtime, reporting culture and HSE costs are the most important factors on maintenance of the project. To the best of our knowledge, this is the first study considering RE and HSE factors to optimize maintenance of the project.

I. Introduction

RECENTLY the importance of RE has been pointed by numerous studies in order to analyze effective factors of RE in the system to able to recover to its initial/proper state. In this study construction project of a power plant has been considered as a system and beside the RE factors, related HSE factors which is crucial for certifying health, safety and environment issues in the construction site and their effects on the progress/maintenance of project have been considered and analyzed in order to find the most effective factors that improving them, could result in a project with increased level of resilience and also better progression of the project.

One of the goals of the construction project is to be finished as soon as the planned date, since the role of humans and personnel is crucial in achieving the objectives, especially who are dealing with executive operation in the construction site, who are working in an environment with plenty of risks, safety management tool became one good method to control and limit the incidents. It could minimizing accidents. Safety culture could help the project to reach to its targets, also resilience engineering (RE) is a novel approach that could control and limit incidents and accidents in the high-risk environment, in the previous studies RE is not considered. DEA models were employed to analyze the RE factors in a power plant construction project. One of the contribution of this paper is the incorporation of RE factors and DEA analysis to identify prominent effecting project factors and take new strategies in the future construction projects of the same type.

This study analyzes the defined HSE and RE factors of a construction project of a combined cycle power plant on the maintenance of the case project by DEA tools so that by the optimization models of fuzzy DEA and ZDEA, the most effecting factor and the most productive month of the project is defined, for taking new strategies in the next projects in a way that failures and accidents become low and lower and the maintenance of the project become high and higher.

This study is in a phase of construction of such a plants that has its own issues, problems and difficulties, as a case study we analyzed our research in a combined cycle power plant in Yazd-Iran. Also in this study we consider HSE factors, Resilience engineering factors altogether and we assess them on the maintenance of the project.

Definition of the RE, HSE and maintenance factors has been pointed in the following of introduction, the rest of this paper has been constructed as following: methodology and the structure of our study in section II, explanation of the case study and data analysis in section III, results and discussion and sensitivity analysis in section IV and conclusion in section V.

A. Resilience Engineering

Three system states in the operation of an industrial process can be distinguished as catastrophic, upset and normal ones. Project-oriented companies try to keep system in normal state and to achieve this aim through the manipulation of operation variables. Whenever accidents or incidents happens. RE can help the system to recover from catastrophic or upset state to normal state[1].

Resilience is defined as "the ability of an organization (system) to keep or recover quickly to a stable state, allowing it to continue operations during and after a major mishap or in the presence of continuous significant stresses” [2].

Here is some prominent studies described the concept and features of systems which are resilient [3], [4]. In order to increase the resilient level of the systems four factors has developed by Azadeh and Salehi [5]. In current study, six principles proposed by Hollnagel and Woods [6] and three principles which are Self-Organization, Team work and Redundancy and introduced by Azadeh et al. [7] will be used. These nine principles described as follows:

• **Management commitment:** Senior management percepts problems and hardships of personnel especially those related to safety issues, and attempts to solve them [2].

• **Reporting culture:** Identify the whole context and atmosphere of the project in which personnel feel free to report safety issues [8].

• **Learning:** Getting lessons from the normal state of work and abnormal events like accidents, is an important point of view in RE and there is quite emphasis on that [8].

• **Awareness:** management will be aware of what happens in the construction site by data that are collected [9].

• **Preparedness:** Problems and hardships that are in result of safety issues, human performance and equipment breakdowns is predicted by the project team, and they becomes ready in order to response [9].

• **Flexibility:** When an unexpected event occurs, if the organization is agile enough to response the event, whether by using on hand resources or other external resources, this organization called to be flexible [9].

• **Self-organization**: Self-organization happens when the authority is distributed in project personnel [10]. In such systems, there are interdependent entities issuing orders which collaborate with each other and share information and try to adjust themselves to the feedback of other agents [11]. These kind of systems normally conquer a wide range of faults and variation [10].

• **Teamwork:** productivity, adaptability and job satisfaction will increase when teamwork becomes to work [12]. Due to the individual and organizational pressures RE basis says that human errors are unavoidable [13]. Teamwork is on the basis of mutual support, communications, leadership, and situation monitoring [14]. When there are a pile of tasks, if the staff assist and support each other, organizational, individual pressures and human errors will be reduced, and as a result reliability and safety will be improved [7].

• **Redundancy:** Redundancy means the availability of alternative pathways of resources such as Equipment, machines and manpower in order to respond and use when the basic parts and elements such as project equipment is inaccessible and unavailable [15]. In order to develop such systems, required elements in the case of disruptions, disturbances, and non-normal conditions, must be procured and be on hand in advance [16]. Redundancy in current study, has been considered in resources like equipment, machinery and manpower.

B. Health, Safety and Environment

Due to sensitiveness of Health Safety and Environment (HSE) issue, they have to be considered priori than any other subject and nothing can equal to be important as protection of human health, safety and the environment [17]. It is unfortunately truth that the forgotten right of all the workers and employees is to work safely in an environmentally responsible manner.

One of the most important objectives of a construction project must be terminating the project with minimum injuries and minimum damage to the environment. In this study seven factor has been considered as HSE indexes, these are: Checkup and Examination, Issue Health Card for Personnel, Instruction, Identified dangers and assessment of the risks, HSE Encouragement, HSE Caveat, HSE Costs and gasoline usage.

Checkup& examination and issue health card for personnel are related to health factor that are the data of periodic health checkup of the project personnel and the health card indicates the data of the sensitive personnel which they may affect the health of other personnel.

For safety factor following indexes has been considered:

Instruction: related data of the number of personnel, instructed by HSE experts before and during execution work.

Identified dangers and assessment of the risks: the number of HSE risks which has been identified by HSE experts and further assessed.

HSE Encouragement, HSE Caveat: are the recorded number of encouraging personnel for their commitment in practice and on the other hand vice versa.

HSE cost: related HSE costs has been recorded.

Gasoline usage: the amount of used gasoline for execution of the project like usage of the cranes, are recorded.

C. Maintenance

“The main purpose of maintenance is to retain systems in or to restore them to a functioning state. Maintenance also contributes to improved system knowledge and inter-discipline coordination that may benefit the entire organization” [18]. The growing complexity and significance of the projects and the importance of completing the project within its planned schedule has made us to consider the maintenance program in project execution. One of the most important of the reason is the availability and reliability of project equipment, machinery and manpower is vital for keep the project in the functioning state [19].

In this study the factor of project system down time which means the time which the project has been hold due to equipment issues or accidents or incidents due to HSE affairs or any unpredicted element, affected the maintenance of the project, and the project progress percent in different month of the project are considered as a maintenance factors.

Most of studies are performed in a plant that is currently in process and maintained [7, 21, 22], while this study is performed in a construction phase of such plants that has its own issues, problems and difficulties. Also in this study we consider HSE factors, Resilience engineering factors altogether and we assess them on the maintenance of the project. Features of this study with respect to previous studies is shown in TABLE I. Methodology

In this study, effective maintenance factors are identified in a combined cycle power plant construction project by HSE and RE and Z-number DEA. The most crucial factors which will affect the maintenance of the project will be available by considering and modeling of HSE and RE factors according to the process which is depicted in Fig 1.

In most industrial projects in Iran, there is a system of project management, and within this kind of system the data relating to the project and HSE affairs are being recorded by headquarters of the project team. There are different sub-contractors that are managed by a general contractor. According to defined factors for this study in previous section HSE and maintenance factors are considered by the available data in different month of the project execution life cycle. Different month of the project which is 38 month in this study are considered to be the decision making units. Relating resilience data are considered by interviewing a group of managerial board. In order to, certify reliability of the data, alpha Cronbach is computed by SPSS®.

TABLE I.
FEATURES OF THIS STUDY VERSUS OTHER STUDIES AND METHODS

	Resilience factors	HSE factors	Maintenance factors	Project oriented company	Practicality in real world	Statistical method	Identification of important factors	Sensitivity analysis
Azadeh et al. [20]	✓		✓		✓	✓		
Azadeh et al. [21]	✓				✓	✓	✓	✓
Shirali et al. [22]	✓	✓			✓	✓		
Azadeh et al. [7]	✓	✓			✓	✓	✓	✓
This study	✓	✓	✓	✓	✓	✓	✓	✓

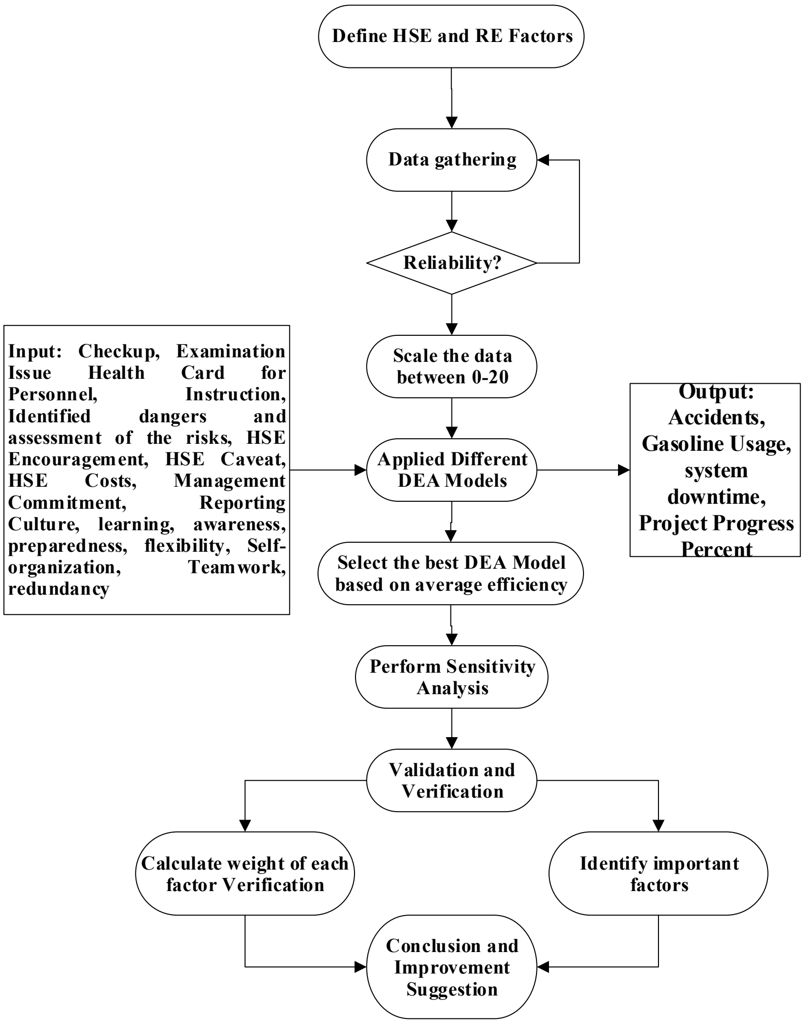

Fig 1. Schematic View of the Proposed Approach

D. FDEA

In real world problems, when the input and output values of the data are vague and not exact, some fuzzy models have been presented for dealing with uncertainty in the data envelopment analysis. Fuzzy DEA is one of the methods that output and input variables are asymmetrical triangular shaped fuzzy numbers and there is a lower bound and upper bound for the input and output variables of DMU values[23]. Consider $\tilde{x}_{ij} = (x_{ij}^{p}, x_{ij}^{m}, x_{ij}^{0})$ fuzzy values of the input variable and $y_{ij} = (y_{ij}^{p}, y_{ij}^{m}, y_{ij}^{0})$ fuzzy values of the output variable which have three pessimistic, mean and optimistic values. In this model, α cuts from the interval [0, 1] are the parts of fuzzy sets that generates regular sets, and by each α, linear programming model is used in order to optimize solution[24]. The model is on the following Eq (1). In our problem there are 38 number of DMU's, 16 number of input factors and 4 number of output factor. The values for pessimistic and optimistic of the collected data are considered as following:

Minimum value of the each factor from its data is divided by two and the value is subtracted from the corresponding value of the DMU for Pessimistic state and it is added for optimistic state.

Optimum value of θ refers to efficiency of the DEA model.

Indices	
i	Indices of DMUs
j	Indices of inputs
r	Indices of outputs
n	Number of DMUs
m	Number of inputs
s	Number of outputs
DMU(*i*)	The ith DMU
DMU(0)	The target DMU (*i* = 0)
Parameters	
$\widetilde{Zx}_{ji}$	Z-number value of input j related to DMU *i*
$\widetilde{Ax}_{ji}$	Fuzzy value of input j related to DMU *i*
$\widetilde{Bx}_{ji}$	Fuzzy reliability value of input j related to DMU *i*
$\widetilde{Zy}_{ji}$	Z-number value of output r related to DMU *i*
Variables	
λ_i	Weight variables in the proposed model for obtaining the efficiencies of DMUs
θ_0	Objective value (efficiency) of the DEA model

$$Min\ \theta \qquad \text{Eq (1)}$$

S.t.

$$\theta\left(\alpha x_{ip}^{m} + (1-\alpha)x_{ip}^{p}\right) \geq \sum_{j=1}^{38} \tau_j \left(\alpha x_{ij}^{m} + (1-\alpha)x_{ij}^{o}\right) \quad i = 1,..,16$$

$$\left(\alpha y_{rp}^{m} + (1-\alpha)y_{rp}^{o}\right) \leq \sum_{j=1}^{38} \tau_j \left(\alpha y_{rj}^{m} + (1-\alpha)y_{rj}^{o}\right) \quad r = 1,..,4$$

$$\sum_{j=1}^{38} \tau_j = 1,$$

$$\tau_j \geq 0 \quad j = 1, \dots, 38$$

E. Z-number DEA

The concept of Z-numbers DEA was introduced by Zadeh [25] which is dealing with reliability of information and it is consist of two parts Z= (A, B). A is a fuzzy number of the variable which is described in previous part and B is the extent of the reliability of each of three A values. The extent of reliability could be the amount of sureness, believes of people about a phenomenon, etc. a theorem have been proven by Kang et al [26] which transforms Z-number to normal fuzzy set. In this paper the CCR model and the MATLAB coded for proposed model that is developed by Azadeh and Kokabi [27] is used to optimize solution. In this model$\widetilde{Zx}_{ji} = (\widetilde{Ax}_{ji}, \widetilde{Bx}_{ji})$, $\widetilde{Ax}_{ji}$ is the triangular fuzzy number and $\widetilde{Bx}_{ji}$ is the certainty measure of $\widetilde{Ax}_{ji}$. The structure of the CCR model are presented in Eqs (2) and (3).

$$Min\ \theta_0 \qquad \text{Eq (2)}$$

S.t.

$$\sum_{i=1}^{n} \lambda_i \widetilde{Zx_{j\iota}} \geq \theta_0 \widetilde{Zx_{j\iota}} \qquad j = 1, \dots, m$$

$$\sum_{i=1}^{n} \lambda_i \widetilde{Zy_{r\iota}} \geq \widetilde{Zy_{r0}} \qquad r = 1, \dots, s$$

$$\lambda_i \geq 0 \qquad i = 1, \dots, n$$

$$Max\ \theta_0 = \sum_{r=1}^{s} u_r \widetilde{Zy_{r0}} \qquad \text{Eq (3)}$$

S.t.

$$\sum_{j=1}^{m} v_j \widetilde{Zx_{j0}} = 1$$

$$\sum_{r=1}^{s} u_r \widetilde{Zy_{r\iota}} - \sum_{j=1}^{m} v_j \widetilde{Zx_{j\iota}} \leq 0, \qquad i = 1, \dots, n$$

$$u_r, v_j \geq 0 \qquad r = 1, \dots, s, \;\; j = 1, \dots, m$$

II. CASE STUDY

The study has been implemented on a combined cycle power plant project in Yazd-Iran. The cooling system of the power plant is kind of ACC which is suitable for dry climates. The combined cycle part has been synchronized on November 2016. About 1,337,830 Man-hour had been working throughout the project. An integrated strict system of HSE had been implemented through the construction site by MAPNA Company which in this system the statistics of the project was being recorded, and during the life cycle of the project there was no incident which lead to death. According to the previous section required data collected from MAPNA Company.

In our case study, models of DEA are utilized in order to recognize the performance of RE and HSE in a power plant project. Factors such as Checkup, Examination Issue Health Card for Personnel, Instruction, Identified dangers and assessment of the risks, HSE Encouragement, HSE Caveat, HSE Costs, redundancy, Management Commitment, preparedness, awareness, flexibility, learning, Self-organization, Reporting Culture, Teamwork, are considered as Input and four factor which are Accidents, Gasoline Usage, system downtime, Project Progress Percent are considered to be output of the model.

The important objective of current study is to evaluate maintenance of different month of the project and to determine the most important factors in overall performance.

III. Results and Discussion

Fuzzy DEA and Z-number DEA are effective methodology for analyzing the efficiency of project performance in different month which are considered as DMUs. Related data to the issues of safety, health and environment and project maintenance has been collected from a combined cycle power plant, according to the experience of the writer and interviewing from project staff, nine factor of RE have been weighted in different month of the case project, due to the uncertainty of the weights and possible mistakes in recording data, we analyzed via FDEA and Z-number DEA in order to find the best month as an effect pattern and also determine the important factors that investment in such factors in the future projects could increase the resilient and maintenance level of the same type of projects.

A. Reliability Test on Data

The data achieved, are analyzed in SPSS® software. Using Cronbach's alpha via SPSS®, the Data has been analyzed and Cronbach's alpha's value is 87% that is quite acceptable. Table II is the output of the SPSS® software.

Table II.
SPSS Result

Cronbach's Alpha	N of Items (Number of data)
0.869	20

B. Result of Fuzzy DEA and Z-number DEA

Collected Data is weighted for performing Fuzzy DEA and Z-number DEA, the following weights in Table III has been used for applying Z-number DEA. All the data are scaled into [0, 20] since we could see better the difference between results and the whole result and data are according to this scale. By applying the methods, efficiency scores of both methods for different alphas are computed, following result is shown in Fig 2.

Optimum alpha for both models are considered base on maximum average efficiency, for Fuzzy DEA optimum alpha is 0.05 and for Z-number DEA is 0.1, Table IV shows the result of the models, and also Table V shows the corresponding average efficiency values.

Table III.
Z-Number Weights

Sure	[15,17.5,20]
Usually	[10,12.5,15]
Likely	[0,5,10]

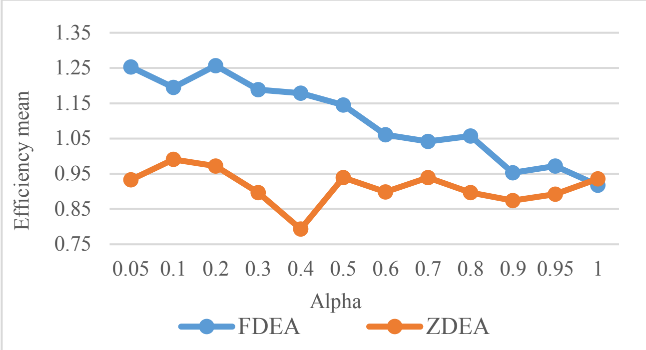

Fig 2. Alpha Results

Table IV.
FDEA & Z-DEA Ranking

DMU (Month)	FDEA α=0.05	FDEA Rank	Z-Number DEA α=0.01	Z-Number DEA Rank
1	1.4955	20	1.2138	16
2	1.6947	4	1.3054	1
3	1.7321	2	1.2833	3
4	1.7643	1	1.3022	2
5	1.7171	3	0.0000	35
6	0.0000	35	1.2687	4
7	1.4872	21	1.1992	21
8	1.5736	10	1.2155	12
9	1.5543	15	1.2188	11
10	1.5736	10	1.2143	14
11	1.5044	19	1.1562	23
12	0.0000	35	1.2316	9
13	1.6165	7	0.0000	35
14	0.7924	32	0.6086	33
15	1.4428	23	1.2082	19
16	1.6007	9	1.2233	10
17	1.0727	29	0.9732	28
18	1.5736	10	1.2150	13
19	1.3863	24	0.0000	35
20	0.0000	35	0.0000	35
21	0.8878	31	0.7801	30
22	1.6230	5	1.2417	7
23	1.5515	16	1.1654	22
24	1.5343	18	1.1999	20
25	0.0000	35	1.2138	17
26	1.5420	17	1.2138	15
27	1.1261	27	0.9841	27
28	1.1024	28	0.9688	29
29	1.2980	25	1.0660	25
30	1.1923	26	1.0534	26
31	1.4472	22	1.1395	24
32	1.6021	8	1.2331	8
33	1.5667	14	1.2106	18
34	0.7470	33	0.6653	32
35	1.6230	5	1.2424	6
36	1.5729	13	1.2540	5
37	0.7045	34	0.5023	34
38	0.8957	30	0.6690	31

Table V.
Average Efficiency

FDEA	Z-Number DEA
1.25258	0.99054

For developing Fuzzy model, min and max of each DMU is considered to be half of minus and plus of the minimum of the every factor values. And following weights are considered for Z-number DEA:

Table IV shows the efficiency of each DMU. As previously stated, DMU's are the different month of the project, and the value of efficiency shows performance of each month that the higher the ranks are the more is efficient month in case of progress and maintenance.

C. Noise and Result

In order to reinforce the certify the result of the Fuzzy DEA, we have analyzed the Model with exertion of the noise in the data, which we randomly selected 30 data from the rows and columns of the data in the corresponding value has been changed with faraway values and again Fuzzy DEA model has been run for different α cuts, the results are shown in Fig 3.

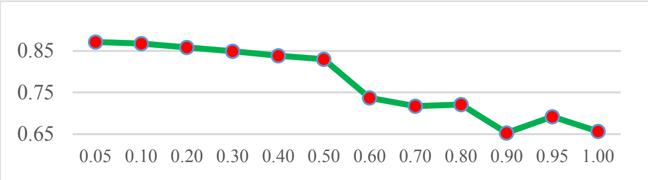

Fig 3. Noised FDEA

As it is shown in above figure, again we see that the maximum average efficiency occurs in the α cut of the 0.05.

The spearman test between the result of Fuzzy DEA and Noised Data fuzzy DEA has been run and the result for different α cuts are shown in Fig 4.

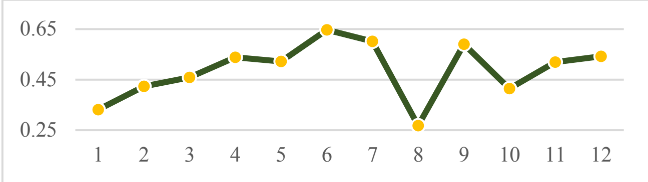

Fig *4. Spearman test*

D. Sensitivity Analysis

For performing sensitivity analysis, the prepared Table of data with the upper and lower bound values, and the weights $\widetilde{Bx}_{ji}$ each of the columns of the factors removed once. The fuzzy DEA and Z-number DEA model was run with the α that has a maximum average efficiency, in order to calculate the efficiency of the model in the absence of that factor, if the average efficiency become less, it shows that the omitted factor has significant effect on the entire model, and respectively vice versa. The following result are in Table VI. The most effective factors on FDEA analysis are HSE encouragement, system downtime, preparedness, awareness, HSE costs and HSE caveats. The most effective factors are shown in Fig 5. The most effective factors on Z-number DEA are flexibility, project progress, system downtime, reporting culture and HSE costs. The most effective factors are shown in Fig6.

TABLE VI.
AVERAGE EFFICIENCY ANALYSIS

Factor (Eliminated)	FDEA	Z-number DEA y	Factor (Eliminated)	FDEA	Z-number DEA y
Checkup, Examination	1.33304	1.01696	**Awareness**	1.15376	1.02737
Issue Health Card for Personnel	1.28893	1.04400	**Preparedness**	1.14570	0.99797
Instruction	1.19265	0.97528	**Flexibility**	1.27583	1.08762
Identified Dangers and Assessment of the Risks	1.22779	0.92095	**Self-Organization**	1.29249	0.95619
HSE Encouragement	1.38442	1.03127	**Teamwork**	1.31924	1.02213
HSE Caveat	1.34780	0.98304	**Redundancy**	1.19714	0.92349
HSE Costs	1.35043	1.06603	**Accidents**	1.28589	1.00704
Management Commitment	1.24152	0.99154	**Gasoline Usage**	1.25429	0.96959
Reporting Culture	1.25406	0.91063	**System Downtime**	1.13223	0.90549
Learning	1.28028	0.99110	**Project Progress Percent Per month**	1.18154	0.89802

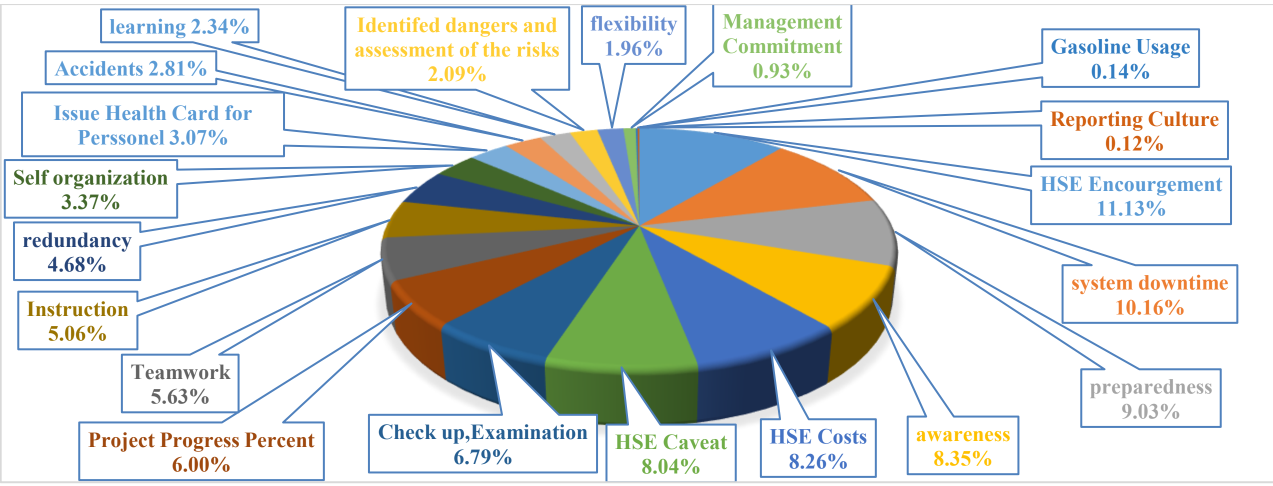

Fig 5. Weight of Factors in fuzzy DEA model

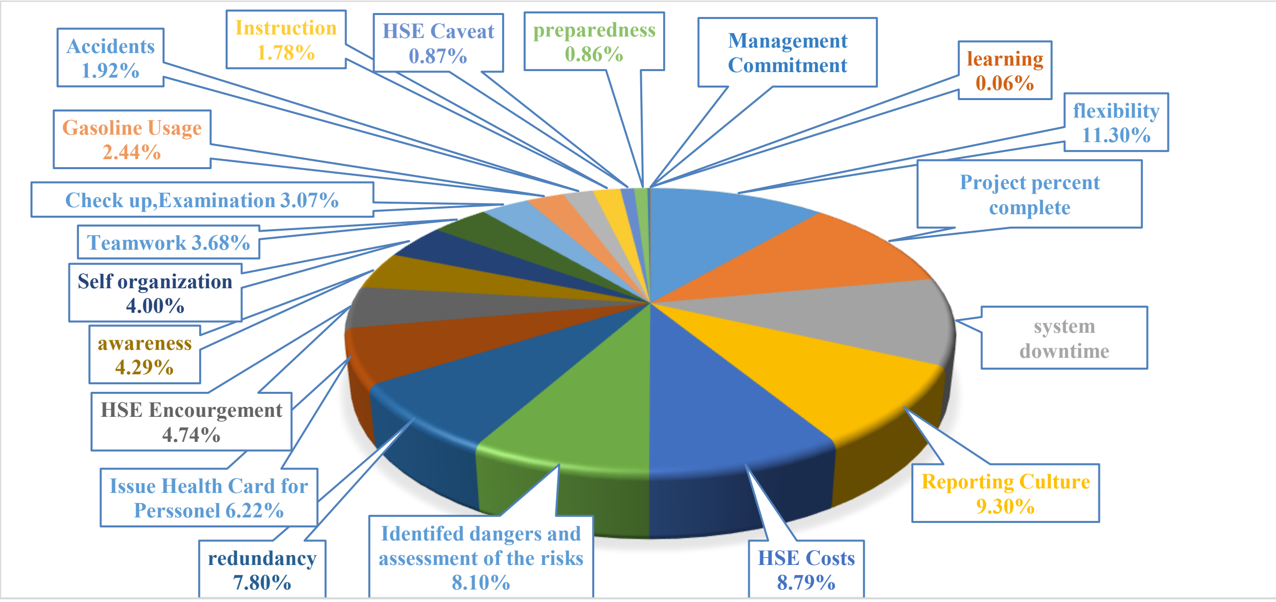

Fig 6. Weight of Factors in Z-number DEA

E. Validation and Verification

For validation of z-number model the correlation between the average efficiency of Fuzzy DEA and Z-number DEA are calculated by MINITAB®. The correlation is computed by spearman value between different alphas of the both models. The results are depicted in Fig 7.

Since the optimum alpha is 0.1 for Z-number method, correlation between Fuzzy DEA for this alpha is .721 so the value is substantial and the model is verified.

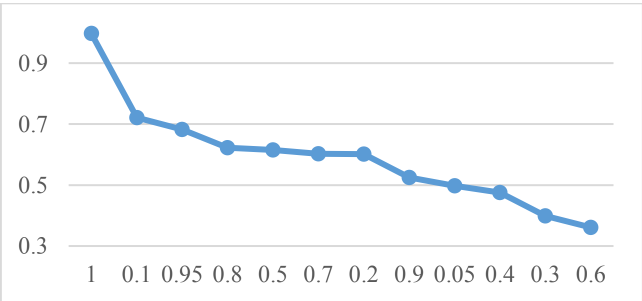

Fig 7. Correlation (Spearman value)

IV. Conclusion

Resilience engineering (RE) is a novel approach for safety improvement of highly risk systems such as Power plants and construction projects. This study identifies Resilience Engineering, HSE and maintenance factors of a power plant construction project by Z-number DEA. We believe to our knowledge, this is the first study examines the Resilience and HSE factors with respect to maintenance of the project by Z-number DEA. For do this, related data was collected from MAPNA Company in one of its project. Then DEA methods are applied to assess different factors effecting on maintenance of the project. According to higher average of efficiencies best DEA model selected. DMU efficiencies are related to efficiency of the project in different months, which the sixteenth month has the highest rank that maintenance scores was better than other month of the project. Sensitivity analysis is used to determine the important factors, the results in this case of project show that flexibility, and project percent progress, system downtime, reporting culture and HSE costs are the most important factors on maintenance of the project. Giving more attention to improve flexibility, project progress, reporting culture and more investment in HSE cost and also decreasing system downtime would result in better maintaining the project and decrease the project time period. And we recommend that creating a Maintenance planning in the construction phase of the project could considerably mitigate the failures and increase the efficiency of the system.

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