The Impact of Redundancy and Teamwork on Resilience Engineering Factors by Fuzzy Mathematical Programming and Analysis of Variance in a Large Petrochemical Plant

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1. Introduction

In recent years, new ideas (e.g., resilience engineering, RE) on how to improve and maintain safety have started a revolutionary movement in the maintenance of complex systems and have put forward a new pattern for analyzing the positive contribution of people at all organizational levels, rather than just emphasizing human errors [1]. RE is focused on how to help people dealing with complexities in difficult situations to achieve success. Therefore, RE emphasizes the understanding of how it is possible to achieve this success, and how people learn and self-adapt to create safety in the face of gaps, hazards, trade-offs, and multiple goals in a dynamic environment [1]. Similarly, the concept of resilience has been used over years in other disciplines, such as psychology, ecology, and physics. In all of these fields, the purpose is to understand systems' ability to survive, adapt, and recover [2].

Some important studies that which have been conducted in the RE field are reviewed in this study. Abech et al [3] studied opportunities and challenges for improving RE in an oil distribution plant. They analyzed how the system was resilient in some ways and brittle in others. Huber et al [1] investigated the effects of RE on safety in a chemical company. The findings showed that enhancing safety performance hinges upon an organization's dynamic capacity to reflect on and adapt its models of risk as operations and insights into them evolve. Gomes et al [4] studied production/safety trades-off in pilots' work in the helicopter transportation system for the Campos Basin oil fields in Brazil. The study investigated how the transport system is resilient and brittle, given the
workload demands and economic pressures, Costella et al [5] introduced a new approach to evaluate health and safety management systems. Their approach had two new features: (1) bringing together the three main auditing methods to health and safety (HS); and (2) emphasizing the RE perspective on HS. The RE perspective on HS considers four major factors (flexibility, learning, awareness, and top management commitment). Shirali et al [6] presented a new approach for quantitative evaluation of RE using a questionnaire and based on principal component analysis. Data relating to RE factors in the 11 units of a process industry using a questionnaire were gathered and analyzed by means of a principal component analysis approach. Also, the poor indicators and the process units were determined. The results of the study may enable the managers to identify the current weaknesses and challenges in the resilience of the system. Saurin and Júnior [7] presented a new framework to identify and analyze the sources of resilience and brittleness jointly, which do not constrain the identification process to any specific unit of analysis within the studied system. They investigated the application of the framework on two air taxi carriers as a case study.

Existing uncertainty in petrochemical plants can lead to an increased risk. RE is a new and proactive attitude that is used to enhance safety in complex industrial systems. Literature review indicates that there are only a few quantitative studies available in this field. Managers and other decision makers require quantified data to make appropriate decisions in uncertain condition. Furthermore, the review of literature shows that few researchers, if any, have used fuzzy data envelopment analysis (FDEA) and analysis of variance (ANOVA) for the aim of assessing safety performance in a resilient system. Therefore, the major motivation of this study is the stated research gaps.

Nowadays, the need for the improvement of resilient systems is strongly felt. Hence, this study investigates the impact of four factors of self-organization, teamwork, redundancy and fault-tolerance on resilient systems. This is the first study to apply FDEA and ANOVA approaches to analyze data related to RE factors. The present study has been conducted to occupy this niche in the literature. Table 1 shows the features of this study versus other studies.

### 2. Materials and methods

#### 2.1. Study participants

In June 2013, a study based on integrated RE was conducted in a petrochemical company to check the performance of the safety and human resources. The company was founded in 1987 as had more than 3,000 employees. Eleven departments were selected to answer the questionnaire. Departments and the number of people who were involved in each department are as follows:

- Laboratory (managers: 2, staff or operators: 9)
- Process (managers: 1, staff or operators: 6)
- Planning (managers: 4, staff or operators: 4)
- Quality Assurance (managers: 1, staff or operators: 3)
- Health and Safety Executive (managers: 3, staff or operators: 3)
- Inspection (managers: 2, staff or operators: 8)
- Maintenance (managers: 3, staff or operators: 11)
- Utility (managers: 6, staff or operators: 15)
- Information Technology (managers: 1, staff or operators: 4)
- Polymer Operation (managers: 10, staff or operators: 10)
- Chemical Operation (managers: 4, staff or operators: 5)

In this study, judgment sampling, which is a type of purposive sampling techniques was used. The distribution of questionnaires...
lasted about 2 days. The respondents could select a number from 1 to 10 to answer the questions, similar to the 5-point Likert scale. The questionnaire was completed by 115 respondents from 11 departments including 37 managers and 78 operators.

2.2. Questionnaire design

The six items are identified in a resilient system or organization [14]. These items are as follows:

- Management commitment: Top management commitment is one of the parties that are effective on occupational safety and health of people in each system [15].
- Reporting culture: This increases the staff’s willingness to report problems [14].
- Learning: The prominence of RE is learning from the analysis of normal work, but this does not mean that RE ignores learning from accidents, incidents, and other events [14].
- Awareness: Data gathering at the plant can help management understand the quality of human performance [14].
- Preparedness: Preparedness of emergency groups and team members can be effective to respond quickly [16].
- Flexibility: The work system design should be flexible. Design should support the natural human strategies for dealing with hazards, rather than applying a particular strategy [17].

Azadeh et al [12] suggested four items to improve the safety performance of complex systems and hazardous environments such as petrochemical plants. The brief description of the items is as follows [Fig. 1]:

- Self-organization: In self-organization systems, order comes from the actions of related operators who exchange information, take actions, and persistently adjust to feedback about others’ actions [18].
- Teamwork: Teamwork can decrease individual and organizational pressures when there is a high workload of system and accordingly, human errors decrease and the reliability of system rises [19,20].
- Redundancy: Redundancy is the presence of alternative pathways for use when components become unavailable in normal conditions [21,22].
- Fault-tolerance: The main purpose of fault-tolerant systems is to keep the specified performance of a system constant despite the existence of errors [23,24].

First, according to the indexes of RE framework and the four indexes mentioned above, a structured questionnaire including 32 questions was developed for personnel [1,12,25] and then each of the RE factors was covered by at least three questions. Some questions of the questionnaire are as follows:

1. Top-level commitment (e.g. Do you feel you have the ability to stop production if safety is at risk?)
2. Just culture (e.g. Do you feel comfortable reporting safety issues/problems to your boss?)
3. Learning culture (e.g. How do you ensure that the feedback or revisions are distributed through the whole organization when accidents happen? Changed manuals, policies, etc.)
4. Awareness and opacity (e.g. Do you think you know what is going on now in this company?)
5. Preparedness (e.g. Do you think that your safety culture and safety procedures are prepared for the future?)
6. Flexibility (e.g. Are there human resources—managers, operators, etc.—with multiple skills to deal with sudden accidents?)

### Table 2
The results of independent samples t test for equality of means

|                          | T    | df | Sig. (2-tailed) |
|--------------------------|------|----|-----------------|
| Management commitment    | 0.975| 18 | 0.343           |
| Reporting                | 0.25 | 18 | 0.806           |
| Learning                 | 1.493| 18 | 0.153           |
|Awareness                 | 1.716| 18 | 0.103           |
|Preparedness              | 1.206| 18 | 0.244           |
|Flexibility               | 1.853| 18 | 0.083           |
|Self-organization         | 0.234| 18 | 0.818           |
|Teamwork                 | 1.674| 18 | 0.111           |
|Redundancy                | 0.834| 18 | 0.415           |
|Fault-tolerance           | 1.945| 18 | 0.068           |

df, degrees of freedom; Sig., significance.

### Table 3
The results of independent samples t test for equality of means

|           | T    | df | Sig. (2-tailed) |
|-----------|------|----|-----------------|
|Managers   | 0.675| 18 | 0.556           |
|Staff      | 0.215| 18 | 0.301           |

df, degrees of freedom; Sig., significance.
The impact of self-organization. Fuzzy data envelopment analysis results: technical efficiency.

Table 4
| Department name                | $TE_{Rank}$ | $df$ | Sig. (2-tailed) |
|--------------------------------|-------------|------|-----------------|
| Process                        | 0.245       | 18   | 0.468           |
| Planning                       | 0.913       | 18   | 0.257           |
| Quality Assurance              | -1.116      | 18   | 0.325           |
| Health and Safety Executive    | 0.116       | 18   | 0.244           |
| Inspection                     | -1.053      | 18   | 0.080           |
| Maintenance                    | 0.234       | 18   | 0.818           |
| Utility                        | 0.574       | 18   | 0.111           |
| Information Technology         | -0.534      | 18   | 0.415           |
| Polymer Operation              | 1.045       | 18   | 0.068           |
| Chemical Operation             | 0.367       | 18   | 0.214           |

df, degrees of freedom; Sig., significance.

7. Self-organization (e.g. If the system faces a problem, does your department have the adequate authority—from the boss—for decision making?)

8. Teamwork (e.g. Do you assist your colleagues, when the workload is high?)

9. Redundancy (e.g. If one of the operators of the critical departments of the system—e.g. control room operator—encounters a problem, is there any alternative to it?)

10. Fault-tolerance (e.g. If one of the critical components of the system—components, machinery, servers, and software—faces a problem, can the total system continue the work?)

2.3. FDEA

Sometimes, input and output data have imprecise or vague values in real-world problems. The various fuzzy methods were proposed for dealing with the imprecise and ambiguous data in data envelopment analysis [26]. One of these methods is FDEA. The fuzzy Banker, Charnes, and Cooper model for ranking the layout of alternatives is as follows:

Model (1):

$$\min \theta$$

s.t.

$$\theta x_{ip} \geq \sum_{j=1}^{33} t_j y_{ij} \quad \forall i = 1, ..., 4,$$

$$\tilde{y}_{ip} \leq \sum_{j=1}^{33} t_j \tilde{y}_{ij} \quad \forall r = 1, ..., 6,$$

$$t_j \geq 0 \quad \forall j = 1, ..., 33.$$ 

Where $i, r,$ and $j$ represent the input variables, output variables, and decision-making units (DMUs), respectively. $x_{ij}$ and $y_{ij}$ are input and output variables of DEA which are asymmetrical triangular-shaped fuzzy numbers as discussed before. $\theta x_{ip}$ and $\tilde{y}_{ip}$ are the

Table 5

| DMU No. | $\alpha = 0.1$ | $\alpha = 0.3$ | $\alpha = 0.5$ | $\alpha = 0.7$ | $\alpha = 0.9$ | $\alpha = 1$ |
|---------|----------------|----------------|----------------|----------------|----------------|--------------|
|         | TE Rank        | TE Rank        | TE Rank        | TE Rank        | TE Rank        | TE Rank      |
| 1       | 1.270          | 2              | 1.180          | 5              | 1.090          | 8            |
| 2       | 1.240          | 6              | 1.150          | 8              | 1.060          | 16           |
| 3       | 1.180          | 10             | 1.110          | 14             | 1.010          | 26           |
| 4       | 1.170          | 12             | 1.130          | 11             | 1.090          | 6            |
| 5       | 1.180          | 11             | 1.120          | 13             | 1.070          | 15           |
| 6       | 1.160          | 15             | 1.100          | 19             | 1.040          | 20           |
| 7       | 1.140          | 17             | 1.110          | 15             | 1.080          | 14           |
| 8       | 1.210          | 8              | 1.150          | 9              | 1.080          | 12           |
| 9       | 1.140          | 18             | 1.070          | 21             | 1.020          | 25           |
| 10      | 1.120          | 19             | 1.080          | 20             | 1.050          | 17           |
| 11      | 1.070          | 29             | 1.040          | 28             | 1.000          | 28           |
| 12      | 1.050          | 26             | 1.060          | 23             | 1.030          | 24           |
| 13      | 1.200          | 9              | 1.160          | 7              | 1.120          | 3            |
| 14      | 1.260          | 4              | 1.220          | 2              | 1.170          | 2            |
| 15      | 1.160          | 13             | 1.140          | 10             | 1.110          | 5            |
| 16      | 1.090          | 23             | 1.010          | 32             | 0.940          | 33           |
| 17      | 1.160          | 14             | 1.120          | 12             | 1.080          | 11           |
| 18      | 1.140          | 16             | 1.100          | 18             | 1.050          | 19           |
| 19      | 1.500          | 1              | 1.410          | 1              | 1.310          | 1            |
| 20      | 1.110          | 21             | 1.100          | 16             | 1.090          | 9            |
| 21      | 1.120          | 20             | 1.100          | 17             | 1.080          | 13           |
| 22      | 1.050          | 33             | 1.010          | 33             | 0.990          | 30           |
| 23      | 1.090          | 24             | 1.040          | 27             | 0.990          | 29           |
| 24      | 1.060          | 31             | 1.020          | 31             | 0.980          | 31           |
| 25      | 1.270          | 3              | 1.180          | 4              | 1.090          | 7            |
| 26      | 1.260          | 5              | 1.190          | 3              | 1.110          | 4            |
| 27      | 1.240          | 7              | 1.170          | 6              | 1.080          | 10           |
| 28      | 1.070          | 30             | 1.050          | 25             | 1.040          | 22           |
| 29      | 1.080          | 27             | 1.070          | 22             | 1.050          | 18           |
| 30      | 1.050          | 32             | 1.040          | 26             | 1.030          | 23           |
| 31      | 1.100          | 22             | 1.030          | 30             | 0.980          | 32           |
| 32      | 1.090          | 20             | 1.050          | 24             | 1.040          | 21           |
| 33      | 1.070          | 28             | 1.040          | 29             | 1.010          | 27           |
upper bound for input variables ($\bar{y}_{ij}$) and lower bound for output variables ($\gamma_{ij}$), respectively [27]. Substituting fuzzy values $\bar{x}_{ij}$ and $\gamma_{ij}$ with $\bar{x}_{ij} = (x_{ij}^m, x_{ij}^p, x_{ij}^s)$ and $\gamma_{ij} = (\gamma_{ij}^m, \gamma_{ij}^p, \gamma_{ij}^s)$, respectively, and using $\alpha$-cut method, the abovementioned model can be expressed as follows:

Model (2):

$$\min \theta$$

s.t.  
$$\theta \left( \alpha x_{ij}^m + (1 - \alpha)x_{ij}^p \right) \geq \sum_{j=1}^{33} t_{ij} \left( \alpha y_{ij}^m + (1 - \alpha)y_{ij}^p \right) \quad \forall i = 1, ..., 4,$$  
$$\alpha y_{ij}^m + (1 - \alpha)y_{ij}^p \leq \sum_{j=1}^{33} t_{ij} \left( \alpha y_{ij}^m + (1 - \alpha)y_{ij}^p \right) \quad \forall r = 1, ..., 6,$$  
$$\sum_{j=1}^{33} t_{ij} = 1, \quad \forall i = 1, ..., 33,$$  
$$t_{ij} \geq 0, \quad \forall j = 1, ..., 33.$$

In Model (2), $\alpha$ is a parameter belonging to the interval [0,1] and $\alpha$-cuts are slices of a fuzzy set that produces regular sets. This model is a parametric linear programming model that can be used for obtaining the optimum solution for each given value of $\alpha$ [28]. It should be noted that since the input indicators including research and educational expenses, teaching hours, and the number of human resources is crisp, their most likely, pessimistic, and optimistic values are the same (i.e., $x_{ij}^m = x_{ij}^p = x_{ij}^s$). Since the objective of this study was to analyze the efficiency of branches (DMUs) based on output indicators, the output-oriented Banker, Charnes, and Cooper model has been utilized and the efficiency and rank of each branch have been determined based on the second model for different $\alpha$-cuts [27].

3. Results

3.1. Experiment: The case study

In the petrochemical plant, 11 departments were selected for the purpose of this study. Every department was partitioned to three subsections: managers, staff, and total personnel. Every section was named a DMU. For example, the managers of the Laboratory department were named DMU1. Therefore, the total number of DMUs is 33. In order to analyze data in fuzzy mode, the mean of data related to any indicator was considered as most likely value, the minimum value of data related to any indicator was considered as pessimistic value, and the maximum value of data related to any indicator was considered as optimistic value.

Choosing input—output variables is an important step in DEA approach [29,30]. According to the nature of the DMUs under evaluation—where the change in output is not a function of direct change in input values—an output-oriented DEA model with a variable returns to scale frontier type is selected. All the six
variables are considered as output variables and the four considered items of this study are as input variables (Fig. 1).

The data obtained from the questionnaires were analyzed by SPSS software. To assess the reliability of the collected data, Cronbach α was calculated by SPSS software and was found to be 90%. For validation of data obtained from the questionnaire, independent t test was performed on the 10 factors that were introduced previously. In independent t test, two groups were selected randomly from each factor. The two groups contained 10 samples. Therefore, difference of means between the two groups was calculated. According to Table 2, the results show that p value of each factor is < 0.05. Hence, there is no significant difference between means of two groups in each factor. Therefore, validity of questionnaire is confirmed by t test.

In this study, difference of means between groups and departments was investigated. Independent t test was used in order to calculate the mentioned differences. The results are shown in Tables 3 and 4. All p values in the two mentioned tables are > 0.05. By considering this point, it is clear that there is no significant difference between managers and staff, or between departments.

3.2. FDEA Results

This study adopts FDEA to assess and optimize DMUs’ performance in the petrochemical plant by considering uncertainty data. Finding the efficiency of different departments was of interest in this study. To this end, fuzzy data were inputted to the FDEA model to obtain the ranking of DMUs. This was gained by considering pessimistic, optimistic, and most likely values. For 33 DMUs, there will be 99 times running (pessimistic, most likely, and optimistic).

Each factor of the four above-mentioned factors was inserted into FDEA model in order to determine the efficiency score and rank of each DMU (Fig. 1). In other words, the impact of each mentioned factor was evaluated separately on RE items and system efficiency. Tables 5, 6, 7, and 8 show FDEA results for all DMUs in the study by Model (1) in different α-cuts (0.1, 0.3, 0.5, 0.7, 0.9, 1); column 1 indicates DMU number while columns 2 and 3 report efficiency score and rank of each DMU.

3.3. ANOVA and least significant difference experiments

This section deals with investigating and comparing the influences of the four mentioned factors on resilient systems and their efficiencies by using SPSS software. At first, six comparisons among integrated RE factors were done by ANOVA test for different α-cuts (0.1, 0.3, 0.5, 0.7, 0.9, 1) and then for some of these factors, a least significant difference (LSD) test was done. ANOVA can be used for analyzing the differences between group means. It is a gathering of statistical models developed by Fisher [31]. The ANOVA test is known for comparing three or more means of groups or variables, so there is a need for an ANOVA test to see if there is any significant difference among the efficiency mean scores of the
four mentioned factors (Fig. 1). The test was done using SPSS software and the results are shown in Table 10. In the ANOVA test, when $p$ (sig) is less than significance level ($a$), the null hypothesis is rejected. This indicates that at least one group differs from the other groups [31].

For discovering the pattern of difference between means, ANOVA needs an additional comparison of mean of each group by pairwise comparisons. In 1935, Fisher developed the first pairwise comparison technique and is called the LSD test. This technique can be used only if the null hypothesis is rejected in ANOVA test and there is a significant difference among the means of groups, so the LSD test gives the pattern of difference [31]. For LSD test, it is assumed that the variances of groups are equal.

Also, for each level of significance, a mean plot is drawn. Mean plots are used to see if the mean varies between different groups of the data.

- Compare means at the $a$-cut = 0.1

The results of ANOVA at the $a$-cut = 0.1 are shown in Table 10. It is shown that at the 0.1 level, there is a significant difference between means of groups (because sig. < $a$); therefore, there is a need for LSD test. LSD results are shown in Table 11. According to LSD results, the pattern of means is as follows (largest to smallest): teamwork, redundancy, self-organization, and fault-tolerance. Therefore, teamwork had the greatest impact (Fig. 2).

Table 8
The impact of fault-tolerance. Fuzzy data envelopment analysis results: technical efficiencies (TE) and ranks for all decision-making units (DMUs) at different $a$-cuts

| DMU No. | $a$-cut | TE | Rank | $a$-cut | TE | Rank | $a$-cut | TE | Rank | $a$-cut | TE | Rank | $a$-cut | TE | Rank | $a$-cut | TE | Rank |
|---------|---------|----|------|---------|----|------|---------|----|------|---------|----|------|---------|----|------|---------|----|------|
| 1       | 0.1     | 1.223 | 3 | 1.148 | 3 | 1.069 | 5 | 0.984 | 16 | 0.890 | 22 | 1.011 | 8 |
| 2       | 0.3     | 1.223 | 3 | 1.148 | 3 | 1.069 | 5 | 0.984 | 16 | 0.890 | 22 | 1.011 | 8 |
| 3       | 0.5     | 1.223 | 3 | 1.148 | 3 | 1.069 | 5 | 0.984 | 16 | 0.890 | 22 | 1.011 | 8 |
| 4       | 0.7     | 1.223 | 3 | 1.148 | 3 | 1.069 | 5 | 0.984 | 16 | 0.890 | 22 | 1.011 | 8 |
| 5       | 0.9     | 1.223 | 3 | 1.148 | 3 | 1.069 | 5 | 0.984 | 16 | 0.890 | 22 | 1.011 | 8 |
| 6       | 1.0     | 1.223 | 3 | 1.148 | 3 | 1.069 | 5 | 0.984 | 16 | 0.890 | 22 | 1.011 | 8 |

Table 9
The comparison for determining the most efficient item at different $a$-cuts

| $a$-cut | A = 0.1 | A = 0.3 | A = 0.5 | A = 0.7 | A = 0.9 | A = 1 |
|---------|---------|---------|---------|---------|---------|-------|
| Technical efficiency mean | Self-organization | 1.155 | 1.180 | 1.059 | 1.014 | 0.986 |
| | Teamwork | 1.213 | 1.179 | 1.155 | 1.089 | 1.000 |
| | Redundancy | 1.204 | 1.148 | 1.093 | 1.046 | 1.004 |
| | Fault-tolerance | 1.097 | 1.040 | 0.992 | 0.949 | 0.908 |
| Effective item | Teamwork | Teamwork | Teamwork | Teamwork | Redundancy | Redundancy |
The results of ANOVA at the \( \alpha \)-cut = 0.3 are shown in Table 10. It is shown that at the 0.3 level, there is a significant difference between means of groups (because \( \text{Sig.} < \alpha \)); therefore, there is a need for LSD test. According to LSD results (Table 11), the pattern of means is as follows (largest to smallest): teamwork, redundancy, self-organization, and fault-tolerance. Therefore, teamwork has the greatest impact (Fig. 3).

- Compare means at the \( \alpha \)-cut = 0.5

The results of ANOVA at the \( \alpha \)-cut = 0.5 are shown in Table 10. It is shown that at the 0.5 level, there is a significant difference between means of groups (because \( \text{Sig.} < \alpha \)); therefore, there is a need for LSD test. According to LSD results (Table 11), the pattern of means is as follows (largest to smallest): redundancy, teamwork, self-organization, and fault-tolerance. Therefore, redundancy has the greatest impact (Fig. 4).

- Compare means at the \( \alpha \)-cut = 0.7

The results of ANOVA at the \( \alpha \)-cut = 0.7 are shown in Table 10. It is shown that at the 0.7 level, there is a significant difference between means of groups (because \( \text{Sig.} < \alpha \)); therefore, there is a need for LSD test. LSD results are shown in Table 11. According to the table, the pattern of means is as follows (largest to smallest): teamwork, redundancy, self-organization, and fault-tolerance. Therefore, teamwork has the greatest impact (Fig. 5).

- Compare means at the \( \alpha \)-cut = 0.9

The results of ANOVA at the \( \alpha \)-cut = 0.9 are shown in Table 10. It is shown that at the 0.9 level, there is a significant difference between means of groups (because \( \text{Sig.} < \alpha \)); therefore, there is a need for LSD test. According to LSD results (Table 11), the pattern of means is as follows (largest to smallest): redundancy, teamwork, self-organization, and fault-tolerance. Therefore, redundancy has the greatest impact (Fig. 6).

- Compare means at the \( \alpha \)-cut = 1

The result of ANOVA is shown in Table 10. It is shown that at the \( \alpha \)-cut = 1 level, there is no significant difference between means of groups (because \( \text{Sig.} > \alpha \)); therefore, there is no need for LSD test. It is

### Table 10
The results of ANOVA test at different \( \alpha \)-cuts

| \( \alpha \)-cut | Sig. |
|------------------|------|
| 0.1              | 0.012|
| 0.3              | 0.004|
| 0.5              | 0.001|
| 0.7              | 0.003|
| 0.9              | 0.024|
| 1                | 1.034|

### Table 11
Multiple comparison by LSD test at different \( \alpha \)-cuts

| (I) DMU     | (J) DMU     | Mean Difference (I – J) \( \alpha \)-cut = 0.1 | Mean Difference (I – J) \( \alpha \)-cut = 0.3 | Mean Difference (I – J) \( \alpha \)-cut = 0.5 | Mean Difference (I – J) \( \alpha \)-cut = 0.7 | Mean Difference (I – J) \( \alpha \)-cut = 0.9 |
|-------------|-------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Self-organization | Teamwork    | -0.057818                                   | -0.071333                                    | -0.095970                                    | -0.074879                                    | -0.031061                                    |
| Redundancy   | Teamwork    | -0.049303                                   | -0.040000                                    | -0.034333                                    | -0.032364                                    | -0.034727                                    |
| Fault-tolerance | Teamwork    | 0.057727                                   | 0.067816                                     | 0.067394                                    | 0.064970                                    | 0.060970                                    |
| Self-organization | Teamwork    | 0.057818                                   | 0.071333                                    | 0.095970                                    | 0.074879                                    | 0.031061                                    |
| Redundancy   | Teamwork    | 0.008515                                   | 0.031333                                    | 0.061636                                    | 0.042515                                    | -0.003667                                    |
| Fault-tolerance | Teamwork    | 0.115545                                   | 0.139152                                    | 0.163364                                    | 0.139848                                    | 0.092030                                    |
| Redundancy   | Teamwork    | 0.049303                                   | 0.040000                                    | 0.034333                                    | 0.032364                                    | 0.034727                                    |
| Fault-tolerance | Teamwork    | 0.008515                                   | 0.031333                                    | 0.061636                                    | 0.042515                                    | 0.003667                                    |
| Fault-tolerance | Teamwork    | 0.107030                                   | 0.107818                                    | 0.101727                                    | 0.097333                                    | -0.05697                                    |
| Fault-tolerance | Teamwork    | -0.057727                                  | -0.067816                                    | -0.067394                                    | -0.064970                                    | -0.060970                                    |
| Redundancy   | Fault-tolerance | -0.115545                                 | -0.139152                                    | -0.163364                                    | -0.139848                                    | -0.092030                                    |
| Fault-tolerance | Redundancy  | -0.008515                                  | -0.107030                                    | -0.107818                                    | -0.101727                                    | -0.097333                                    |

* The mean difference is significant at the 0.05 level.
noted that redundancy has the best performance at the $\alpha$-cut $= 1$ (Fig. 7).

4. Discussion

In this study, the most efficient factor was determined. Tables 5, 6, 7, and 8 show efficiency scores and rank of all DMUs by considering different $\alpha$-cut values for self-organization, teamwork, redundancy, and fault-tolerance, respectively.

In Table 9, the efficiency means of the four mentioned variables and their impacts are shown by considering different $\alpha$-cut values. The table also shows that teamwork and redundancy variables have the highest influence on resilient systems. According to the results, teamwork has the best performance for $\alpha = 0.1$, $\alpha = 0.3$, $\alpha = 0.5$, and $\alpha = 0.7$ and redundancy maximizes the system efficiency for $\alpha = 0.9$ and $\alpha = 1$.

In general, the results show as $\alpha$ approaches 1 and the fuzzy system gets closer to a certain mode ($\alpha = 0.9$ and $\alpha = 1$), redundancy will play a more important role and has the greatest impact on the resilient system. In contrast, as $\alpha$ approaches 0 and the system becomes fuzzier ($\alpha = 0.3$ and $\alpha = 0.1$), the role of teamwork in the resilient system will become more substantial. Thus, it can be stated that redundancy and teamwork have the best performance.

ANOVA and LSD tests were done to verify the results of this study. The results of the tests show redundancy has a vital role in certain mode and teamwork plays an important role in uncertain mode. Also, obtained results of the tests confirm the obtained results of the FDEA approach.

It is noted that the four debated factors in this study were introduced by Azadeh et al [12]. There is only one study that evaluates and analyzes the effect of the mentioned factors on resilient systems. Azadeh et al [12] conducted a similar study in a petrochemical plant in certain condition. In the study, the influence of the four mentioned factors including self-organization, teamwork, redundancy, and fault-tolerance on a resilient system was calculated and analyzed by means of DEA and statistical methods. The obtained results similarly indicated that teamwork and redundancy have a considerable role in enhancing the efficiency of the investigated system. Hence, teamwork and redundancy play a significant role in resilient systems in both certain and uncertain condition.

The results of applying $t$ test on obtained data from a questionnaire showed that there is no significant difference between
departments and also people. In addition, the results of fuzzy DEA indicated as α approaches 0 and the system becomes fuzzier, teamwork will play an important role and has the greatest impact on the resilient system. In contrast, as α approaches 1 and the fuzzy system gets closer to a certain mode, the role of redundancy in the resilient system will become more substantial. Thus, it can be stated that redundancy and teamwork have the best performance. Thus, they have the greatest impact on resilience engineering in the selected uncertain environment.

Conflicts of interest

All authors have no conflicts of interest to declare.

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