Safety and Health at Work 7 (2016) 307–316

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

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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ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form
30 March 2016
Accepted 28 April 2016
Available online 14 May 2016

Keywords:
fuzzy data envelopment analysis
petrochemical plant
redundancy
resilience engineering
teamwork

ABSTRACT

Background: Resilience engineering (RE) is a new paradigm that can control incidents and reduce their consequences. Integrated RE includes four new factors—self-organization, teamwork, redundancy, and fault-tolerance—in addition to conventional RE factors. This study aimed to evaluate the impacts of these four factors on RE and determine the most efficient factor in an uncertain environment.
Methods: The required data were collected through a questionnaire in a petrochemical plant in June 2013. The questionnaire was completed by 115 respondents including 37 managers and 78 operators. Fuzzy data envelopment analysis was used in different α-cuts in order to calculate the impact of each factor. Analysis of variance was employed to compare the efficiency score means of the four above-mentioned factors.
Results: The results showed that as α approached 0 and the system became fuzzier ($\alpha = 0.3$ and $\alpha = 0.1$), teamwork played a significant role and had the highest impact on the resilient system. In contrast, as α approached 1 and the fuzzy system went toward a certain mode ($\alpha = 0.9$ and $\alpha = 1$), redundancy had a vital role in the selected resilient system. Therefore, redundancy and teamwork were the most efficient factors.
Conclusion: The approach developed in this study could be used for identifying the most important factors in such environments. The results of this study may help managers to have better understanding of weak and strong points in such industries.

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

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2093-7911/$ — see front matter
http://dx.doi.org/10.1016/j.shaw.2016.04.009

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

Table 1
Features of this study versus other studies

Study	Feature												
	Management commitment	Reporting culture	Learning/ training	Awareness	Preparedness/ anticipate	Flexibility	Teamwork	Redundancy	Fault-tolerance	Self-organization	Deterministic approach	Fuzzy approach	ANOVA
This study	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
Integrated RE framework	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
RE framework	✓	✓	✓	✓	✓	✓							
Woods 2003 [8]	✓	✓	✓	✓	✓	✓							
Carvalho et al 2008 [9]	✓	✓	✓	✓	✓	✓			✓				
Costella et al 2009 [5]	✓	✓	✓	✓	✓	✓							
Gomes et al 2009 [4]		✓	✓		✓								
Hansson et al 2009 [10]		✓	✓	✓	✓	✓							
Huber et al 2009 [1]	✓	✓	✓	✓	✓	✓							
Morel et al 2009 [11]	✓	✓	✓	✓	✓	✓							
Saurin and Júnior 2011 [7]	✓	✓	✓	✓	✓	✓							
Shirali et al 2013 [6]	✓	✓	✓	✓	✓	✓					✓		
Azadeh et al 2014 [12]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Azadeh and Salehi 2014 [13]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		

RE, resilience engineering.

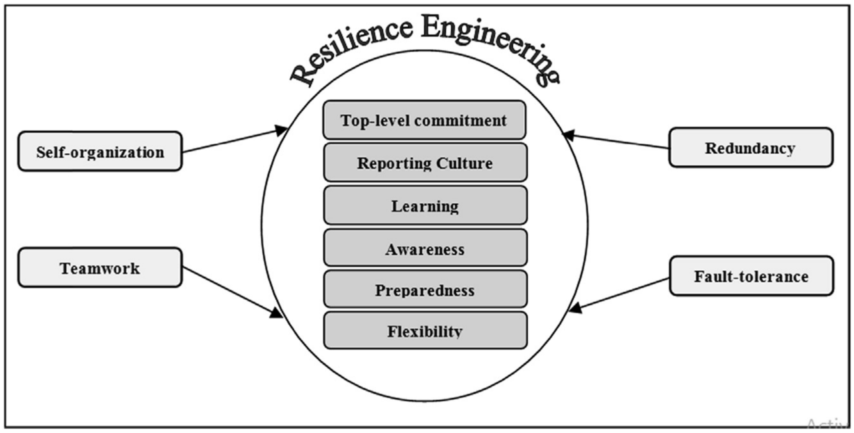

Fig. 1. The effect of the suggested items on resilience engineering.

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	0.08
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.

Table 4
The results of independent samples *t* test for equality of means

Department name	T	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):

$$\begin{aligned}
&\min \theta \\
&\text{s.t.} \\
&\theta \tilde{x}_{ip} \geq \sum_{j=1}^{33} \tau_j \tilde{x}_{ij} \quad \forall i = 1, \ldots, 4, \\
&\tilde{y}_{rp} \leq \sum_{j=1}^{33} \tau_j \tilde{y}_{rj} \quad \forall r = 1, \ldots, 6, \\
&\sum_{j=1}^{33} \tau_j = 1 \\
&\tau_j \geq 0 \quad \forall j = 1, \ldots, 33.
\end{aligned}$$

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

Table 5
The impact of self-organization. Fuzzy data envelopment analysis results: technical efficiencies (TE) and ranks for all decision-making units (DMUs) at different α-cuts

DMU No.	α = 0.1		α = 0.3		α = 0.5		α = 0.7		α = 0.9		α = 1	
	TE	Rank	TE	Rank	TE	Rank	TE	Rank	TE	Rank	TE	Rank
1	1.270	2	1.180	5	1.090	8	0.990	23	0.880	31	1.030	7
2	1.240	6	1.150	8	1.060	16	0.940	31	0.800	33	0.950	31
3	1.180	10	1.110	14	1.010	26	0.900	33	0.810	32	0.950	30
4	1.170	12	1.130	11	1.090	6	1.050	7	1.020	7	1.140	1
5	1.180	11	1.120	13	1.070	15	1.010	18	0.940	22	0.960	24
6	1.160	15	1.100	19	1.040	20	1.000	21	0.940	25	0.980	18
7	1.140	17	1.110	15	1.080	14	1.040	9	1.010	9	1.060	5
8	1.210	8	1.150	9	1.080	12	1.010	20	0.920	28	0.950	25
9	1.140	18	1.070	21	1.020	25	1.010	19	1.000	17	0.980	17
10	1.120	19	1.080	20	1.050	17	1.030	13	1.010	13	1.100	3
11	1.070	29	1.040	28	1.000	28	0.970	27	0.930	26	0.960	21
12	1.090	26	1.060	23	1.030	24	1.000	22	0.960	19	0.970	19
13	1.200	9	1.160	7	1.120	3	1.080	3	1.030	3	1.060	4
14	1.260	4	1.220	2	1.170	2	1.110	2	1.040	2	1.030	10
15	1.160	13	1.140	10	1.110	5	1.060	4	1.020	5	1.020	12
16	1.090	23	1.010	32	0.940	33	0.910	32	0.890	30	0.940	32
17	1.160	14	1.120	12	1.080	11	1.030	12	0.980	18	0.960	20
18	1.140	16	1.100	18	1.050	19	0.980	24	0.910	29	0.960	22
19	1.500	1	1.410	1	1.310	1	1.200	1	1.070	1	1.100	2
20	1.110	21	1.100	16	1.090	9	1.060	5	1.020	4	1.030	9
21	1.120	20	1.100	17	1.080	13	1.060	6	1.020	6	1.000	16
22	1.030	33	1.010	33	0.990	30	0.970	26	0.950	20	0.950	27
23	1.090	24	1.040	27	0.990	29	0.950	29	0.920	27	0.950	26
24	1.060	31	1.020	31	0.980	31	0.950	30	0.940	24	0.940	33
25	1.270	3	1.180	4	1.090	7	1.040	11	1.010	11	1.030	6
26	1.260	5	1.190	3	1.110	4	1.050	8	1.010	10	1.020	11
27	1.240	7	1.170	6	1.080	10	1.020	15	1.010	14	1.000	14
28	1.070	30	1.050	25	1.040	22	1.020	16	1.010	15	1.030	8
29	1.080	27	1.070	22	1.050	18	1.030	14	1.010	12	1.010	13
30	1.050	32	1.040	26	1.030	23	1.020	17	1.010	16	1.000	15
31	1.100	22	1.030	30	0.980	32	0.960	28	0.940	21	0.960	23
32	1.090	25	1.050	24	1.040	21	1.040	10	1.020	8	0.950	28
33	1.070	28	1.040	29	1.010	27	0.970	25	0.940	23	0.950	29

Table 6
The impact of teamwork. Fuzzy data envelopment analysis results: technical efficiencies (TE) and ranks for all decision-making units (DMUs) at different α-cuts

DMU No.	α = 0.1		α = 0.3		α = 0.5		α = 0.7		α = 0.9		α = 1	
	TE	Rank	TE	Rank	TE	Rank	TE	Rank	TE	Rank	TE	Rank
1	1.900	1	1.900	1	1.900	1	1.336	3	1.047	2	1.099	2
2	1.132	16	1.077	17	1.035	22	1.071	9	0.995	17	0.914	33
3	1.092	22	1.056	24	1.052	18	1.108	6	0.999	16	0.929	32
4	1.186	13	1.136	11	1.094	11	1.055	10	1.018	6	1.138	1
5	1.303	5	1.321	5	1.335	4	1.108	5	0.947	25	0.981	19
6	1.214	9	1.202	8	1.213	8	1.054	11	0.932	26	0.984	18
7	1.149	15	1.113	12	1.080	12	1.048	12	1.016	7	1.055	4
8	1.900	3	1.900	2	1.900	2	1.900	2	1.900	1	1.033	7
9	1.218	8	1.210	7	1.257	6	1.123	4	1.038	3	1.000	14
10	1.122	17	1.089	14	1.064	15	1.040	14	1.014	8	1.097	3
11	1.091	23	1.071	19	1.056	16	1.025	19	0.993	18	0.975	21
12	1.087	25	1.061	22	1.037	21	1.011	24	0.980	20	0.972	22
13	1.219	7	1.180	9	1.135	10	1.077	8	1.021	4	1.053	5
14	1.900	2	1.900	3	1.900	3	1.900	1	0.826	33	1.041	6
15	1.437	4	1.368	4	1.248	7	1.091	7	0.908	29	1.000	12
16	1.113	20	1.030	31	0.945	33	0.919	33	0.894	31	0.957	28
17	1.277	6	1.287	6	1.301	5	1.029	17	0.901	30	0.958	27
18	1.198	11	1.170	10	1.159	9	0.978	28	0.850	32	0.950	29
19	1.080	28	1.033	30	0.993	30	0.967	30	0.950	22	0.969	23
20	1.064	29	1.061	23	1.053	17	1.043	13	1.020	5	0.998	16
21	1.054	31	1.046	27	1.034	23	1.019	22	1.002	15	0.988	17
22	1.028	33	1.010	33	0.990	31	0.969	29	0.948	23	0.947	30
23	1.088	24	1.037	29	0.994	29	0.952	31	0.920	28	0.959	26
24	1.062	30	1.023	32	0.984	32	0.946	32	0.928	27	0.946	31
25	1.193	12	1.079	16	1.028	26	1.015	23	1.004	13	1.007	11
26	1.200	10	1.109	13	1.068	14	1.037	15	1.011	9	1.020	9
27	1.176	14	1.082	15	1.031	25	1.006	26	0.992	19	0.999	15
28	1.081	27	1.065	21	1.048	20	1.029	18	1.009	11	1.029	8
29	1.096	21	1.072	18	1.049	19	1.031	16	1.011	10	1.010	10
30	1.053	32	1.042	28	1.031	24	1.019	21	1.007	12	1.000	13
31	1.117	18	1.053	25	1.023	27	1.011	25	1.003	14	0.976	20
32	1.116	19	1.070	20	1.069	13	1.023	20	0.964	21	0.964	25
33	1.082	26	1.051	26	1.021	28	0.991	27	0.947	24	0.966	24

upper bound for input variables ($\tilde{x}_{ij}$) and lower bound for output variables ($\tilde{y}_{ij}$), respectively [27]. Substituting fuzzy values $\tilde{x}_{ij}$ and $\tilde{y}_{ij}$ with $\tilde{x}_{ij} = (x^p_{ij}, x^m_{ij}, x^o_{ij})$ and $\tilde{y}_{ij} = (y^p_{ij}, y^m_{ij}, y^o_{ij})$, respectively, and using α-cut method, the abovementioned model can be expressed as follows:

Model (2):

$$
\begin{aligned}
&\min \theta \\
&\text{s.t.} \\
&\theta\left(\alpha x^m_{ip} + (1-\alpha)x^p_{ip}\right) \geq \sum_{j=1}^{33} \tau_j \left(\alpha x^m_{ij} + (1-\alpha)x^o_{ij}\right) \quad \forall i = 1, \ldots, 4, \\
&\alpha y^m_{rp} + (1-\alpha)y^o_{rp} \leq \sum_{j=1}^{33} \tau_j \left(\alpha y^m_{rj} + (1-\alpha)y^p_{rj}\right) \quad \forall r = 1, \ldots, 6, \\
&\sum_{j=1}^{33} \tau_j = 1 \\
&\tau_j \geq 0 \qquad \forall j = 1, \ldots, 33.
\end{aligned}
$$

In Model (2), α is a parameter belonging to the interval [0,1] and α-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 α [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., $x^m_{ij} = x^p_{ij} = x^o_{ij}$). 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 α-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

Table 7
The impact of redundancy. Fuzzy data envelopment analysis results: technical efficiencies (TE) and ranks for all decision-making units (DMUs) at different α-cuts

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	1.232	10	1.116	16	1.007	26	0.898	32	0.787	32	0.970	24
2	1.259	8	1.201	8	1.138	7	1.120	5	1.113	2	0.956	28
3	1.227	12	1.146	12	1.071	14	1.037	14	1.005	16	0.936	33
4	1.189	16	1.138	13	1.094	12	1.055	10	1.018	7	1.138	1
5	1.474	2	1.394	2	1.302	2	1.194	2	1.069	3	1.012	8
6	1.342	4	1.274	4	1.200	4	1.125	4	1.018	8	1.000	13
7	1.174	18	1.124	14	1.081	13	1.045	12	1.014	10	1.055	4
8	1.276	6	1.221	5	1.143	6	1.043	13	0.959	23	1.007	12
9	1.162	19	1.106	17	1.055	16	1.019	20	0.993	19	0.998	16
10	1.119	23	1.083	22	1.053	17	1.029	17	1.009	14	1.097	2
11	1.082	29	1.015	30	0.968	30	0.934	28	0.912	29	0.965	25
12	1.047	32	1.006	33	0.965	31	0.924	30	0.921	27	0.954	30
13	1.076	30	1.028	29	1.007	27	0.993	23	0.981	21	0.963	26
14	1.900	1	1.900	1	1.900	1	1.900	1	1.900	1	1.083	3
15	1.105	24	1.042	28	0.962	32	0.863	33	0.782	33	0.979	21
16	1.084	28	1.010	31	0.941	33	0.914	31	0.888	30	0.939	32
17	1.241	9	1.204	7	1.147	5	1.058	9	0.980	22	0.979	22
18	1.145	20	1.089	20	1.017	24	0.927	29	0.842	31	0.956	27
19	1.145	21	1.075	23	0.990	29	0.938	27	0.917	28	0.952	31
20	1.396	3	1.332	3	1.264	3	1.178	3	1.067	4	1.035	5
21	1.299	5	1.216	6	1.124	9	1.049	11	0.994	18	0.990	18
22	1.028	33	1.010	32	0.990	28	0.969	26	0.948	25	0.954	29
23	1.140	22	1.095	18	1.041	20	0.982	24	0.942	26	0.990	17
24	1.101	25	1.052	26	1.010	25	0.978	25	0.957	24	0.970	23
25	1.205	14	1.083	21	1.028	23	1.014	21	1.004	17	1.007	10
26	1.200	15	1.117	15	1.071	15	1.036	15	1.011	12	1.020	7
27	1.176	17	1.090	19	1.034	22	1.007	22	0.992	20	0.999	15
28	1.085	27	1.068	25	1.051	18	1.032	16	1.011	11	1.028	6
29	1.089	26	1.071	24	1.048	19	1.028	18	1.009	13	1.010	9
30	1.056	31	1.046	27	1.035	21	1.022	19	1.008	15	1.000	14
31	1.205	13	1.187	9	1.132	8	1.078	6	1.027	5	1.007	11
32	1.260	7	1.162	11	1.107	11	1.069	8	1.023	6	0.984	20
33	1.228	11	1.169	10	1.117	10	1.070	7	1.015	9	0.989	19

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. Then, 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

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 α-cuts

DMU No.	α = 0.1		α = 0.3		α = 0.5		α = 0.7		α = 0.9		α = 1	
	TE	Rank	TE	Rank	TE	Rank	TE	Rank	TE	Rank	TE	Rank
1	1.223	3	1.148	3	1.069	5	0.984	16	0.892	22	1.011	8
2	1.093	12	0.999	24	0.913	26	0.828	27	0.743	30	0.860	32
3	1.032	27	0.953	29	0.880	30	0.810	31	0.744	29	0.847	33
4	1.445	1	1.365	1	1.277	1	1.176	1	1.069	1	1.242	1
5	1.086	15	0.994	25	0.902	28	0.817	30	0.735	31	0.871	30
6	1.058	21	0.986	26	0.912	27	0.836	26	0.772	25	0.890	29
7	1.136	8	1.102	6	1.070	4	1.039	4	1.012	5	1.055	3
8	1.144	7	1.058	11	0.968	20	0.869	25	0.767	26	0.908	26
9	1.078	16	1.000	23	0.950	22	0.924	20	0.910	20	0.940	19
10	1.119	10	1.083	7	1.053	7	1.029	9	1.009	9	1.097	2
11	1.042	25	0.979	28	0.928	25	0.902	24	0.894	21	0.933	22
12	1.026	30	0.984	27	0.947	23	0.920	22	0.921	18	0.932	23
13	1.076	17	1.028	17	1.007	16	0.993	15	0.981	15	0.963	14
14	0.988	32	0.889	33	0.786	33	0.681	33	0.574	33	0.863	31
15	0.969	33	0.921	32	0.872	31	0.818	29	0.762	27	0.892	28
16	1.086	14	1.011	20	0.941	24	0.914	23	0.888	23	0.943	18
17	1.026	29	0.951	30	0.889	29	0.824	28	0.755	28	0.908	25
18	1.018	31	0.945	31	0.871	32	0.797	32	0.721	32	0.901	27
19	1.045	24	1.005	22	0.964	21	0.923	21	0.881	24	0.923	24
20	1.055	22	1.056	13	1.046	9	1.031	7	1.011	6	0.998	12
21	1.037	26	1.028	18	1.018	15	1.004	14	0.989	14	0.980	13
22	1.028	28	1.010	21	0.990	17	0.969	17	0.948	16	0.944	17
23	1.088	13	1.030	16	0.988	18	0.951	18	0.920	19	0.949	16
24	1.058	20	1.018	19	0.981	19	0.946	19	0.928	17	0.938	20
25	1.193	5	1.079	9	1.028	13	1.014	12	1.004	12	1.007	9
26	1.200	4	1.107	5	1.065	6	1.034	5	1.010	7	1.020	6
27	1.176	6	1.082	8	1.031	11	1.006	13	0.992	13	0.999	11
28	1.072	18	1.057	12	1.042	10	1.025	10	1.008	10	1.029	4
29	1.095	11	1.075	10	1.052	8	1.030	8	1.010	8	1.013	7
30	1.050	23	1.041	14	1.031	12	1.019	11	1.007	11	1.000	10
31	1.277	2	1.189	2	1.150	2	1.103	2	1.038	2	1.028	5
32	1.065	19	1.032	15	1.026	14	1.032	6	1.027	4	0.933	21
33	1.131	9	1.107	4	1.089	3	1.068	3	1.036	3	0.955	15

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 (α), 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 α-cut = 0.1

The results of ANOVA at the α-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. < α); 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 9
The comparison for determining the most efficient item at different α-cut

α-cut		A = 0.1	α = 0.3	α = 0.5	α = 0.7	α = 0.9	α = 1
Technical efficiency mean	Self-organization	1.155	1.108	1.059	1.014	0.969	0.997
	Teamwork	1.213	1.179	1.155	1.089	1.000	0.997
	Redundancy	1.204	1.148	1.093	1.046	1.004	0.998
	Fault-tolerance	1.097	1.040	0.992	0.949	0.908	0.963
Effective item		Teamwork	Teamwork	Teamwork	Teamwork	Redundancy	Redundancy

Table 10
The results of ANOVA test at different α-cuts

	Sig.
α-cut = 0.1	0.012
α-cut = 0.3	0.004
α-cut = 0.5	0.001
α-cut = 0.7	0.003
α-cut = 0.9	0.024
α-cut = 1	1.034

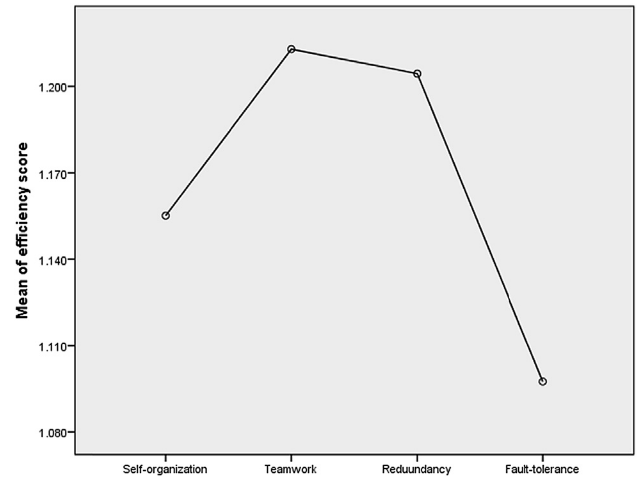

Fig. 2. Mean plot at $\alpha = 0.1$.

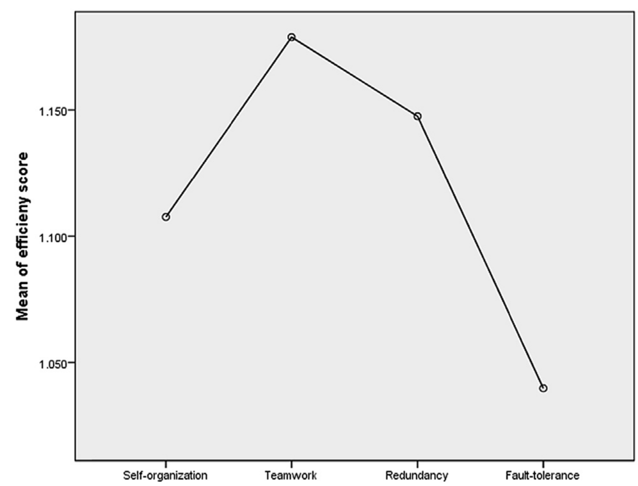

Fig. 3. Mean plot at $\alpha = 0.3$.

- Compare means at the α-cut = 0.3

The results of ANOVA at the α-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 sig. < α); 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 α-cut = 0.5

The results of ANOVA at the α-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 sig. < α); 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 α-cut = 0.7

The results of ANOVA at the α-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 sig. < α); 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 α-cut = 0.9

The results of ANOVA at the α-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 sig. < α); 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 α-cut = 1

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

Table 11
Multiple comparison by LSD test at different α-cuts

(I) DMU	(J) DMU	Mean Difference (I − J) α-cut = 0.1	Mean Difference (I − J) α-cut = 0.3	Mean Difference (I − J) α-cut = 0.5	Mean Difference (I − J) α-cut = 0.7	Mean Difference (I − J) α-cut = 0.9
Self-organization	Teamwork	−0.057818*	−0.071333*	−0.095970*	−0.074879*	−0.031061
	Redundancy	−0.049303*	−0.040000*	−0.034333*	−0.032364	−0.034727
	Fault-tolerance	0.057727*	0.067818*	0.067394*	0.064970*	0.060970*
Teamwork	Self-organization	0.057818*	0.071333*	0.095970*	0.074879*	0.031061
	Redundancy	0.008515*	0.031333*	0.061636*	0.042515*	−0.003667
	Fault-tolerance	0.115545*	0.139152*	0.163364*	0.139848*	0.092030*
Redundancy	Self-organization	0.049303*	0.040000*	0.034333*	0.032364	0.034727
	Teamwork	−0.008515*	−0.031333*	−0.061636*	−0.042515*	0.003667
	Fault-tolerance	0.107030*	0.107818*	0.101727*	0.097333*	0.095697*
Fault-tolerance	Self-organization	−0.057727*	−0.067818*	−0.067394*	−0.064970*	−0.060970*
	Teamwork	−0.115545*	−0.139152*	−0.163364*	−0.139848*	−0.092030*
	Redundancy	−0.107030*	−0.107818*	−0.101727*	−0.097333*	−0.095697*

* The mean difference is significant at the 0.05 level.

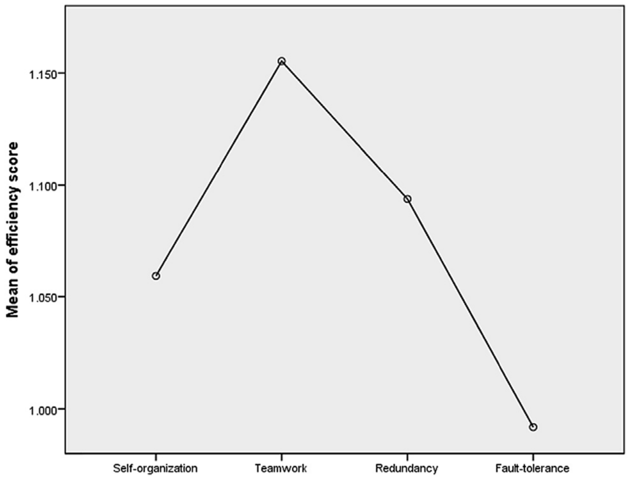

Fig. 4. Mean plot at $\alpha = 0.5$.

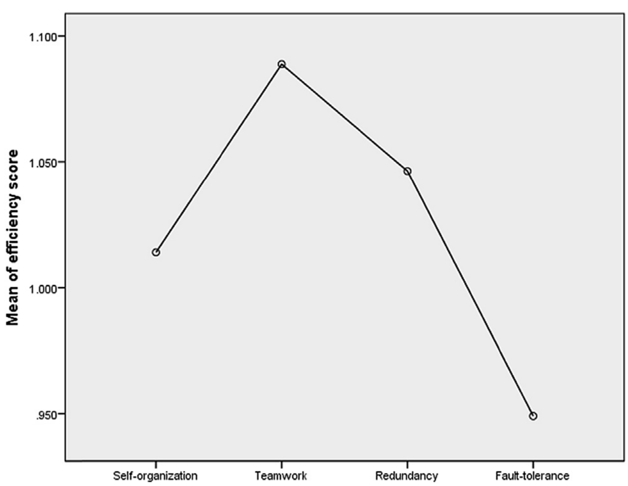

Fig. 5. Mean plot at $\alpha = 0.7$.

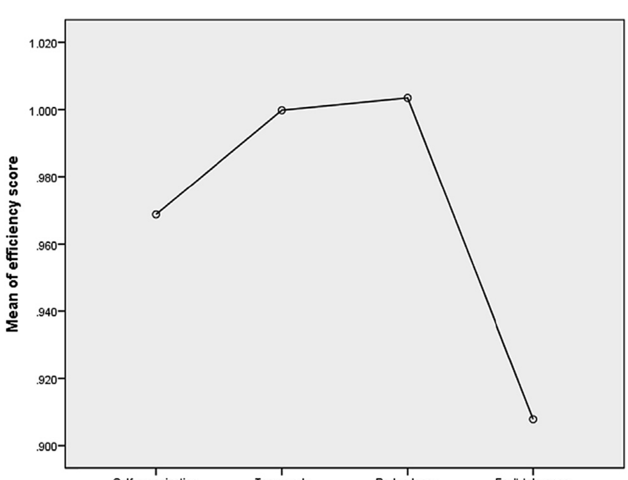

Fig. 6. Mean plot at $\alpha = 0.9$.

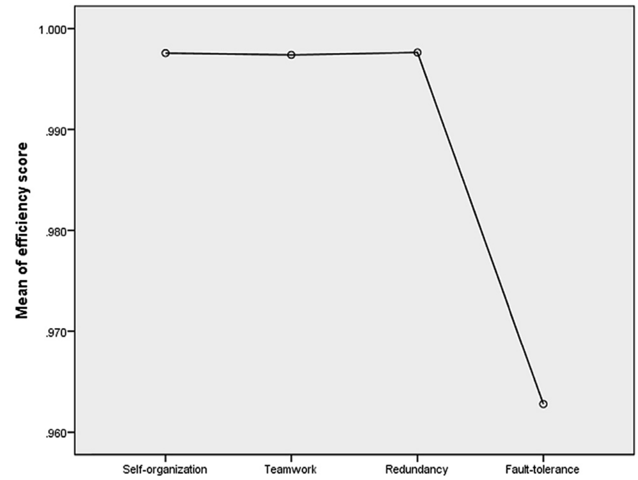

Fig. 7. Mean plot at $\alpha = 1$.

noted that redundancy has the best performance at the α-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 α-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 α-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 α 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 α 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.

Acknowledgment

The authors are grateful for the valuable comments and suggestions from the respected reviewers. Their valuable comments and suggestions have enhanced the strength and significance of our paper. This study was supported by a grant from the Iran National Science Foundation (grant number 94002128). The authors are grateful for the financial support provided by the Iran National Science Foundation.

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