Journal of Turkish

Operations Management

PERFORMANCE IMPROVEMENT OF INFORMATION SYSTEM OF A BANKING SYSTEM BASED ON INTEGRATED RESILIENCE ENGINEERIING DESIGN

S. H. Iranmanesh, A. Mollajan, L. Aliabadi

Department of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran

hiranmanesh@ut.ac.ir , leyla.aliabadi@ut.ac.ir , ali.mollajan@ut.ac.ir

ARTICLE INFO

Article History:

Received: 22.11.2018

Revised: 11.12.2018

Accepted: 06.03.2019

Keywords:

Performance Evaluation; Banking System; Integrated Resilience Engineering (IRE); Data Envelopment Analysis (DEA); Perturbation Analysis

ABSTRACT

Integrated resilience engineering (IRE) is capable of returning banking systems to normal state in extensive economic circumstances. In this study, information system of a large bank (with several branches) is assessed and optimized under severe economic conditions. Data envelopment analysis (DEA) models are employed to achieve the objective of this study. Nine IRE factors are considered to be the outputs and a dummy variable is defined as the input of the DEA models. Standard questionnaire is designed and distributed among executive managers to be considered as the decision-making units (DMUs). Reliability and validity of the questionnaire is examined based on Cronbach's alpha and t-test. The most appropriate DEA model is determined based on average efficiency and normality test. It is shown that the proposed integrated design provides higher efficiency than conventional resilience engineering design. Results of sensitivity and perturbation analysis indicate that self-organization, fault tolerance and reporting culture respectively compose about 50 percent of total weight.

1. Introduction

Operational risks are considered to be important sources that can significantly exert negative effects on safety of systems and or organizations (Hollnagel, 2007; Malaek et al., 2014; Sharahi et al., 2014). For this reason, a sound risk management can be regarded as a useful solution to effectively help management of system safety (Golgeci and Ponomarov, 2013). Concerning traditional risk management policies, due to its undesirable outcomes, most of managers did not invest sufficient efforts or, at least, did not conclude risk management proceedings of their organization were successful enough (Saenz and Revilla, 2014). The basic reason behind ineffectualness of classical risk management is, in fact, reliance of its policies and practices on statistical information and risk identification whereas a large number of risks are still unknowable or unpredictable and, also, most of statistical information might not exist (Fiksel et al., 2015). Therefore, it seems that dealing with operational risks experienced in practice is so complicated and safety assurance of systems and/or organizations cannot be achieved successfully by traditional risk analysis (Hollnagel, 2007). That is, some more effective approaches are required. In recent years, Resilience Engineering (RE) has been introduced as a sound solution to safety and risk management and has received particular attentions in complex and socio-technical systems (Steen and Aven, 2011).

Resilience Engineering is a novel way of thinking about safety. While most of traditional methods of risk management are mainly based upon estimation of probability of failure, Resilience Engineering (RE) seeks for ways to increase capability of systems and develop processes which are flexible and robust enough. This is to examine and modify risk models successfully and utilize available resources effectively where the system has to operate under different disruptions and/or economic pressures (Dekker et al., 2008). Concerning developing proper risk models, in order to improve performance of safety and human resources in complex systems, additional elements are suggested to be added to the basic factors of RE framework. This model is commonly referred to as Integrated Resilience Engineering (IRE) (Azadeh et al., 2014). IRE framework is, in fact, a good solution to more effectively deal with operational risks that may arise in operational environments associate with complex and large systems, especially socio-economic systems (Azadeh et al., 2014).

Wide applications of principles of RE/IRE in various specialized fields may indicate its relative strength and usefulness for dealing with some kinds of problems related to the safety requirement of systems/organizations in a more effective way . In this regard, because of severe economic circumstances in the world, safety of "banking system" is highlighted. In fact, due to "high impact of operational risks particularly posed from associated operational environments to the banking systems", "the need to have a good model to provide successful forecasts for different types of operational risks", "significance of ability and skill of banking systems to foresee the future and adjust themselves to deal with any sudden breakage", and "the necessity of capability of the banking system to successfully launch all its essential processes under both foreseen and unforeseen conditions", it is clarified that utilization of basic principles of IRE in order to study safety requirement of banking systems is helpful (Holling, 1973; Tazi and Amalberti, 2006; Haimes, 2009; Woods and Hollnagel, 2006; Furniss et al., 2011; Hollnagel, 2011; Dolif et al, 2012). Indeed, attempts to apply IRE principles to the safety management of banking systems may pave the way for returning banking systems to the normal state and reaching a resilient banking system. In this study, specifically, "information system" of a large bank (with several branches), as the concerned case, is addressed. To evaluate resiliency of the information system of this bank, performance of the system is given to be considered.

The rest of the paper is organized as follows: In section two, first of all a brief review of Resilience Engineering (RE) and Integrated Resilience Engineering (IRE) concept are presented and, then, the principles of IRE is also discussed. Moreover, as a subsection of the section two, a brief review of Data Envelopment Analysis (DEA) technique is also presented. Finally, the relevant literature is briefly reviewed to provide an overview of all prior work and researches related to the main challenge of the article. Section three is to present the methodology of the work. In section four, the experiment is expressed. Section five provides the computational results obtained from running the experiments on the basis of the collected data. Finally, in section six, conclusion and discussion are presented.

2. Literature Review

2.1. Principles of resilience engineering

Resilience Engineering (RE) concept was first utilized to explain a characteristic of timber, and to justify why some kinds of wood could tolerate unexpected and heavy loads with no breakage (Hollnagel and Woods, 2006). Next, this useful concept was also helpfully employed to evaluate ability of some kinds of materials that were able to tolerate well in severe conditions in Admiralty (…). However, in the Twenty-First Century, the RE concept was specifically employed as a useful tool to develop strategies and/or business models in dynamic positioning (Holling, 1973). Nowadays; in order to meet the "safety requirement" of any complex system, the RE concept is being actively used as a particular strategic concept (Morel et al., 2009).

Regarding the Resilience Engineering (RE) concept, a wide variety of definitions is presented in literature. According to Woods and Hollnagel (2006), "Resilience Engineering is a model that concentrates on how to support human beings deal with complexity under pressure to meet prosperity". They define the "Resilience Engineering as an effort to increase capability of a complex socio-technical system to absorb or adjust to variations, disruptions, and disturbances". In view of Anderson et al. (2013), "Resilience Engineering signifies a theoretical change in the safety discipline. However, RE can be regarded as a practical approach which concentrates on need for developing systems which is capable of adjusting to some sorts of changes in the environment in which they can operate and successfully support all employees in a safe adjustment". Fairbanks et al. (2014) describe "Resilience Engineering" as a conscious design and creation of systems which have the capacity of resilience". RE concept is, in fact, to find good ways for learning and adjusting to all internal and external system/organization conditions quickly and ensuring safety for an environment with risks, exchanges, and several objectives and economic pressures (Hollnagel et al., 2006). For this purpose, the concept of RE is employed to examine and modify risk models and help managers to efficiently utilize all existing resources in presence of all economic pressures and safety challenges. Hence, from this perspective, the RE concept is to try to find suitable ways for enhancing all skills and capabilities which an organization may require to successfully cope with safety problems. All of these efforts may result in establishing organizational processes robust and flexible inherently. Indeed, the main idea of the RE is modifying "risk management processes" to make them "robust" and "flexible" enough (Gilmour, 2006).

To introduce the principles of Resilience Engineering (RE), the work accomplished by Hollnagel et al. (2006) was the first attempt and six principles of Resilience Engineering (RE) were established. According to Hollnagel et al. (2006), Resilience Engineering pillars upon six key principles including "Management Commitment", "Reporting Culture", "Learning", "Awareness", "Preparedness", and "Flexibility". In 2014, Azadeh et al.(2014) also developed RE framework and added another four items as additional elements that should be given as basic principles of RE. On the basis of their study, "Redundancy", "Fault-Tolerant", "Self-Organization", and "Teamwork" should be considered to be another four key principles of RE. That is, ten basic elements are presented as fundamental principles of RE.

It is obvious that, in a consistent way, in different fields and applications, each of these ten items has different and particular definition and interpretation (Wreathall, 2006). However, it seems that presenting a standard and general definition for each item could be useful. On the basis of this idea, each of these basic elements of RE can be defined as followings;

- **Management commitment:** Senior management of systems is expected to recognize difficulties and problems of system people and tries to resolve them. Indeed, tendency of managers to invest in safety and assignment of resources in a timely and proactive way is one of the most important parameters in a resilient system (Wreathall, 2006). Moreover, the management commitment principle affirms that safety is, in fact, a core organizational value rather than a transitory priority (Saurin and Carim junior, 2011).

- **Reporting culture:** The fact is that with no precise reporting culture, the willingness of staff to report the safety issues may decrease. Thus, the ability of organization to learn from its weaknesses and/or flaws in defensive states may be limited (Wreathall, 2006).
- **Learning:** Resilience Engineering emphasizes learning from the analysis of standard and regular activities whereas it does not consider learning from unexpected/expected accidents. Based on learning principle, running the acceptable performance of plans is as significant as designing them. This may be effective in decreasing the gap between work as conceived by managers and work as really performed by operators (Saurin and Carim Junior, 2012). This principle proposes that resilient systems must be conscious of what has happened (Hollnagel, 2009).
- **Awareness:** Collection of all required data can provide this opportunity for the management to be conscious of what occurs in the system/organization. Hence, management of the system/organization can be conscious of such issues as the performance quality of system/organization's people (Wreathall, 2006).
- **Preparedness:** The system is expected to be capable of making appropriate prediction of difficulties and problems originating from safety issues and/or performance of human beings and always is ready to provide proper responses (Wreathall, 2006).
- **Flexibility:** The ability of system for self-reorganization once some of expected / unexpected variations and forces from external environment(s) are faced is referred to as flexibility. Flexibility actually is an important factor to deal with unforeseen events. An organization can be considered to be resilient when it is capable to be quickly responsive to the unexpected events. Organizations can be supported by their own secondary sources and other resources in face of events and/or accidents.

2.2.Data envelopment analysis (DEA)

Data envelopment analysis (DEA) is one of the most useful technique for evaluating performance and ranking Decision Making Units (DMU) such as industries, business firms, schools, hospitals, cities, facilities layouts, banks, etc. to transform multiple inputs into multiple outputs .(Cooper, 2011). DEA is a nonparametric research technique and a mathematical optimization method based on a linear programming model. As this technique is easy to understand may have relatively considerable performance comparing to other similar evaluation methods or techniques. This property of DEA paves the way for recognizing efficient and inefficient units (Zou and Wei, 2009; Azadeh and Salehi, 2014; Serrano Cinca et al.,2006;Honma and Hu, 2013).

With respect to this approach, in 1978, the CCR output-oriented model under the assumption of constant returns to scale (CRS) was developed (Charnes et al., 1978). In addition, in 1984, on the basis of the assumption of variable returns to scale (VRS), the earlier models were improved and the BCC model was introduced (Banker et al, 1984

2.2.1. The CCR Model:

Basically, the CCR output-oriented model is to maximize the outputs so that the inputs of model to be constant. As the Eq.(1) –Eq. (4) also show, specifically; in the present study, we are interested in performance evaluation of forty DMUs with nine outputs (represented by x) and one dummy input (represented by y), respectively

$$\text{Max } \theta \tag{1}$$
s.t.
$$x_{i0} \geq \sum_{j=1}^{40} \lambda_j x_{ij} \qquad i=1 \tag{2}$$
$$\theta y_{r0} \leq \sum_{j=1}^{40} \lambda_j y_{ij} \qquad r=1,\ldots,9 \tag{3}$$
$$\lambda_j \geq 0 \tag{4}$$

With respect to the model above, x_ij represents the value of ith input for jth DMU. Moreover, y_ij is to express the value of rth output for jth DMU. In addition, x_i0 and y_r0 also represent ith input and rth output value for target DMU, respectively.

Regarding the CCR model above, the constraint (2) clearly expresses that the weighted sum of inputs cannot be more than value of ith input for target DMU, x_i0 . Also, constraint (3) implies that the weighted sum of outputs must be more than ɵy_r0 where ɵ denotes the efficiency score of each DMU. Moreover, the constrain (4) is also to impose the non-negativity restriction.

2.2.2. BCC Model:

$$\text{Max}\theta$$
s.t.
$$x_{i0} \geq \sum_{j=1}^{40} \lambda_j x_{ij} \qquad i=1$$
$$\theta y_{r0} \leq \sum_{j=1}^{40} \lambda_j y_{ij} \qquad r=1,\ldots,9$$
$$\lambda_j \geq 0$$
$$\sum_{j=1}^{40} \lambda_j = 1$$

2.3.Relevant Works

In context of nuclear power plants, on the basis of principles of Resilience Engineering (RE), Carvalho et al. (2008) proposed an appropriate framework in three levels of nuclear power plants to properly handle micro incidents. The proposed framework is capable to accurately predict control actions of operators and establish processes required to obtain probability of the impact of some undesirable outcomes in system. Dolif et al. (2013) were the first to try to use the principles of RE in order to predict heavy rains in Rio de Janeiro. Results of their research indicate that "tacit knowledge" of experts should also be regarded as one critical factor of resilience. Gomes et al. (2009) used RE in the helicopter transportation system for the Campos Basin oil fields in Brazil so as to understand how the system could be resilient or brittle while some kinds of economic pressures are imposed to the system. Moreover, in view of Gomes et al. (2009), RE can be helpfully utilized for situations in which the system has to experience some high demands. Huber et al. (2009) addressed the important inquiry that whether a given systems /organization has an enough capacity to deal with changing nature of operational risks or not. To answer such a critical question, they applied RE concept and considered the results for a chemical company site. The results indicated that an effective factor in performance of system safety is system dynamic capacity and it can be effectively used to improve the risk models. Jeffcott et al.(2009) used RE in clinical handover to consider development of measurement, improvement, and anticipation tools using recognizing methods for evaluating resilience in health and care systems. Park et al. (2013) defined the term of "Resilience" as a consequence of a recursive process that includes; "Sensing", "Anticipation", "Learning", and "Adaptation". Moreover, in order to further clarify successes and/or challenges the resilience approach may face, management of behavior of complex natural systems is also presented. In that regard, as a specific case, management of the 2011 flooding in the Mississippi River Basin is discussed. Steen et al. (2011) concluded that old ways of risk cannot be regarded as proper solutions. To deal with different kinds of operational risks, they propose the RE and define RE as a new perspective of risk management. They emphasizes that RE, as a good solution, encompasses all recognition sources, causes analysis, vulnerabilities analysis, resilience analysis and risk description. Shirali et al. (2012) emphasized the significant importance of risk management and safety in chemical plants. To deal with the safety problems in chemical plants, they proposed the RE as an effective tool for recognizing safety problems and challenge in chemical plants. "lack of certain experiments about RE", "vagueness of RE level", "selection of production without safety", "lack of reporting systems", "religious opinions", "old methods and handbooks", "weak feedback loops", and some of "economic issues" are all introduced as main challenges the chemical plants managers usually face in ensuring the safety requirement. Shirali et al. (2013) were the first to mention the lack of quantitative evaluation of RE as a gap in safety management studies. To deal with this gap, they proposed a new quantitative approach. They designed a questionnaire and distributed it among 11 units which belong to a specific process industry. On the basis of results six important factors including "top management commitment", "Just culture", "learning culture", "awareness and opacity", "preparedness", and "flexibility" are identified. Following identifying these six factors, the principal component analysis (PCA) approach is employed and the data gathered were accurately analyzed. Saurin et al. (2011) employed principles of RE in context of electric power industry to develop a more effective approach for evaluating health and safety of the management system. Dinh et al. (2012) independently introduced other principles or factors so as to assess resilience of a process. "Detection Potential", "Design", "Human Factor", "Emergency Response Plan", and "Safety Management" are all suggested as essential factors necessary for evaluating resilience of the process. Further, "Controllability", "Flexibility", "Minimization of Failure", "Early Detection", "Administrative Controls/Procedures", and "Limitation of Effects" are also introduced as basic principles required for assessing the resilience of a process.

3. Methodology

In this study, for the purpose of clarifying the role of Integrated Resilience Engineering (IRE) concept and Data Envelopment Analysis (DEA) technique in evaluating performance of information systems developed to support all of banking services and\or activities, we take the following steps, in turn. As the first step, in order to assess performance of information system which is to effectively support some kinds of banking services and/or activities, a standard questionnaire is designed on the basis of principles and concepts of IRE. At the second step, we need to make us sure of content validity. Regarding this step, if result of the validity test is satisfying, we can go to the next step. Otherwise, we have to go back to the step one. As the third step, all required data are collected. For this purpose, the questioner, designed at the previous step, as the main tool of this study to gather all its required data, is actively used. Concerning this step, top, middle, and low-level managers of the bank organization are considered to be survey participants of the study. At the fourth step, the reliability test is performed. Regarding this step, if result of the reliability test is ok, we can go to the next step. Otherwise, we have to go back to the step one. At the fifth step, for the purpose of utilizing the DEA technique, **"**Management

Commitment", "Reporting Culture", "Learning Culture", "Awareness", "Flexibility", "Redundancy", "Fault-tolerant", "Self-organization", and "Teamwork" are all defined as the "outputs" and, on the other hand, one "dummy variable" is given as the "input". As the sixth step, following defining outputs and inputs at the previous step, we use the DEA models to determine the most appropriate DEA model. Regarding this step, "executive managers" of different branches of the concerned bank are considered to be the Decision Making Units (DMUs). At the seventh step, we determine the most appropriate DEA model based upon highest value for average efficiency and alpha value of the normality test. Eighth step is to select the most efficient DMU based on ranks reported for the DMUs. At step ninth, sensitivity analysis is performed to recognize significant IRE factors. At this step, one of IRE factors is removed and the DEA model is run again. At tenth step, we need to obtain weight of each factor. Specifically, in the present study, for the purpose of obtaining the weight of each of factors, we need to obtain percentage changes in efficiency score of the concerned factor. As the eleventh step, the Bartlett and Normality Test for the efficiency of each factor are performed. At the next step (twelfth step), we need to make sure of normality distribution of the residuals. Concerning this step, if the residuals follow a specific normal distribution, we can go to the next step and run Paired t-test. Otherwise, we have to go to the next step thirteenth and perform kruskal-wallis test.

3.1.The Questionnaire Design

In present study, for the purpose of learning about opinions of the participants of the study, a standard questionnaire is designed. This questionnaire, specially designed for this study is the main instrument of the research and consists of a series of standard questions. These standard questions are to elicit all specific information and/or data from the respondents.

With respect to the prepared questionnaire (refer to Appendix I), it should be noted that the all included questions designed based on the all nine factors (principles) of the IRE concept. The questionnaire consists of two sections. The first section is to collect demographic information including "age" and "education" of the respondents. The second section is to study the nine basic factors (principles). Following distributing the questionnaire among about forty individuals of managers, who are responsible at different levels of organization of the concerned the bank, all the required real raw data are provided. Results obtained from analysis of the questionnaire are presented in the Appendix II.

3.2.Reliability and Content Validity of the Questionnaire

The reliability of the questionnaire is examined based on the Cronbach's coefficient alpha. In addition, the content validity of the questionnaire is also approved based on both "elites' points of view" and "principles and/or theories discussed in the relevant literatures".

4. Experiment

The experiment is executed in different branches of the concerned banks. The prepared standard questionnaire is distributed and performance of information system is evaluated by employing IRE and DEA models. Indeed, DEA models are usefully employed to identify performance of the IRE model especially developed for the present study. In this regard, IRE factors are considered to be the outputs of the DEA model. Clearly, the main objective of the study is to evaluate performance of information system and identify important IRE factors for the specific case concerned in this study.

Fig1. Methodology of the Study in Algorithmic Display

4.1.Data collection

The answer sheet particularly designed for the questionnaire is, in fact, a ruler marking between 1 and 10 (two numbers 1 and 10 represent very low and very high value, respectively). In addition, the response included continuous numbers. As mentioned earlier, about performance of the information system in different branches of the concerned bank, forty individuals of the managers were inquired.

4.2.Test of Reliability on the Questionnaire

In order to assess the reliability of the questionnaire, Cronbach's alpha is computed using statistical software package SPSS 22.0. For this study, on the basis of the collected data, considering twenty inquiries, the value of Cronbach's alpha is equal to 0.8271 and it is acceptable.

5. Results

5.1. Results of DEA

In order to evaluate performance of all involved unites by running the DEA model, all nine IRE factors are considered to be the “outputs” and, on the other hand, the defined “dummy variable” is given as the “input” of the model. To run the full ranking BCC and CCR output-oriented model, Auto Assess is effectively used.

Results obtained from running full ranking output-oriented DEA model is given in Table1. According to Table 1, the efficiency and rank of each DMU is also reported. In addition, the value of efficiency score for each DMU indicates performance of the information system developed in each branch of the concerned bank.

Table 1. Results obtained from running full ranking output-oriented DEA model

DMU	CCR model		BCC model		DMU	CCR model		BCC model	
	Efficiency	Rank	Efficiency	Rank		Efficiency	Rank	Efficiency	Rank
1	0.975	29	0.975	29	21	0.906389	39	0.906389	39
2	0.981752	27	0.981752	27	22	0.991416	25	0.991416	25
3	0.971264	32	0.971264	32	23	1	19	1	19
4	1	17	1	17	24	1.022727	7	1.044444	7
5	1	18	1	18	25	1.047512	2	1.088854	2
6	1.028818	4	1.055556	4	26	1	20	1	20
7	0.880499	40	0.880499	40	27	0.991891	24	0.991891	24
8	0.979021	28	0.979021	28	28	1.018741	9	1.035714	8
9	1.044776	3	1.085714	3	29	1.025641	6	1.05	6
10	1.027027	5	1.052632	5	30	1	21	1	21
11	0.925	37	0.925	37	31	1.003636	15	1.007143	15
12	1.062607	1	1.117528	1	32	0.965722	34	0.965722	34
13	1.010986	13	1.020919	13	33	0.993548	23	0.993548	23
14	1.017544	10	1.034483	10	34	0.975	30	0.975	30
15	0.956591	35	0.956591	35	35	1	22	1	22
16	0.973684	31	0.973684	31	36	0.987924	26	0.987924	26
17	0.95	36	0.95	36	37	1.013907	12	1.026471	12
18	1.015798	11	1.030435	11	38	1.018834	8	1.035546	9
19	0.966402	33	0.966402	33	39	1.008681	14	1.016425	14
20	0.920821	38	0.920821	38	40	1.001906	16	1.003661	16

Now, in order to find the best DEA model, we have to consider the both normality test' alpha and average efficiency. The results of such considerations are shown in Table 2. Furthermore, the probability plot of BCC and CCR are also shown in Fig.2 and Fig.3, respectively.

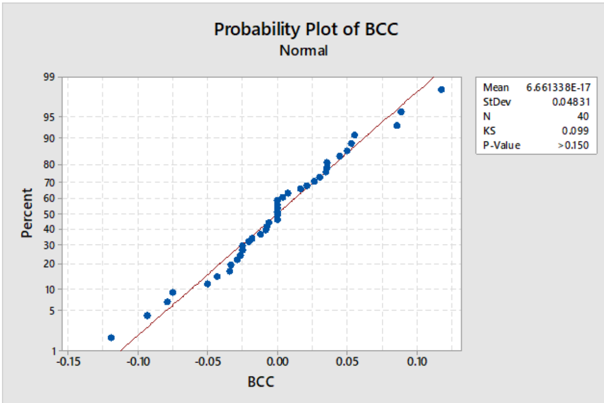

Fig 2. Results of Normality Test for BCC Model

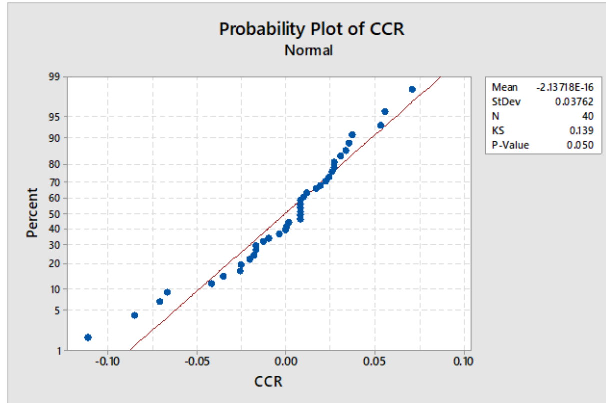

Fig 3. Results of Normality Test for CCR Model

Table 2. Average efficiency and Normality test 'alpha for full ranking output-oriented DEA model.

DEA model	BCC	CCR
Normality test's alpha	>0.15	0.05
Average efficiency	0.999936	0.991527

As can be seen in Table 2, comparing with CCR model, the average efficiency and the normality test's alpha of the BCC model are relatively higher. Hence, for this case, we utilize the BCC model to evaluate the performance of the DMUs under study. On the basis of the results reported for the BCC model, DMU 12 has the highest value of efficiency. Therefore, since any DMU with the efficiency score less than 1 should be regarded as an inefficient unit, applying policies and conditions of DMU 12 could be recommended as a good solution to achieve a better performance of IRE factors in their branch.

5.2.Sensitivity Analysis

Regarding this particular case of the study, we perform a sensitivity analysis to recognize significant IRE factors. During this analysis, at each run, one factor should be removed and this process is repeated nine times. The results are presented in Table 3.

Table 3. Results of sensitivity analysis for each factor

DMU	management commitment	reporting culture	learning culture	awareness	Flexibility	teamwork	Redundancy	self-organization	Fault tolerant
1	0.975	0.975	0.975	0.975	0.975	0.975	0.975	0.975	0.9
2	0.968085	0.981752	0.981752	0.981752	0.981752	0.975806	0.981752	0.981752	0.981752
3	0.971264	0.971264	0.962585	0.964912	0.971264	0.970443	0.971264	0.971264	0.971264
4	1	1	1	1	1	1	0.939914	1	1
5	1	1	1	1	0.999008	1	1	1	1
6	1.055556	1.026316	1.055556	1.055556	1.055556	1.042784	1.055556	1.05	1.055556
7	0.880499	0.880499	0.880499	0.879599	0.880499	0.879699	0.87798	0.87878	0.880499
8	0.979021	0.979021	0.979021	0.979021	0.979021	0.979021	0.962437	0.972222	0.979021
9	1.078571	1.085714	1.085714	1.04	1.085714	1.085714	1.085714	1.085714	1.085714
10	1.052632	1.052632	1.009852	1.052632	1.052632	1.052632	1.052632	1.052632	1.052632
11	0.915254	0.925	0.925	0.925	0.925	0.925	0.925	0.925	0.925

12	1.089677	1.117067	1.099693	1.117528	1.117528	1.117528	1.098366	1.117528	1.110338
13	1.020919	1.015238	1.020919	1.020919	1.020919	1.014	1.006218	0.990394	1.020919
14	1.034483	1.034483	1.034483	1.034483	1.034483	1	1.007194	1.034483	1.034483
15	0.954545	0.895105	0.95	0.956591	0.956591	0.956591	0.956591	0.956591	0.956591
16	0.973684	0.973684	0.827193	0.973684	0.973684	0.973684	0.973684	0.973684	0.973684
17	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.88
18	1.030435	1.017073	1.030435	1.02459	1.030435	1.030435	1.030435	1.021127	1
19	0.965164	0.966402	0.966402	0.9375	0.966402	0.966402	0.952273	0.966402	0.966402
20	0.920821	0.920821	0.9125	0.920821	0.920821	0.920821	0.920821	0.917219	0.905325
21	0.906389	0.906389	0.888889	0.906389	0.906389	0.90411	0.905325	0.906389	0.906389
22	0.990169	0.991416	0.991416	0.991416	0.991416	0.983333	0.989051	0.991416	0.991416
23	1	1	1	1	1	1	0.9625	1	1
24	1.028169	1	1.044444	1.044444	1.044444	1.044444	1.044444	1.044444	1.044444
25	1.088854	1.088854	1.068256	1.088854	1.085094	1.086754	1.088854	1.016949	1.088854
26	1	1	1	1	1	1	1	1	0.976705
27	0.986272	0.980564	0.991344	0.991891	0.991891	0.991891	0.989844	0.965396	0.991772
28	1.035714	1.012294	1.035714	1.035714	1.035714	1.035714	1.035714	1	1.035714
29	1.05	1.05	1.05	1.05	1.05	1.05	1.05	0.9875	1.05
30	1	1	1	1	1	1	0.997373	0.95	1
31	1.007143	1.007143	1.007143	1.007143	1.007143	0.963047	1.007143	1.007143	1
32	0.965625	0.965722	0.965722	0.965722	0.965722	0.9633	0.963287	0.95	0.960686
33	0.993548	0.993548	0.993548	0.993548	0.991517	0.993548	0.993548	0.9875	0.970546
34	0.975	0.975	0.975	0.975	0.975	0.975	0.975	0.975	0.932306
35	1	1	1	1	1	1	0.913907	1	1
36	0.970283	0.987924	0.987924	0.987924	0.987924	0.987924	0.985675	0.9625	0.982114
37	1.020432	1.026471	1.026471	1.026471	1.026471	1.0264	1.026471	1	1.007746
38	1.035519	1.014085	1.017841	1.035546	1.035546	1.035546	1.030612	0.993506	1.035546
39	1.015907	1.00576	1.016247	1.016019	1.01271	1.016425	1.016425	0.988345	1.007036
40	1.003661	1	1	1.003661	1.003661	1.002347	1.003661	1	0.997089

According to the Table 3, at column 1, management commitment is to be omitted from the factors list and, therefore, this column is to report the efficiency score for each DMU without the management commitment factor. Moreover, in order to identify the significant IRE factors, we need to also obtain the average efficiency of each column of the Table 3 (each IRE factor to be omitted) as well. Results of this consideration are shown in Table 4.

Table 4 .Average efficiency of each omitted factor on the basis of results of sensitivity analysis.

Deleted factors								
Management commitment	reporting culture	learning culture	awareness	flexibility	teamwork	redundancy	Self-organization	Fault tolerant
0.99720741	0.994306	0.99266407	0.99773327	0.99967379	0.99688363	0.99254167	0.98864701	0.99143861

Furthermore, the difference between total average efficiency (obtained based on nine IRE factors) and average efficiency obtained from removing each of IRE factors (reported in Table 4) is also given in Table 5.

Table 5. Difference between average efficiency before and after factor deletion.

Omitted factor

management commitment	reporting culture	learning culture	awareness	flexibility	teamwork	redundancy	self-organization	Fault tolerant
0.00272885	0.00563025	0.00727219	0.00220298	0.00026247	0.00305263	0.00739459	0.01128924	0.00849764

According to Table 5, it is concluded that deletion of self-organization, fault tolerant, redundancy, learning culture, reporting culture have largest impact on average efficiency, respectively. Hence, for this specific case of study, on the basis of the results obtained from the sensitivity analysis, all these factors should be referred to as critical factors.

5.3.Weight of Factors

Due to the results of sensitivity analysis, it is necessary to obtain the weight of each IRE factor via percentage changes in efficiency score of the factor. Results are shown in Table 6. In order to summarize results presented in Table 6 and provide a good visualization of the results, showing the results as a pie chart seems to be useful (Fig. 4). As seen in Fig.4, weight of the self-organization factor is reported 23 percent. This means considerable significance of this factor in creating performance efficiency.

Table 6. Weight of each IRE factor

weight factors								
Management commitment	reporting culture	learning culture	awareness	flexibility	teamwork	redundancy	Self-organization	Fault tolerant
0.0564619	0.11649397	0.15046679	0.04558131	0.00543067	0.06316107	0.152999331	0.233582595	0.17582235

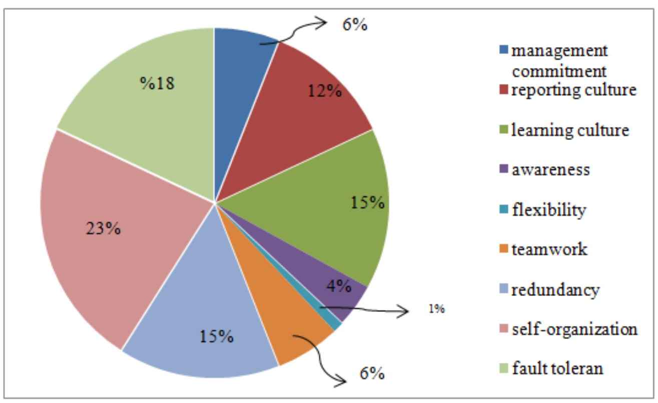

Fig 4. Weight of each IRE factor

5.4.Statistical Analysis

At this section, effect of deletion of the factors is examined. For this purpose, both “normality test” and “variances equality test (Bartlett’s test)” are performed using MINITAB. As seen in Table 7, normality and variance equality of each factor are approved. Hence, the paired t-test can also be carried out by MINITAB. Table 8 shows results of paired t-test. On the basis of results presented in Table 8, deletion factors can significantly affect the efficiency.

6%

Table 7. Results of test of Normality and Bartlett's test

	Management commitment	reporting culture	learning culture	awareness	flexibility	teamwork	redundancy	Self-organiz ation	Fault tolerant
p-value (Normality test)	>0.15	0.098	0.139	> 0.15	> 0.15	0.088	> .15	> 0.1	>0.15
p-value (Bartlett's test)	0.851	0.99	0.495	0.92	0.98	0.977	0.807	0.655	0.4478

Table 8.Results of paired t

Paired t(P-value)								
management commitment	reporting culture	learning culture	awareness	flexibility	teamwork	redundancy	self-organization	Fault tolerant
0.004	0.005	0.032	0.054	0.034	0.018	0.006	0.000	0.002

6. Discussion and Conclusion

Resilience engineering (RE) is a new idea to modify the risk models and improve the safety requirement of complex systems, especially where systems have to operate under different economic pressures and/or various safety challenges. While most of traditional methods of risk management are mainly based upon estimation of probability of failure, Resilience Engineering (RE) seeks for ways to increase capability of systems and develop processes which are flexible and robust enough. Concerning developing proper risk models, in order to improve performance of safety and human resources in complex systems, additional elements are suggested to be added to the basic factors of RE framework. This model is commonly referred to as Integrated Resilience Engineering (IRE). IRE framework is regarded as a sound solution to more effectively cope with operational risks which may arise in operational environments associate with complex and large systems, particularly socio-economic systems.

In recent years, due to severe economic circumstances in the world, safety of "banking system" is highlighted. In fact, due to "high impact of operational risks particularly posed from associated operational environments to the banking systems", "the need to have a good model to provide successful forecasts for different types of operational risks", "significance of ability and skill of banking systems to foresee the future and adjust themselves to deal with any sudden breakage", and "the necessity of capability of the banking system to successfully launch all its essential processes under both foreseen and unforeseen conditions", it is clarified that utilization of basic principles of IRE in order to study safety requirement of banking systems is helpful. Indeed, attempts to apply IRE principles to the safety management of banking systems may pave the way for returning banking systems to the normal state and reaching a resilient banking system.

This study addressed "information system" of a large bank (with several branches), as the concerned case. In order to evaluate resiliency of the information system of this bank, performance of the system is given to be considered. In order to make the concerned system more strong against different kinds of operational risks and improve performance of the system, this study applied all nine principles of Integrated Resilience engineering (IRE) to the system. Results of the study indicated that integrated resilience engineering (IRE) is capable of returning banking systems to normal state, especially in extensive economic circumstances. It was also shown that the proposed integrated design provides higher efficiency than conventional resilience engineering design.

Results of sensitivity and perturbation analysis indicate that self-organization, fault tolerance and reporting culture respectively compose about 50 percent of total weight.

Table 9. Compare this study with other studies.

Studies	Features								
	Resilience factors	Practicability in real world cases	Multiple inputs and outputs	Sensitivity analysis	Optimization	Data complexity and non-linearity	exploration of important factors	Validation of the proposed model	computed weight RE factors
This study	✓	✓	✓	✓	✓	✓	✓	✓	✓
Azadeh et al. (2013)	✓	✓	✓		✓	✓			
Steen et al. (2011)		✓	✓						
Shirali et al. (2013)	✓	✓			✓	✓			
Saurin et al (2011)	✓	✓	✓		✓	✓			
Dolif et al. (2013)		✓			✓				

Appendix I. The Questionnaire

Age
Education:
Please, give a score between 1 and 10 to each inquiry.
Note: 1 implies very low, 10 implies very high

Management commitment	
1	Does your boss often appreciate your work and have you been sense that?
2	Does your boss often appreciate your work and have you been sense that?
reporting culture	
3	Does “the Information Flow” in the information system, submit the usual requirements for security and authorized access of your bank?
4	How do you Evaluate the existing information system about quality and quickness in responding to costumers?
learning culture	
5	Have you learned about the existing information system in your bank
6	Do you think the trainings have resulted in professional behavior of staff to customers
awareness	

7	How much do you think the long term and short term goals of the bank have been transferred to the customers? Are the goals defined clear in the service design?
8	What is your evaluation of presentation and explanation of service quality development plan
9	Are there any instruction in the organization to warn staff about cyberattack in information systems
flexibility	
10	do the existing information system have the ability to control and monitor their own performance ?(for example in the data entry process, if you enter unhallowed data, then the system automatically warn you)
11	if any problem occurs in a part of the information system how many alternative have been considered? (For example an available staff in the software department do that part of the job or the software have the ability to do that by itself)
12	In the condition of leaving a specific position by a client, is there any other staff to do the job simultiously
teamwork	
13	In the condition of extra load work, do the personnel have the ability to help each other to handle the jobs
14	do the staff compensate miss function of each other in order to direct the organization to their goals
redundancy	
15	Are there any alternative solution in the organization when a part of information system crashes?
16	is there any alternative for staff in the condition of absence of anyone
self-organization	
17	If your bank faces with a unpredicted events e.g. a cyberattack, are there any experienced expert to deal with the problem?
18	How possible will be it for you to solve the problem, if you face a problem while working with information systems such as problems caused by user faults, software defects or faults from Infrastructure in use? (without getting involve organization procedures)
fault-tolerant	
19	if a part of information systems in your bank do not work, is your system capable of continuing the work, based on the design it has been created?

20	If a part of substantial components (e.g. servers, soft wares ...) face a problem or a defect, does the system has capability to continue the work for a specific period (enough time to repair)?

Appendix II. Raw data

DMU	Management commitment		reporting culture		learning culture		awareness			flexibility		teamwork			redundancy		Self-organization Fault tolerant			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
1	5	8	8	6	8	5	6	4.5	5	9	8	7	9	6.5	4	6	7	5.5	9	10
2	10	8	7	7	6	8.5	8	8	9	8	7	9	9	9.5	8	6.5	9	7.5	7	6.5
3	5	7	8	6	8	9	10	9	7	10	7	10	8	9	9	5	7	6	8	8
4	9	7	9	8	5	5	7	8	8	6	8	8	5	8.5	9	9	5	8	8	8.5
5	9.5	10	10	9	3	6	8	10	9	10	10	10	9	9	5	7	9	5	8	9
6	6	6	10	10	7	8	9	8	10	10	10	10	10	10	8	8	7	10	8	9.5
7	5	5.5	5	8	7.5	5.5	7	7	6	6	6	6.5	7	7.5	7	6	6	6	6	7.5
8	7	8	10	7	7.5	5.5	6	6	9	7	9	9	8	10	9	8	7	8	8	5
9	10	10	8	10	9	7	10	10	10	10	8	10	9	10	8	6	8	9	7	8
10	8	8	9	9	9	10	10	9	9	10	8	9	8	8	9	8	9	7	9	8
11	8	9	7	5	7	5	3	4	3	9	8	7	9	7	6	4	6	5	8	8
12	10	10	10	9	10	8	8	9	10	10	10	10	10	9	9	9	10	5	10	10
13	8.5	8	8	10	7	5	8	6	9	9	9.5	8	9	10	8	9	9	9	8	9.5
14	6	3.5	7	3	8	8	9	6	6	7	10	10	10	10	8	10	6	4	5	5.5
15	5	8	9	9	8	6	6	7	5	6	5	8	9	6	6.5	5.5	5	6	8	7.5
16	6	4	7	3	10	8	2.5	8	8	7	4	3	8	4.5	4	5.5	3	1	5	4.5
17	6.5	5	4	2	8	6	4	5.5	8	9	6	1	2	3	6	4	6	7	9	9
18	8	2	10	10	5.5	4.5	9	7	10	10	6	10	10	8	6	10	9	8	10	10
19	7.5	10	7	8	7	8	9	9.5	8	6	6	5.5	5	6	8	7	4	6	8	8
20	4	7	8	4	8.5	6.5	4	1	4	6	5	3	9	5	4.5	5.5	6	7	8	8.5
21	6	3	7	6	6	9	7	5	8.5	4	8	9	6	8	9	5	5	5	5	5.5
22	10	7	8	6	8	8	6	8	6	9	10	10	10	9	8	9	9	6	8	8
23	7	4	8	8	8	6	4	7	9	8	5	9	8	9	10	8	5	6	9	9.5
24	10	10	10	10	3.5	2.5	6	7	10	10	10	10	10	8	10	5	10	5	10	10
25	7	10	8	7	8	10	6	10	10	10	10	10	10	9.5	8.5	7.5	10	9	9	9
26	8.5	7	10	8	4.5	5.5	3	4	3	2	7	7	5	6.5	8.5	6.5	7	10	10	10
27	8	8	9	9	9	6	4	5	4	3	8	7	6	8.5	8	7	8	10	9	9
28	7	8	10	9	8	5	6	5	4	3	8	8	7	8	6	8	9	10	10	10
29	6.5	8	8	6	9	5	4	5	6	5	9	10	5	8	8	7	10	10	10	9.5
30	5	8	8	8	10	6	4	5	6	6	9	8	7	7.5	8	8	10	9	9	9
31	3	8	9	9	8	6	5	7	5	10	7	10	10	10	7.5	6.5	8	5	9	9
32	7	8	8	8	7	7	5	5	8	8	8	5	10	6	9	5	9	8	9	9
33	1.5	9	9	7	8	8	4	8	8	9	10	8	5	7	6	6	10	7	10	9.5
34	6	7	10	5	9	6.5	1	9	8	5	5	8	6	7	8	2	9	6	10	9
35	5	10	9	6	8	7	6	7	9	2	8	7	8	6	10	8	8	4	8	8
36	8	10	9	8	7.5	5.5	3	8	8	7	6	9	8	8	10	3	8	9	10	8.5
37	8	10	9	9	9	7	4	6	6	6	9	9	9	9	6	4	10	8	10	10
38	7.5	8	10	9	8	9	9	9	5	4	10	6	7	8	8	9	10	8	9	9
39	5	9	10	9	7	7	7	8	9	10	10	7	10	7	9	5	9	9	10	9.5
40	6.5	8	9	10	9	8	5	8	7	8	6	9	10	8.5	8	5	9	7	10	10

References

- Abech, M. P., Berg, G., Delis, M. G., Guimaraes, L., and Woods, D. D. (2006, April). Analyzing resilience of an oil distribution plant. In *Systems and Information Engineering Design Symposium, 2006 IEEE,* pp. 216-221
- Azadeh, A., and Salehi, V. (2014). Modeling and optimizing efficiency gap between managers and operators in integrated resilient systems: The case of a petrochemical plant. *Process Safety and Environmental Protection*, 92(6), pp. 766-778.
- Azadeh, A., Foroozan, H., Ashjari, B., Motevali Haghighi, S., Yazdanparast, R., Saberi, M. and Torki Nejad, M., 2016. Performance assessment and optimization of a large information system by combined customer relationship management and resilience engineering: a mathematical programming approach. *Enterprise Information Systems*, pp.1-15.
- Azadeh, A., Ghaderi, S. F., Anvari, M., Izadbakhsh, H. R., Rezaee, M. J., and Raoofi, Z. (2013). An integrated decision support system for performance assessment and optimization of

decision-making units. *The International Journal of Advanced Manufacturing Technology*, 66(5-8), pp. 1031-1045.
- Azadeh, A., Ghaderi, S. F., Anvari, M., Izadbakhsh, H. R., Rezaee, M. J., and Raoofi, Z. (2013). An integrated decision support system for performance assessment and optimization of decision-making units. *The International Journal of Advanced Manufacturing Technology*, 66(5-8), pp. 1031-1045.
- Azadeh, A., Haghighi, S. M., & Salehi, V. (2015). Identification of managerial shaping factors in a petrochemical plant by resilience engineering and data envelopment analysis. *Journal of Loss Prevention in the Process Industries*, 36, pp. 158-166.
- Azadeh, A., Rouzbahman, M., Saberi, M., and Valianpour, F. (2014). An adaptive algorithm for assessment of operators with job security and HSEE indicators. *Journal of Loss Prevention in the Process Industries*, 31, 26-40.
- Azadeh, A., Salehi, V. and Salehi, R., 2016. A resilience-based model for performance evaluation of information systems: the case of a gas company. *Enterprise Information Systems*, pp.1-15.
- Azadeh, A., Salehi, V., Arvan, M., and Dolatkhah, M. (2014). Assessment of resilience engineering factors in high-risk environments by fuzzy cognitive maps: A petrochemical plant. *Safety Science*, 68, pp. 99-107.
- Banker, R. D., Charnes, A., and Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management science*, *30*(9), pp. 1078-1092.
- Carvalho, P. V., dos Santos, I. L., Gomes, J. O., and Borges, M. R. (2008). Micro incident analysis framework to assess safety and resilience in the operation of safe critical systems: a case study in a nuclear power plant. *Journal of loss prevention in the process industries*, *21*(3), pp. 277-286.
- Charnes, A., Cooper, W. W., and Rhodes, E. (1978). Measuring the efficiency of decision making units. *European journal of operational research*, *2*(6), pp. 429-444.
- Cooper, W. W., Seiford, L. M., and Zhu, J. (2011). *Handbook on data envelopment analysis* (Vol. 164). Springer Science & Business Media.
- Costella, M. F., Saurin, T. A., and de Macedo Guimarães, L. B. (2009). A method for assessing health and safety management systems from the resilience engineering perspective. *Safety Science*, *47*(8), pp. 1056-1067.
- Dekker, S., Hollnagel, E., Woods, D., and Cook, R. (2006). Resilience Engineering: New directions for measuring and maintaining safety in complex systems. *The second Progress Report*.
- Dinh, L. T., Pasman, H., Gao, X., and Mannan, M. S. (2012). Resilience engineering of industrial processes: Principles and contributing factors. *Journal of Loss Prevention in the Process Industries*, *25*(2), pp. 233-241.
- Dolif, G., Engelbrecht, A., Jatobá, A., da Silva, A. J. D., Gomes, J. O., Borges, M. R., ... and de Carvalho, P. V. R. (2013). Resilience and brittleness in the ALERTA RIO system: a field study about the decision-making of forecasters. *Natural hazards*, *65*(3), pp. 1831-1847.
- Fiksel, J., Polyviou, M., Croxton, K. L., and Pettit, K. J. (2015) From risk to resilience: Learning to deal with disruption, *MIT Sloan Management Review*, Winter Issue.
- Gilmour, G., 2006. Open Assessment Training Tools for Resilience Engineering .http://gavin.brokentrain.net/upload/scs-final-29 11 06.pdf (21.10.12).

- Golgeci, I., and Ponomarov, S. Y. (2013) Does firm innovativeness enable effective responses to supply chain disruptions? An empirical study, *Supply Chain Management: An International Journal*, 18(6), pp. 604–617.
- Gomes, J. O., Woods, D. D., Carvalho, P. V., Huber, G. J., and Borges, M. R. (2009). Resilience and brittleness in the offshore helicopter transportation system: the identification of constraints and sacrifice decisions in pilots' work. *Reliability Engineering & System Safety*, *94*(2), pp. 311-319.
- Haimes, Y. Y. (2009). On the Complex Definition of Risk: A Systems-Based Approach. *Risk analysis*, *29*(12), pp. 1647-1654.
- Herrera, I.A., Hollnagel, E., Habrekke, S., (2010). Proposing safety performance indicators for helicopter offshore on the Norwegian Continental Shelf. *In: Proceedings of the 10th International Probabilistic Safety Assessment & Management Conference*, Seattle, USA.
- Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, pp. 1-23.
- Hollnagel, E., Woods, D.D., 2006. In: Hollnagel, E., Woods, D.D., Leveson, N. (Eds.), Epilogue: Resilience Engineering Concepts, Resilience Engineering: Concepts and Precepts. *Ashgate Publishing Co.*, Aldershot, pp. 347–358.
- Hollnagel, E. (2011). RAG – The resilience analysis grid. In: E. Hollnagel, J. Pariès, D. D.Woods and J. Wreathall (Eds). Resilience Engineering in Practice. *A Guidebook. Farnham, UK: Ashgate.*
- Hollnagel, E., Woods, D.D., Leveson, N., 2007. Resilience Engineering: Concepts and Precepts. *Ashgate Publishing, Ltd.*
- Honma, S., and Hu, J. L. (2013). Total-factor energy efficiency for sectors in Japan. *Energy Sources, Part B: Economics, Planning, and Policy*, *8*(2), pp. 130-136.
- Huber, S., van Wijgerden, I., de Witt, A., and Dekker, S. W. (2009). Learning from organizational incidents: Resilience engineering for high-risk process environments. *Process Safety Progress*, *28*(1), pp. 90-95.
- Jeffcott, S. A., Ibrahim, J. E., and Cameron, P. A. (2009). Resilience in healthcare and clinical handover. *Quality and Safety in Health Care*, *18*(4), pp. 256-260.
- Ling-Ling, F., and Yong-Duan, S. (2010). On fault-tolerant control of dynamic systems with actuator failures and external disturbances. *Acta Automatica Sinica*, *36*(11), pp. 1620-1625.
- Malaek, S. M.B., Mollajan, A., Ghorbani, A. and Sharahi, A., "A New Systems Engineering Model Based on the Principles of AxiomaticDesign," Journal of Industrial and Intelligent Information, 2014, Vol. 3, No. 2, pp. 143-151.
- Melnyk, S. A., Closs, D. J., Griffis, S. E., Zobel, C. W., and Macdonald, J. R. (2014) Understanding supply chain resilience, *Supply Chain Management Review*, Jan/Feb2014, 18(1), pp. 34–41.
- McDonald, N. (2006) Organisational resilience and industrial risk. *E. Hollnagel, D.D. Woods and N. Leveson, eds. Resilience engineering: concepts and precepts*, Hampshire: Ashgate, pp. 155–179.
- Morel, G., Amalberti, R., and Chauvin, C. (2009). How good micro/macro ergonomics may improve resilience, but not necessarily safety. *Safety Science*, *47*(2), pp. 285-294.
- Saurin, T. A., and Júnior, G. C. C. (2011). Evaluation and improvement of a method for assessing HSMS from the resilience engineering perspective: A case study of an electricity distributor. *Safety Science*, *49*(2), pp. 355-368.

- Saurin, T. A., and Junior, G. C. C. (2012). A framework for identifying and analyzing sources of resilience and brittleness: a case study of two air taxi carriers. *International Journal of Industrial Ergonomics*, *42*(3), pp. 312-324.
- Serrano Cinca, C., Mar Molinero, C., and Chaparro García, F. (2006). Behind DEA efficiency in financial institutions.
- Sharahi, A. ; Tehrani, R. ; Mollajan, A. (2014), 'An Axiomatic Model for Development of the Allocated Architecture in Systems Engineering Process', World Academy of Science, Engineering and Technology, International Science Index, Industrial and Manufacturing Engineering, 1(10), 319.
- Shirali, G. H. A., Motamedzade, M., Mohammadfam, I., Ebrahimipour, V., and Moghimbeigi, A. (2012). Challenges in building resilience engineering (RE) and adaptive capacity: A field study in a chemical plant. *Process safety and environmental protection*, *90*(2), pp. 83-90.
- Shirali, G. A., Mohammadfam, I., and Ebrahimipour, V. (2013). A new method for quantitative assessment of resilience engineering by PCA and NT approach: A case study in a process industry. *Reliability Engineering & System Safety*, *119*, pp. 88-94.
- Steen, R., and Aven, T. (2011). A risk perspective suitable for resilience engineering. *Safety science*, *49*(2), pp. 292-297.
- Storseth, F., Tinmannsvik, R., Oien, K., 2009. Building Safety by Resilient Organization – A Case Specific Approach. *ESREL*, pp. 7–10.
- Tazi, D., Amalberti, R., 2006. Resilience of maintenance organization in a refining plant. *In: Proceedings of the Second Resilience Engineering Symposium*, Ecole des mines de Paris, France.
- Teoh, S.Y., Yeoh, W. and Zadeh, H.S., 2017. Towards a resilience management framework for complex enterprise systems upgrade implementation. *Enterprise Information Systems*, 11(5), pp.694-718.
- Vugrin, E. D., Warren, D. E., and Ehlen, M. A. (2011). A resilience assessment framework for infrastructure and economic systems: Quantitative and qualitative resilience analysis of petrochemical supply chains to a hurricane. *Process Safety Progress*, *30*(3), pp.280-290.
- Wreathall, J. (2006). Properties of resilient organizations: an initial view. *Resilience engineering concepts and precepts. Burlington, VT: Ashgate*.
- Zhang, W.J. and Lin, Y., 2010. On the principle of design of resilient systems–application to enterprise information systems. *Enterprise Information Systems*, 4(2), pp.99-110.
- Zimmermann, K. Y. L. A., Paries, J. E. A. N., and Amalberti, R. E. N. É. (2011). Distress call from the flight deck: cross-cultural survey of aviation professionals reveals perception that flight safety is decreasing. *Safety Science Monitor*, 15(2), pp. 1-10.
- Zou, L. L., and Wei, Y. M. (2009). Impact assessment using DEA of coastal hazards on social-economy in Southeast Asia. *Natural hazards*, 48(2), pp. 167-189.