Performance Improvement of Information System of a Banking System Based on Integrated Resilience Engineering Design

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

***Abstract*—**Integrated resilience engineering (IRE) is capable of returning banking systems to the 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. A 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 the conventional RE design. Results of sensitivity and perturbation analysis indicate that self-organization, fault tolerance, and reporting culture respectively compose about 50 percent of total weight.

***Keywords*—**Banking system, data envelopment analysis, DEA, integrated resilience engineering, IRE, performance evaluation, perturbation analysis.

I. Introduction

OPERATIONAL risks are considered to be important sources that can significantly exert negative effects on safety of systems and or organizations [1]. For this reason, a sound risk management can be regarded as a useful solution to effectively help management of system safety [2].

Concerning traditional risk management policies, due to its undesirable outcomes, most of managers did not invest sufficient efforts, or at least, did not conclude that risk management proceedings of their organization were successful enough [3]. 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 [4]. 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 [1]. 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 [5].

RE 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, 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 [6]. 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 RE (IRE) [7]. IRE framework is, in fact, a good solution to more effectively deal with operational risks that may arise in operational environments associated with complex and large systems, especially socio-economic systems [7].

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 [8]-[14]. 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

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considered.

The rest of the paper is organized as follows: in section 2, first of all, a brief review of RE and IRE concept is presented and, then, the principles of IRE are also discussed. Moreover, as a subsection of Section II, a brief review of 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 III is to present the methodology of the work. In Section IV, the experiment is expressed. Section V provides the computational results obtained from running the experiments on the basis of the collected data. Finally, in Section VI, conclusion and discussion are presented.

II. Literature Review

A. Principles of RE

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 [11]. 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 21st century, the RE concept was specifically employed as a useful tool to develop strategies and/or business models in dynamic positioning [8]. Nowadays, in order to meet the “safety requirement” of any complex system, the RE concept is being actively used as a particular strategic concept [15].

Regarding the RE concept, a wide variety of definitions is presented in literature. According to [11], “RE is a model that concentrates on how to support human beings deal with complexity under pressure to meet prosperity”. They define the “RE as an effort to increase capability of a complex socio-technical system to absorb or adjust to variations, disruptions, and disturbances”. In view of [16], “RE 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”. Reference [17] describes “RE” 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 [18]. 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 [19].

To introduce the principles of RE, the work accomplished by [18] was the first attempt, and six principles of RE were established. According to [18], RE relies on six key principles including “Management Commitment”; “Reporting Culture”; “Learning”; “Awareness”; “Preparedness”; and “Flexibility”. In 2014, [20] 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 [21]. 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 follows:

- **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 [21]. Moreover, the management commitment principle affirms that safety is, in fact, a core organizational value rather than a transitory priority [22].
- **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 [21].
- **Learning:** RE 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 [22]. This principle proposes that resilient systems must be conscious of what has happened.
- **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 [21].
- **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 [21].
- **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 of being 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.

B. DEA

DEA is one of the most useful techniques for evaluating performance and ranking DMUs such as industries, business firms, schools, hospitals, cities, facilities layouts, banks, etc. to transform multiple inputs into multiple outputs [23]. DEA is a nonparametric research technique and a mathematical optimization method based on a linear programming model. As this technique is easy to understand, it 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 [24]-[27].

1. The CCR Model

Basically, the CCR output-oriented model is to maximize the outputs so that the inputs of model are constant. As (1)-(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.

$$x_{i0} \geq \sum_{j=1}^{40} \lambda_j \, x_{ij} \quad i=1 \tag{2}$$

$$\theta y_{r0} \leq \sum_{j=1}^{40} \lambda_j \, y_{ij} \quad r=1,\dots,9 \tag{3}$$

$$\lambda_j \geq 0 \tag{4}$$

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. BCC Model

$$\text{Max } \theta \tag{5}$$
s.t.

$$x_{i0} \geq \sum_{j=1}^{40} \lambda_j \, x_{ij} \quad i=1 \tag{6}$$

$$\theta y_{r0} \leq \sum_{j=1}^{40} \lambda_j \, y_{ij} \quad r=1,\dots,9 \tag{7}$$

$$\lambda_j \geq 0 \tag{8}$$

$$\sum_{j=1}^{40} \lambda_j = 1 \tag{9}$$

C. Relevant Works

In context of nuclear power plants, on the basis of principles of RE, [28] proposed an appropriate framework in three levels of nuclear power plants to properly handle micro incidents. The proposed framework is capable of accurately predicting control actions of operators and establishes processes required to obtain probability of the impact of some undesirable outcomes in system. Reference [14] was 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. Reference [29] 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 [29], RE can be helpfully utilized for situations in which the system has to experience some high demands. Reference [30] addressed the important inquiry that whether a given system/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. Reference [31] 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. Reference [32] 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. Reference [5] 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 emphasize that RE, as a good solution, encompasses all recognition sources, causes analysis, vulnerabilities analysis, resilience analysis and risk description. Reference [33] 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. Reference [34] was 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. Reference [22] 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. Reference [35] 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.

III. Methodology

In this study, for the purpose of clarifying the role of IRE concept and 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 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. The eighth step is to select the most efficient DMU based on ranks reported for the DMUs. At ninth the step, 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 the 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 Tests 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.

A. The Questionnaire Design

In the 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 are 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 the distribution of 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 Appendix II.

B. 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".

IV. 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."

TABLE I
RESULTS OBTAINED FROM RUNNING FULL RANKING OUTPUT-ORIENTED DEA MODEL

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

A. 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, 40 individuals of the managers were inquired.

B. 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 20 inquiries, the value of Cronbach's alpha is equal to 0.8271 and it is acceptable.

V. RESULTS

A. 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 are given in Table I.

According to Table I, 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. 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 II. Furthermore, the probability plots of BCC and CCR are also shown in Fig. 2 and Fig. 3, respectively.

As can be seen in Table II, 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.

TABLE II
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

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.

B. 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 III.

According to the Table III, 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 Table III (each IRE factor to be omitted) as well. Results of this consideration are shown in Table IV.

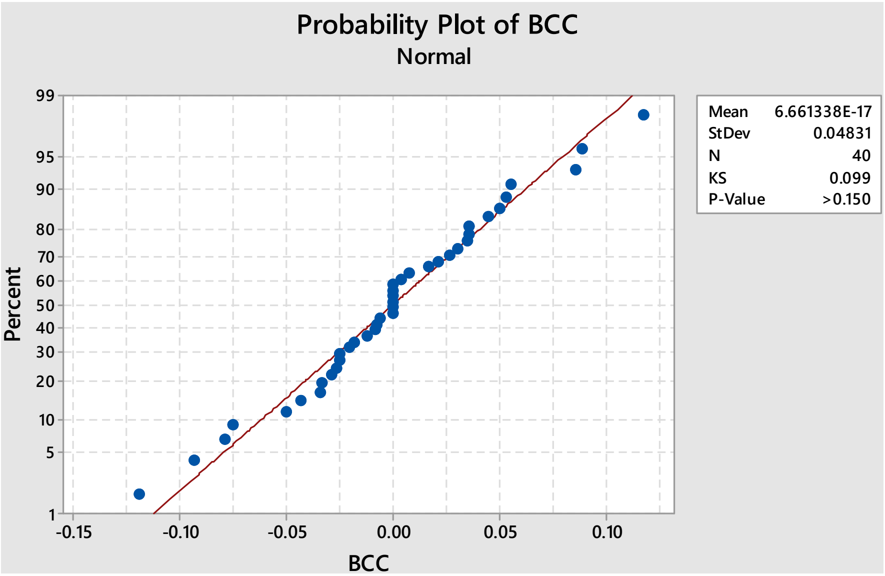

Fig. 1 Results of normality test for BCC model

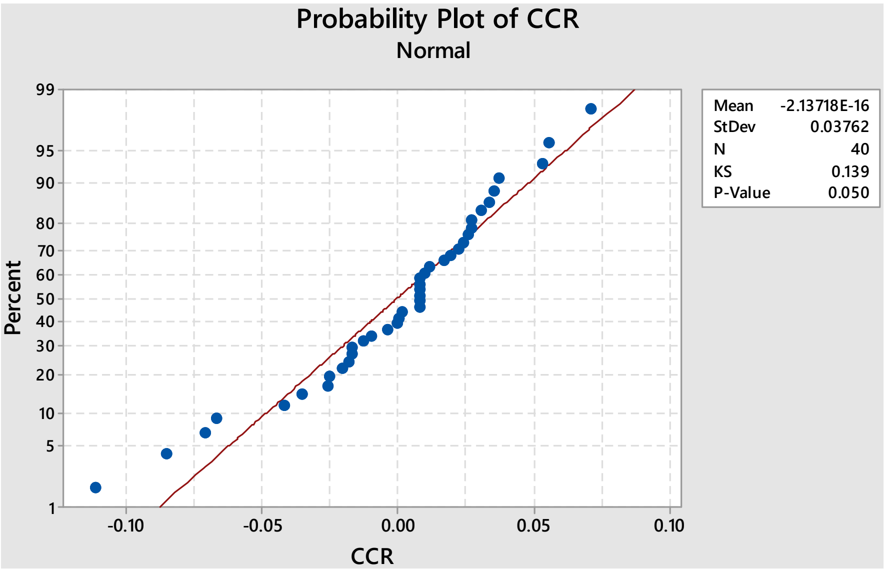

Fig. 2 Results of normality test for CCR model

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 IV) is also given in Table V.

According to Table V, 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.

C. 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 VI. In order to summarize results presented in Table VI and provide a good visualization of the results, showing the results as a pie chart seems to be useful (Fig. 3). As seen in Fig. 3, weight of the self-organization factor is reported 23 percent. This means considerable significance of this factor in creating performance efficiency.

Weight of each IRE factor is given in Fig. 3;

D. 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 VII, normality and variance equality of each factor are approved. Hence, the paired t-test can also be carried out by MINITAB. Table VIII shows results of paired t-test. On the basis of results presented in Table VIII, deletion factors can significantly affect the efficiency.

TABLE III
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

TABLE IV
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

TABLE V
DIFFERENCE BETWEEN AVERAGE EFFICIENCY BEFORE AND AFTER FACTOR DELETION

Omitted Factors								
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

TABLE VI
DIFFERENCE BETWEEN AVERAGE EFFICIENCY BEFORE AND AFTER FACTOR DELETION

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

TABLE VII
RESULTS OF TEST OF NORMALITY AND BARTLETT'S TEST

Weight Factors								
Management Commitment	**Reporting Culture**	**Learning Culture**	**Awareness**	**Flexibility**	**Teamwork**	**Redundancy**	**Self-Organization**	**Fault Tolerant**
>0.15	0.098	0.139	> 0.15	> 0.15	0.088	> .15	> 0.1	>0.15
0.851	0.99	0.495	0.92	0.98	0.977	0.807	0.655	0.4478

TABLE VIII
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

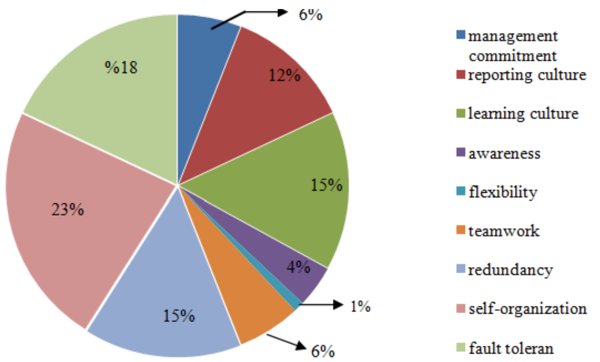

Fig. 3 Weight of each IRE factor

VI. CONCLUSION

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, 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 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 IRE to the system. Results of the study indicated that the proposed integrated design provides higher efficiency than traditional RE design. In addition, sensitivity and perturbation analysis also signify that self-organization, fault tolerance, and reporting culture create about 50 percent of total weight.

APPENDIX

TABLE IX
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. 2014) [25]	✓	✓	✓		✓	✓			
Steen et al. (2011) [5]		✓	✓						
Shiralietal. (2013) [34]	✓	✓			✓	✓			
Saurin et al 2011) [22]	✓	✓	✓		✓	✓			
Dolif et al. (2013) [14]		✓			✓				

TABLE X
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 alternatives 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 simultaneously
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)?

TABLE XI
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

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