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A new method for quantitative assessment of resilience engineering by PCA and NT approach: A case study in a process industry

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ABSTRACT

In recent years, resilience engineering (RE) has attracted widespread interest from industry as well as academia because it presents a new way of thinking about safety and accident. Although the concept of RE was defined scholarly in various areas, there are only few which specifically focus on how to measure RE. Therefore, there is a gap in assessing resilience by quantitative methods. This research aimed at presenting a new method for quantitative assessment of RE using questionnaire and based on principal component analysis. However, six resilience indicators, i.e., top management commitment, Just culture, learning culture, awareness and opacity, preparedness, and flexibility were chosen, and the data related to those in the 11 units of a process industry using a questionnaire was gathered. The data was analyzed based on principal component analysis (PCA) approach. The analysis also leads to determination of the score of resilience indicators and the process units. The process units were ranked using these scores. Consequently, the prescribed approach can determine the poor indicators and the process units. This is the first study that considers a quantitative assessment in RE area which is conducted through PCA. Implementation of the proposed methods would enable the managers to recognize the current weaknesses and challenges against the resilience of their system.

1. Introduction

The increasing complexity in highly technological systems such as process industries is leading to potentially disastrous failure modes and new kind of safety issues. Traditional risk assessment is not adequate to analyze risks that exist in the socio-technical system [1]. However, in recent years, RE has attracted widespread interest from industry as well as academia because it presents a new way of thinking about safety and accident [2]. This thinking focuses on how to help people to cope with complexity under pressure to obtain success [3]. Because this is still a relatively new concept, it is obvious that there are some unanswered questions on how well it can deliver on its promise [4].

While several qualitative studies have been conducted in limited areas, quantitative researches, especially in the process industries, remained relatively undeveloped. Only a few publications closely related to process industries were found [5]. On the other hand, although the concept of RE was defined scholarly in various areas, there are only few which specifically focus on how to measure RE [6]. Therefore, there is a gap in assessing resilience by quantitative methods. Of course, as Woods pointed out, we can only measure the potential for resilience but not resilience itself [7]. Nevertheless, this paper is aimed at quantitative assessment of RE based on six resilience indicators, i.e., top management commitment, Just and learning culture, awareness and opacity, preparedness and flexibility using PCA and numerical taxonomy (NT) approach. Thus, a questionnaire was designed to measure mentioned six indicators. Our aim was to examine the validity of a survey method for measuring potential of RE in a process industry.

1.1. Principal component analysis

PCA is widely utilized in multivariate statistics such as factor analysis. It reduces the number of variables under study and consequently the ranking and analysis of indices (process units) [8]. An objective of PCA is to identify linear combinations of the variables that are useful in accounting for the variation in original variables. In other words, there will be a new set of variables such that each new variable in this set is called a principal component. The first new variable y_1 explains the maximum variance in the sample data and so forth. These principal components (new variables) are uncorrelated. PCA is done by recognizing the Eigen structure of the covariance or singular value decomposition of the original data [8].

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1.2. Numerical taxonomy

Numerical taxonomy approach is capable of identifying homogeneous from non-homogeneous cases. Moreover, a group of process units is divided to homogeneous sub-groups by given indicators. It also ranks the process units in a separate group. After defining new measures, for following taxonomy process, the distance of every two process units for each indicator is calculated. Also by noting the distance matrix, the process units can be ranked [9].

2. Resilience engineering

2.1. Limitations of the qualitative approaches to assess the resilience of a system

Interpreting the results of the qualitative assessments is usually difficult for the employees, because they generate a large number of hypotheses and therefore the results cannot easily be explained in certain levels of accuracy. On the other hand, developing accurate numerical models to describe and predict these intangible results is very difficult for the management systems and therefore they have fewer tendencies to RE based on qualitative approaches [19]. Meanwhile, issues of anonymity and confidentiality can reveal problems when presenting the findings.

2.2. Definition

Resilience has been defined in literature in many different ways; consider, for example, two definitions: (1) resilience refers to capability of a system to create foresight, to recognize, to anticipate the changing shape of risk before adverse consequences happen [10,11]. (2) Resilience is the inherent ability of a system to adapt its functioning before and during disturbances, so that it can continue operations after a major mishap or in the presence of continuous stresses [2,12].

2.3. Application

The concept of resilience has been used in several disciplines, such as ecology, social and organizational science, psychology, computer science, etc. [5]. On the contrary, application of RE is confined to specified industries, such as nuclear power plant and electricity distributor [13,14], sea fishing [15], health care systems [16], aviation [17,18], and the process industry [19]. Our literature review in the various databases up to 2012 showed that most studies in RE areas are qualitative. Therefore, tendency towards them is less than quantitative studies (at least in the plant under study) because of their intangible results.

2.4. Principles of RE

Literature review has shown that there is no repertoire of principles (indicators) which is broadly adopted in the academic community and also there are many different terminologies that are accepted by different authors [3]. This article tries to compile a set of principles as a reference to quantitatively assess the potential of RE. Thus, six principles (indicators) were recognized to assess the potential for resilience [3,12,20,21]. The reasons for this were that they are able to identify potential concerns in the system's performance based on a process which translates broad themes into specific system issues [22], focus on proactive aspects of safety rather than only reactive, identify vulnerabilities in the risk assessment and control system, and provide information about effectiveness of safety management underway in the plant.

- Top management commitment: this implies that safety is a core value and devotion to it is above or to the same extent as the other goals in the organization [3].
- Just culture: Ref. [23] describes a Just culture as an atmosphere of trust in which employees are encouraged to report essential safety-related issues.
- Learning culture: it refers to learning not only from incidents, but also from normal works [14].
- Awareness and opacity: employees should be aware both of their current state and the current status of the defenses in the plant. They should also be aware of systems' boundaries and know how close it is to their edge [14,24].
- Preparedness: it implies that the system actively anticipates various threats and prepares for coping with them [24].
- Flexibility: the system's ability to restructure itself in response to various changes and variabilities [24].

3. Method

3.1. Research strategies and sample

This article is a part of a large research of RE assessment. The research utilized various methodologies, which consist of both qualitative and quantitative methods. In this paper the results of quantitative assessment would be considered using a questionnaire.

The case plant was a large process industry in Iran. The units of the plant are classified into 11, including Distillation, Visbreaker, LPG, Hydro cracker, Hydrogen, Catalytic reforming, Control 3, Storage tanks, Technical Inspection, Utility services and Maintenance with almost 1000 permanent employees, 398 of whom are operational (line) and the rest is staff. The employees work in three shifts, each one about 8 h, and nearly 90% of the employees have at least a 15 year job record. They must perform their tasks in a context with high function complexity, work demand and production pressure. They also have to deal with conflicts between production and safety goals, uncertainty in the process of safety analysis, and gap between works as they are imagined and performed. So, the target of this research was line employees, because they are in the front-line of production and involve mentioned conditions. It is worth mentioning that the plant has been in operation for more than forty years and has shown many incidents in its performance record.

Therefore, each questionnaire was delivered directly to the employees by one of the research team members. The respondents were assured that the responses would remain confidential so that the information could not be traced back to employee respondents. Information on the objectives and carrying out methodology of the research was given to all employees at a separate seminar.

A total of 88 valid questionnaires were gathered from the population of 100. Thus, the response rate of the study was 88%. Three percent of the sample were managers, 20% were supervisors and 77% operators.

3.2. Measures

The questionnaire consisted of six measuring dimensions: a measure of top management commitment, a measure of Just and learning culture, a measure of awareness and opacity, a measure of preparedness, and a measure of flexibility. The questionnaire included a total of 61 Likert-type questions (see Appendix). Five-point Likert-type scales were utilized in this research. A pilot study was conducted by the research group with the experts from the target plant in order to improve the questionnaire. In line with