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Performance evaluation of integrated resilience engineering factors by data envelopment analysis: The case of a petrochemical plant

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ABSTRACT

Petrochemical units are potentially prone to incidents that have catastrophic consequences such as explosion, leakage of toxic materials, and the stoppage of the production process. Resilience engineering (RE) is a new method that can control incidents and limit their consequences. It includes top-level commitment, reporting culture, learning, awareness, preparedness, and flexibility. However, this study introduces a new concept of RE (referred to as integrated RE or IRE) which includes the above factors in addition to self-organization, teamwork, redundancy and fault-tolerant. This study evaluates performance of IRE in a petrochemical plant through considering the obtained data from questionnaires and data envelopment analysis (DEA) approach. Moreover, the performance of RE and the new IRE are compared and discussed. The results show that although there is a strong direct correlation between the DEA results in two frameworks, the mean scores of efficiency in IRE is slightly higher than RE. This is the first study that introduces an integrated approach for RE. In addition, this study is amongst the first ones that examine the behavior of resilience engineering by DEA. Moreover, the superiority of IRE is shown through robust statistical analysis.

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Keywords: Integrated resilience engineering; Data envelopment analysis; Performance measurement; Teamwork; Redundancy

1. Introduction

For years, human errors and individual component failure were considered the main reasons for most accidents (Qureshi, 2007). However, today, it is known that the causation of incidents and accidents can be tracked to the organizational factors, functional performance variability, and the occurrence of unexpected combinations (Shirali et al., 2012). It can be said with excellent reasons that the multidimensional and strongly interactive activities cannot be controlled by a pure traditional method which is aiming to limit errors (Heikkila et al., 2010). Traditional safety systems are based on the reporting and analysis of events, incidents, and accidents. Incidents and accidents reporting can help organizations and systems get an overview of accidents and incidents, but counting negative events (errors, violations, accidents and incidents) does not always reduce the potential risks. In other words, incidents and accidents reporting and error analyzing, in itself, cannot improve safety to a higher level in complex systems and hazardous environments (Huber et al., 2009).

In the past, safety management approaches were reactive while the RE approach marks the maturation of a new and proactive approach to safety management. In a world of finite resources, of irreducible uncertainty, and of multiple conflicting goals; safety is created through proactive resilient processes rather than through reactive barriers and defenses. RE is the capability of systems and organizations to anticipate and adapt to the potential for surprise and failure (Woods and Hollnagel, 2006). It is a proactive approach suggested to remove foregoing constraints. Furthermore, it is a paradigm

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for safety management that concentrates on how to help people to create a foresight, and to anticipate the different forms of risk in order to cope with complexities under pressure and move toward success (Haimes, 2009). RE looks at failure and success as closely related phenomena. In addition, resilience is about having the generic ability to cope with unforeseen challenges, and having adaptable reserves and flexibility to accommodate those challenges (Hollnagel et al., 2008). Therefore, resilience is needed as an additional safety measure (Dinh et al., 2012).

In the context of safety management, RE has been singled out as a new paradigm (Hollnagel et al., 2006, 2008; Nemeth et al., 2009). RE stresses the way success is achieved; how people, systems and organizations learn and adapt, and thus creates safety in an environment with hazards, tradeoffs, and multiple goals (Hollnagel et al., 2006). Indeed, a key idea is that resilience is more than the ability to continue functioning in the presence of stress and disturbances. The ability to adjust how people and systems function is, by far, more important from the point of view of RE (Hollnagel, 2009). The capability of a system to adjust to the constantly changing environment could be a more important predictor of future safety (Dekker, 2006; Dekker and Laursen, 2007). The willingness of managers to invest in the safety area and to assign resources in a timely and proactive method is a key factor in ensuring a resilient organization or system (Gilmour, 2006). Hidden capabilities in RE can be effective in the promotion and improvement of the plant safety situation. The idea behind RE is the investigation into the creation of risk management processes that are robust whilst remaining flexible (Gilmour, 2006).

Some studies have been conducted in the context of RE whose aim was often the improvement of safety system such as oil distribution plant (Abech et al., 2006); refining plant (Tazi and Amalberti, 2006); aviation (Zimmermann et al., 2011); aviation (Dekker et al., 2008); health and safety management systems (Costella et al., 2009); high-risk process environments (Huber et al., 2009); oil and gas exploration (Storseth et al., 2009); electricity distributor (Saurin and Carim Junior, 2011); chemical plant (Shirali et al., 2012); industrial processes (Dinh et al., 2012).

Today, resilience seems to be a strategic concept dealing with the improvement of safety in complex systems, since it could reconcile the notions of performance and safety rather than systematically oppose them (Morel et al., 2009). The performance assessment of departments in most companies is an important issue for managers, decision makers and researchers. There are various methods for estimating efficiency scores of departments. One of these methods is data envelopment analysis (DEA). DEA has many applications in engineering case studies such as data mining (Kusiak and Tseng, 2000), measuring performance of electric power generations (Azadeh et al., 2006), consumption optimization in energy manufacturing sectors (Azadeh et al., 2007a), performance assessment of electric power generations (Azadeh et al., 2007b), performance assessment of decision-making units in power plants (Azadeh et al., 2007c), forecasting electrical consumption in Iran (Azadeh et al., 2007d) and location optimization of wind plants (Azadeh et al., 2011).

In this paper, a new framework is presented based on RE (referred to as integrated RE or IRE). IRE includes the suggested items of Hollnagel and et al. and four new items that will be suggested this paper (Fig. 1). In this paper, the suggested framework of Hollnagel et al. is named RE framework and the suggested framework of this paper is named IRE framework. Thus, RE framework is considered a subset of IRE framework. This study aims at strengthening the scientific platform of safety by providing new insights into the relationship between performance assessment and resilience level. Hence, the present work is not only of theoretical and foundational interest. One of the contributions of this paper is the development of RE framework. Also, the other contribution of the paper would be the calculation of Decision Making Units (DMUs) performance with DEA method through RE and IRE frameworks. The discussion on the role of suggested items on performance of DMUs in an intractable system would be the major part of the present paper analysis.

This paper includes the following structure: the related literature was reviewed in the first section to define the concept of RE. Section 2 presents RE and IRE frameworks. Then, the items of the questionnaire are presented and DEA approach is described in Section 3. Section 4 presents the raw data of this study. Section 5 provides the computational results of this study. Last but not least is the conclusion of this study in section six.

2. The proposed approach

2.1. *Resilience engineering*

In the operation of an industrial process, three system states can be distinguished: normal, upset and catastrophic ones (Dinh et al., 2012). We always try to keep systems in normal state and to achieve this aim through the manipulation of operation variables. Whenever the efforts fail or the actions are neglected, we can use effective recovery methods for recovering system from upset state back to normal state. If these efforts fail too, the system may cross over into a catastrophic state and may have tragic consequences like human loss. RE helps to recover system states after incidents or accidents occurrence rather than prevent incidents or accidents from occurring (Dinh et al., 2012). In other words, resilience is "the ability of an organization (system) to keep or recover quickly to a stable state, allowing it to continue operations during and after a major mishap or in the presence of continuous significant stresses" (Wreathall, 2006).

The items identified in the review are management commitment, reporting culture, learning, awareness, preparedness, flexibility (Fig. 1). Each of these items has a special meaning in a different application field. By customizing each of these items for a special field, we can identify the potential sources of data from which the personnel can evaluate different levels of performance within their organization or system (Wreathall, 2006).

The six indexes in a resilient system or organization are as follows (Wreathall, 2006):

- Management commitment: Top-level management recognizes the concerns and problems of the human performance and tries to solve them (Wreathall, 2006). Also, this item emphasizes that safety is a core organizational value rather than a temporary priority (Costella et al., 2009).
- Reporting culture: it supports the reporting of problems and issues up through the organization or system, yet not tolerating culpable behaviors. Without a just culture of reporting, the willingness of the staff to report problems and issues will be much diminished. Hence, the ability of

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