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Assessment of resilience engineering factors in high-risk environments by fuzzy cognitive maps: A petrochemical plant

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ABSTRACT

It is known that in high-risk environments such as petrochemical plants having a safe environment is very crucial for the system to continue working. In fact, the consequences of unexpected events such as gas leakage, explosion in these systems are almost unbearable. Through dealing with the safety in these systems, several approaches have been proposed. Resilience engineering (RE) is one of these approaches that looks proactive to the subject and represents an alternative to the conventional safety management. This approach seeks ways to improve the ability at all levels of organizations to create processes that are robust and flexible. The main objective of this study is to assess the factors affecting the resilient level of a petrochemical plant and being able to get expanded to other industries. It is achieved through a fuzzy cognitive maps (FCMs) method that considers interactions between factors due to their final calculated weights. The results of FCMs are combined with a set of questionnaire results to enhance the accuracy of final weights. The primary data of this study are obtained from the questionnaire answered by specialists, engineers and top-level managers who work in a petrochemical plant. The results show that the most important factors among all RE factors are awareness, preparedness and flexibility. In addition, redundancy is the factor with the lowest influence on RE. This is the first study for assessment of RE in uncertain and high risk environments such as petrochemical plants by FCM.

0. Motivation and significance

There is a clear need for new approaches in risk assessment and safety management of complex systems such as petrochemical plants. Resilience engineering (RE) has been proposed as a solution to satisfy this need. Assessing and ranking resilience factors can be a very small but functional step toward this new approach that helps practitioners prioritize their concentrations on building a resilient system. None of researches in the literature have assigned priority and weight for the resilience factors. Prioritizing resilience factors can also help managers to efficiently allot their resources to enhance safety by the RE approach. This is the first study for assessment of RE in uncertain and high risk environments such as petrochemical plants by fuzzy cognitive map (FCM).

1. Introduction

For years, most systems used to utilize the conventional risk management approach to deal with risks. While these approaches may have been adequate for the systems that existed at that time, they are inadequate for the present day systems. Based on the conventional approaches to risk and safety, systems are tractable. This means that the principles of functioning are known, descriptions are simple and with few details, and most importantly that a system does not change while it is being described (Hollnagel, 2007). Nevertheless, many present day systems are intractable rather than tractable. In addition, conventional risk management approaches are established upon the knowledge of previous experience, failure reporting and risk assessments by computing historical data-based probabilities. These approaches typically deal with a small number of possible scenarios at a moment (Nemeth, 2008). Hollnagel (2007) proposed some key points in contrast with the above-mentioned characteristics of the conventional risk management approaches that are useful to review:

- Many adverse events cannot be attributed to a breakdown or malfunctioning of components and the normal system functions ("intractable events").
- Effective safety systems can neither be based on hindsight knowledge nor rely on error tabulation and the calculation of failure probabilities.

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- The conventional view of safety (risk) management considers the performance variability of any kind as a threat and something that should be avoided. The result is often the use of constraining means (in particular for human performance variability) such as barriers, interlocks, rules, procedures and the use of automation.

By contrast, RE looks for ways to enhance the ability at all levels of organizations to create processes that are robust and flexible to monitor and revise risk models, and to use resources proactively in the face of disruptions or ongoing production and economic pressures. It is a paradigm for safety management that concentrates on how to help people create a foresight and to anticipate the different forms of risk in order to cope with complexities under pressure and move towards success (Haimes, 2009). This paradigm is concerned with normal work rather than the emphasis on learning from incidents (Saurin and Junior, 2012). RE could harmonize the notions of performance and safety rather than systematically oppose them (Morel et al., 2009). In addition, RE is the inherent capacity of a system to cope with complex and unpredicted events (Shirali et al., 2011). An important source of resilience could be operators who have a deep understanding of an application area (Nemeth, 2008).

In RE, background resilience means the intrinsic ability of a system to adjust its functioning prior to or following changes and disturbances so that it can sustain operations even after a major mishap or in the presence of continuous stress (Steen and Aven, 2011). This means resilience is concerned with monitoring the boundary conditions of the current model for competence (how strategies are matched to demand) and the adjustment or expansion of that model to better accommodate changing demands (Woods and Hollnagel, 2006). So a resilient organization treats safety as a core value but it's not like a commodity that can be enumerated (Woods and Hollnagel, 2006). The characteristics of resilience include experience, intuition, improvisation, the expectation of the unexpected, the examination of preconceptions, thinking outside the box, and taking advantage of fortuitous events (Nemeth, 2008).

Based on Hollnagel (2007), for being resilient, a system should have the following four attributes:

(1) To respond to regular and irregular threats in a robust, yet flexible manner.
(2) To monitor what is going on including its own performance.
(3) To anticipate risks (risk events) and opportunities.
(4) To learn from experience.

Also (Dinh et al., 2012), in their study, proposed six principles that contribute to the resilience of a process. These six principles are Flexibility, Controllability, Early Detection, Minimization of Failure, Limitation of Effects, and Administrative Controls/Procedures.

But based on several studies like (Hollnagel and Woods, 2005; Wreathall, 2006; Saurin et al., 2008), four principles were identified which have interfaces with each other and do not possess strictly defined limits (Costella et al., 2009):

- Top management commitment.
- Increase flexibility (flexibility).
- Learn from both incidents and normal work (learning).
- Be aware of system status (awareness).

Most of the work done in the field of RE contains qualitative and conceptual results rather than quantitative ones. Clearly converting these qualitative results to numerical ones could be a step further in the field and it eases the decision making for management. As investigated by Gibbs (2009), resilience thinking is causally linked with a sort of insight into the system. So it's difficult for managers to evaluate their organizational performance in resilience background. The managers also have few strong technological plans on which they can base resilience arguments. Therefore, it can be difficult to compete against mathematical models claiming to predict risks, failures, and their impacts on systems (Shirali et al., 2012). Consequently, there is a need for numerical models to evaluate system resilience.

This study has been shaped based on the obtained results from a case study in a petrochemical plant. As it's noted by Srivastava and Gupta (2010), Khan and Abbasi (2001), Tveiten et al. (2012), chemical industry is considered as a high risk industry. In addition, based on Costella et al. (2009), the application of RE is particularly suitable for high risk systems with complex characteristics because of (a) the high degree of interconnection between the components of the system (b) uncertainty and variability under such conditions of complexity. So developing RE for chemical plants could be advantageous for the safety of the industry.

This paper contributes to the literature by introducing major factors of resilience and computing the effect of these factors on the system. These are the factors a company is required to have to be called resilient. Hollnagel et al. (2006) related that RE seeks to manage risk and safety proactively by developing methods to measure and enhance the resilience of organizations. So measuring the resilience of a system is an important part of the RE. The factors can be applied to the evaluation of the resilience of a system or process. By means of calculating their effect on the subject, the evaluation would be much more accurate. It is perceived that the procedure occurs in a fuzzy environment. Due to this fact, the impact of the factors is considered to be fuzzy numbers. The fuzzy cognitive maps method is applied to weigh the factors. The *Fuzzy cognitive maps* (*FCMs*) *are fuzzy-graph structures for representing causal reasoning* (Kosko, 1986). This method is deeply discussed in Section 2.

The remainder of the paper is structured as follows: First, the literature related to RE will be summarized to give a background on the topic that contains a literature review. Then, there will be a short discussion of the methodology in section two. In the third section, experimental results are presented. Finally, section four contains the conclusion of this study.

1.1. Literature review

Since it is not a long time when the RE approach has been proposed, there is not a large body of literature related to it. Considering the relevance, two main streams of recent researches are reviewed here: one is focused on papers that have discussed the RE concept and abstract developments; and the other that developed and applied the RE approach in practicing or performing RE in case studies. As it is seen, most of the articles date back to 2010 and later on which shows in itself the potential for new works on the field RE.

1.1.1. RE concept and abstract developments

Steen and Aven (2011) discussed the understanding of the risk concept and the way risk can be assessed and treated. They related that the traditional ways of looking at risks are not suitable for use in RE, but other risk perspectives are at play. Then, in their study, they draw attention to such perspectives. In particular, they focused on one category of perspectives where probability is replaced by uncertainty in the definition of risk. Finally, they argued that the basic ideas of RE can be supported by such risk perspectives. Furniss et al. (2011) provided a framework for reasoning about resilience that requires the representation of the level of analysis (from the individual to operational), a traceable link from