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# Performance optimization of an aluminum factory in economic crisis by integrated resilience engineering and mathematical programming

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ABSTRACT

Economic crisis have created certain challenges for large factories. This has intensified the need for being resilient in face of such disruption. During economic crisis, factories are faced with significant threats in their financial performance and survivorship. In this paper, the performance of an aluminum production plant has been investigated by integrated resilient engineering (IRE). For assessing IRE performance in economic crisis of the case of this study, first a questionnaire based on IRE factors in context of economic crisis is distributed among all expert managers and staff. Afterwards, the Cronbach's alpha test is used to investigate the reliability of the questionnaire's data. Then, best fitted data envelopment analysis (DEA) is used to examine resilience engineering factors in context of economic crisis performance. To validate and verify the results, principle component analysis (PCA) and numerical taxonomy (NT) are utilized. It is found that self-organization, reporting culture, flexibility and learning have the greatest effect on performance. Also, it is shown that integrated resilient engineering is more efficient than resilient engineering. It is proven that the aluminum factory can be more resilient in cases of economic crisis by improving the above factors. The framework of this study may be used for all types of industrial units to identify the most important resilient factors in times of economic crisis. This is the first study that presents an integrated framework for performance optimization of an aluminum factory in economic crisis.

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## 1. Motivation and significance

Nowadays, economic issues are among integral factors for organizations and economic crisis have created certain challenges for large factories. This has increased the need for resilient framework in face of such disruption. During economic crisis, factories are faced with significant threats in their financial performance and survivorship. This also drives the organizations, corporations, factories and industrial units out of normal condition and involves them in disaster. Therefore, decisions and measures of senior and middle managers are considerably important in such conditions. In order to resolve this problem, in this study an approach is proposed for dealing with such challenges to help the organizations for improving their performance in the uncertainty conditions. For this purpose, the integrated resilience engineering (IRE) method in context of the economic crisis is utilized and this is the first study that presents an integrated framework for performance optimization of an aluminum factory in economic crisis.

The following structure presented in this paper: Introduction and literature review are presented respectively in Sections 2 and 3. In Section 4, the methodology studied in this paper including the IRE in economic crisis, questionnaire design and the DEA models are proposed. In Section 5, the data gathering, the input and output variables and reliability and validity of questionnaire are represented named case study. In Section 6, best fitted DEA model, validation and verification of DEA, results of RE and IRE framework and sensitivity analysis are proposed as discussion. Section 7, as the last section of this paper explains the conclusion of the study.

## 2. Introduction

In this section, first the description, importance, consequences and issues of economic crisis and also examples from natural disaster and disaster caused by human has been discussed. Then, the importance and the application of resilience has been explained. The capability and hidden features of resilience engineering (RE) has been proposed. In the end of this section economic resilience has been discussed.

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### 2.1. Economic crisis

In any complex system, a crisis is a period of where the system functions very poorly, warranting immediate corrective action. In economy, a crisis can be described as that period of dismal performance. During this time, the value of institutions, especially financial institutions, drops at unprecedented speeds and everything seems to be valueless. At first glance, economic crisis consists of the emergence of "over-production". Over-production is filling the market with products that are out of customers' afforded (Kettell, 2006). When there is no customer in market and products not sold, consequently, production would decrease and stop. Afterwards factories and industrial units would be closed and millions of laborers would be unemployed (Jaeckel, 2014; Weeks, 2011). That makes it more difficult to sell the products and increases the depth of the crisis. The capitalism credit system stops working (Holgersen, 2015). Debtors will lose their ability to pay their debts in time. There would be a reduction of liquidity in the banking and credit system (Giavazzi and Spaventa, 2011). The share price of the corporations would fall. Institutions of capitalism would be bankrupt. Production risk would happen in factories. Inflation would increase (Foster and Magdoff, 2009) etc.

Lateral effects of recent natural disasters (e.g. Hurricane Katrina of 2005, Japan Earthquake and Tsunami of 2011, Hurricane Sandy of 2012) and disasters caused by human (e.g. Deepwater Horizon oil spill of 2010) underlines the associated vulnerability with the infrastructure, industry and labor force. Although great efforts have focused on studying methods for preventing casualties in large factories, mishaps are still happening in large factories due to different failures caused by economic downturn and crisis (Dinh et al., 2012). During economic crisis, large and small corporations encounter significant threats in their financial performance and consequently their survivorship (Pal et al., 2014). In such huge events, the existence of previous plans play significant roles for public safety (Comfort, 2015).

### 2.2. Resilience

According to Christopher and Peck (2004) resilience is the ability of a system to return to its original state or move to a new, more desirable state after being disturbed. Generally, resilience assessed as the concept that a system is able to avoid the maximum impact (e.g. resilience to disasters (Rose, 2004), robustness (McDaniels et al., 2008), vulnerability (Barker et al., 2013)), disaster risk management (DRM) (Field, 2012; MacAskill and Guthrie, 2014) and the rate that a system can be restored after a disturbance (Barker et al., 2013; Rose, 2004; Zobel, 2010).

### 2.3. Resilience engineering

Previously, safety management methods were utilized to overcome risk (Costella et al., 2009; Haimes, 2009), however the resilience engineering (RE) approach shows the maturation of a new approach to safety management (Azadeh et al., 2014; Hollnagel et al., 2008, 2009; Hollnagel et al., 2007). RE is a paradigm for safety management that concentrates on how to help people deal with complexity under stress to access success (Hollnagel and Woods, 2006; Woods and Hollnagel, 2006). The hidden feature of RE can be effective in enhancement and improvement of the safety condition of the factory (Akselsson et al., 2009; Hollnagel, 2013). The idea behind RE is tending to establish risk management processes that would be robust if they remain flexible (Størseth et al., 2009).

### 2.4. Economic resilience

Economic resilience defined as "The inherent ability and the adaptive response that enables the organizations to avoid maximum potential losses" (Rose and Liao, 2005). Economic resilience primarily has been studied as seismic resilience of communities (Bruneau et al., 2003; Tierney, 1997), disaster analysis (Rose, 2004) and other fields. According to the importance of economic discussions and the existence of economic recession and crisis and the scientific nature of resilience, the performance of Aluminum production plant based on IRE-based approach is assessed.

The present study also has studied the IRE performance in economic crisis. For this purpose, efficiency and ranking of decision making units (DMUs) have been calculated using the data envelopment analysis (DEA) method through factors of RE recommended by Hollnagel et al. (2007) and IRE, recommended by Azadeh et al. (2014). Also, discussing and investigating the effect of the proposed factors in the performance of DMUs in this case study is a major part of the analysis of this paper.

## 3. Literature review

Several studies have been considered concerning economic crisis by RE-based approach. Pal et al. (2014) has focused on the emergent constraints during economic crisis in the past two decades for small and medium Sweden textile and clothing plants. They have proceeded to identify their records and various levels of their effect on economic resilience. Resilience in the economic dimension can also be allocated to choose spatial units for increasing the resilience potential (Östh et al., 2015). The focus can be on the components resilience index which is mainly placed in the economic level such as literacy rate, unevenness of the income distribution, and percentage disabled (Abech et al., 2006). These factors influence the enhancement of economy and quality of life. The breadth and comprehensiveness of the RE approach makes it possible for us to analyze general and minor issues by a special approach, and makes us not be limited to only certain issues. The RE approach has a prominent place in engineering sciences, and it often covers some studies in enhancing safety systems (Miller and Xiao, 2007).

According to Grabowski and Roberts (2016) resilience is a concept to describe the capability of an organization to respond or 'bounce back' untoward, surprising or disruptive incidents. Resilience can be focused on how to understand the compatibility of the system with the emergent changes and disruptions caused by incidents in relation to the expected conditions (Abech et al., 2006). Resilience can also be used for evaluating health and safety management systems (HSMS) (Costella et al., 2009). For many years, safety improvement has been created by reporting events and the analysis of faults and contraventions (Huber et al., 2009). Størseth et al. (2009) offered particular recommendations for creating a resilient organization: (1) Preparing for successful initiative, (2) Assessing integrated operations impact on resilience features (3), Ensuring awareness of work in progress at all levels; and (4) Sharing risks and goals.

Analyzing resilience determines some opportunities for improving the how-to of the compatibility of the system with conditions that challenge the programs and strategies (Abech et al., 2006). Saurin and Carim Júnior (2011) offered some evaluations for improving and evaluating safety and health management systems. Here, a way is offered that poses resilience engineering as a basic philosophy and examines it in a case study about a production factory. The resilience of socio-technical systems still relies mainly on the controlling ability of man in unanticipated incidents (Carvalho et al., 2008).

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