



Optimum design approach based on integrated macro-ergonomics and resilience engineering in a tile and ceramic factory



A. Azadeh*, E. Roudi, V. Salehi

School of Industrial and Systems Engineering, Center of Excellence for Intelligent-Based Experimental Mechanics and Department of Engineering Optimization Research, College of Engineering, University of Tehran, Iran

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ABSTRACT

Integrated resilience engineering (IRE) is a novel approach that has a foresight and proactive attitude towards improving the safety and reliability of complex industrial systems such as tile and ceramic factories. This study is an attempt to present an integrated mathematical approach for analyzing the impact of IRE and macro-ergonomics factors in a tile and ceramic factory. Moreover, this study aims to determine the optimum design approach based on integrated macro-ergonomics and resilience engineering. It also identifies the impact of such integration by Principal Component Analysis (PCA). Data collection was performed in the tile and ceramic factory through questionnaire. Then, the reliability and validity coefficients of the data were calculated through Cronbach's alpha and factor analysis, respectively. Thereafter, the impact of IRE and macro-ergonomics factors is examined by means of data envelopment analysis (DEA) and fuzzy DEA approaches. The results show that the system efficiency is improved by integrating IRE and macro-ergonomics factors. Analysis of variance (ANOVA) also reveals that IRE factors are more effective than macro-ergonomics factors. This study is the first study that presents a robust design approach based on the integration of IRE and macro-ergonomics in a ceramic and tile factory. Second, a unique and integrated approach is presented based on DEA, FDEA, PCA and ANOVA to achieve the above objective. Third, it identifies the weight of each factor through mathematical modeling approach. Fourth, it is a practical approach and may be used to identify the weaknesses and strengths of such systems.

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0. Motivation and significance

In developed and developing countries, causes of accidents at complex industrial systems such as manufacturing industries are investigated. Quite a lot of studies revealed that many of critical incidents have mainly been attributed to design of work systems. However, further inquiries have shown that a combination of many factors, including the lack of human and organizational considerations as well as resilience level in such systems have resulted in deficiency of managers and operators; therefore, the occurrence of a large number of incidents has come out. The majority of studies undertaken in IRE and macro-ergonomics field have been qualitative. This study introduces a framework to quantitatively examine the efficiency of operators in workplaces. The major motif of this study is that this study for the first time presents the optimum design approach based on integrated macro-ergonomics and resilience engineering in a ceramic and tile factory. To attain the

proposed purposes, it suggests a unique and integrated approach based on DEA, FDEA, PCA and ANOVA. In previous studies, weights of each factor were usually acquired based on expert viewpoint. Thus, it is necessary and important to calculate weights of each factor through a precise mathematical model. Furthermore, it is a practical approach and can be used to identify weak areas and strong points of such systems.

1. Introduction

The supposition that most issues related to safety can be answered through the improvement of communications among workforces and managers is one of the limitations of the existing safety research domain. Although communication has a high level of importance, there are some technical matters in an organization which cannot be resolved just through communication. In these areas wherein good communication is essential but not adequate, Macro-ergonomics has a more holistic approach to safety through sociotechnical systems principle in forming a safe and productive work environment (Murphy et al., 2014). Moreover, work related

* Corresponding author.

E-mail address: aazadeh@ut.ac.ir (A. Azadeh).

health problems continue to be a severe problem despite the considerable resources invested in ergonomic developments to establish a sounder work environment. It might be assumed that it is due to the fact that ergonomic activities have customarily focused on micro levels of systems, like human-system interfaces related to particular jobs and work environments (Hendrick, 1995). Simultaneously, the capability to meet new demands from the outside world by successfully managing internal changes has become a vital necessity and a matter of survival for organizations (Ingelgard and Norrgren, 2001).

There are some differences between two notions of micro-ergonomics and macro-ergonomics. Concentrating on man-machine systems, working on the development of workplace and interface design for risk avoidance in the system's day-to-day running are related to micro-ergonomics (Morel et al., 2009). Furthermore, improving the efficiency of sociotechnical systems and reviewing the impact of organizational configurations on human performance and on safety are some of the desired goals of macro-ergonomics. Moreover, macro-ergonomics originates from Total Quality Management doctrines (Carayon, 2003), which is an approach of the design of socio-technical systems and primarily performs the following: (i) the number, training and gratification of staff members, (ii) equipment quality and equipment maintenance, (iii) development of the physical environment, (iv) quality of work processes, and (v) economic production that is adequate in quantity and quality. In this way, it attempts to concentrate on the conditions required to enhance a system as a whole. This is not only an analysis technique (Carayon, 2006; Clegg, 2000), but it also offers the characteristic of acting in a systemic (in conjunction with the technical and organizational features), participative, and progressive way.

The prominent concept that accentuates the crucial influence of social and organizational factors on the design of safe and operative work systems, processes and equipment items is macro-ergonomics. Macro-ergonomics highlights the crucial nature of organizational factors in the design of creative processes and safe work systems and, thereby, it exerts a vital impact on traditional human factors and ergonomics (Hendrick and Kleiner, 2002). By concentrating on ergonomics, some outcomes such as safety, health, comfort, quality, productivity, and satisfaction may be well affected (Hendrick, 2002) and it is obvious that the job design and sociotechnical system, or macro-ergonomics concept, are inevitable for a successful outcome (Nagamachi, 1995).

Hendrick and Kleiner (2001) defined macro-ergonomics as a top-down sociotechnical system approach to the design of organizational and work system structures. They also defined macro-ergonomics as the application of the overall work-system design of individual jobs and human-machine and human-software interfaces of a new method to the interaction between organizational issues and the technology applied in the organization. In this way, a fully coordinated work system is guaranteed. System of ergonomics arose within the UK and Europe in the 1960s (Katz and Kahn, 1966). By 1986, conceptualization of the ergonomics of work systems had been developed to the point of recognizing it as a distinct sub-discipline. At that time, it became officially recognized as macro-ergonomics (Hendrick, 1986a; Hendrick, 1986b).

Macro-ergonomics is involved with improving the structure and related processes of work systems. Therefore, an understanding of macro-ergonomics first requires an understanding of the key dimensions of the work system structure. Understanding of the particular sociotechnical features of a given work system will lead us to macro-ergonomically optimizing these key dimensions of the work system's organizational structure. In fact, the purpose of strategies including macro-ergonomics is to enhance the performance of socio-technical systems and study the influences of organizational structures on safety and human behavior (Azadeh et al.,

2017). In addition, the lack of ergonomics rules influences efficiency, productivity and also the quality of work condition in workplaces (Bertolini, 2007; Azadeh et al., 2016a,b). Moreover, improvements programs at macro-ergonomics level are imperative for optimizing in organizations (Haydee et al., 2011).

It is concluded that the events that occur in systems arise from the way the parts-engineered and human-fit system interact together. Mostly, the error and the consequent failures are both due to the attributes and the effects of many factors, such as bad workplace designs, complicated working processes, unstable workload, hazardous conditions, defective maintenance, uneven attention to production, unprofitable training, lack of motivation and empirical knowledge, non-responsive managerial systems, imperfect planning, non-adaptive organizational structures, inflexible job-based pay systems, random response systems, and unexpected environmental disruption (Meshkati, 1991).

The world is full of infinite resources and complexities as well as multiple conflicting goals; hence, safety is shaped through proactive resilient processes rather than through reactive hindrances and blockades (Woods and Hollnagel, 2006). The increase of complexity in highly technological systems, for instance, process industries leads to possibly calamitous failure styles and also new safety issues. Traditional risk assessment is inadequate for the risk evaluation that exists in the socio-technical system (Qureshi, 2007).

In socio-technical and complex systems, integrated resilience engineering (IRE) has become a significant field for safety management (Steen and Aven, 2011). Moreover, in large-scale and complex systems, some unanticipated conditions may happen, although risk management is fully carried out. From the resilience perspective, minimizing damages and decreasing compensations as well as getting operations back to normal status are priorities for operators when unexpected situations occur. In other words, resilience engineering helps recover system states after the occurrence of incidents instead of event avoidance. Since it is not possible to predict and prevent all threats, incident prevention is a subject of study in other process safety areas (e.g., risk assessment); hence, resilience is needed as an additional safety measure.

For many years, the concept of resilience has been investigated in non-chemical disciplines, such as biology, psychology, organizational science, computer science, and ecology and it has remained relatively undeveloped in manufacturing systems (Dinh et al., 2012). It is supposed that the causation of events and accidents can be tracked to the organizational factors, functional performance variability, and the occurrence of unpredicted combinations (Shirali et al., 2012).

Recently, new notions have started to make a revolution in the safety of complex systems and the ways to improve and keep safety. These notions have also proposed a different new pattern that considers the positive contribution of people at all levels of the organization rather than considers only human errors (Huber et al., 2009).

Resilience engineering offers a new way of thinking about safety and accident; therefore, it has enticed extensive interest from industry and academic environment (Steen and Aven, 2011). This philosophy helps people become aware of ways to deal with the existing complexities in order to gain success (Costella et al., 2009). This is still a new notion and there are some vague and unanswered questions on how well it can stick to its promise (Madni and Jackson, 2009).

RE is a kind of safety attitude based on control and management of disturbances before, during, and after their incidence (Hollnagel et al., 2006). It is also associated with human factors, control theory, and safety engineering (Azadeh et al., 2015a,b). RE concentrates on behaviors to reimburse for poor behavior, poor design, poor systems, and poor conditions (Furniss et al., 2011).

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