Safety Science 102 (2018) 144–158

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

HSE risk prioritization using robust DEA-FMEA approach with undesirable outputs: A study of automotive parts industry in Iran

Samuel Yousefi[a,*], Arash Alizadeh[a], Jamileh Hayati[a], Majid Baghery[b]

[a] Faculty of Industrial Engineering, Urmia University of Technology, Urmia, Iran
[b] Faculty of Management and Accounting, Allameh Tabatabai University, Tehran, Iran

ARTICLE INFO

Keywords:
HSE management
Risk prioritization
Failure modes and effects analysis
Robust DEA
Undesirable outputs
Automotive industry

ABSTRACT

Nowadays, manufacturers realize that enhancing attention in health, safety and environment (HSE) management system leads to significant success in their activities. In order to accomplish HSE integrated management, the first step is identification and assessment of potential risks to control them, which may increase the protection level of employee and efficiency of work environment. Failure modes and effect analysis (FMEA) is one the most used methods in risk assessment. However, conventional FMEA disadvantages such as using risk priority number (RPN) to prioritize risks make this method inefficient in industries. The aim of this study is to present an integrated robust data envelopment analysis (RDEA)-FMEA approach to evaluate and prioritize HSE risks in various industries and to cover disadvantages of traditional scoring system of RPN in FMEA method. In fact, in the present study, prioritization of HSE risks are carried out by considering two extra parameters including cost and duration of treatment (as outputs) in addition to three parameters of severity, occurrence, and detection (as inputs). Additionally, uncertainty and undesirability of mentioned parameters are considered simultaneously. The proposed approach was implemented in a company active in manufacturing spare parts of automotive and then results were compared to conventional DEA model and RPN scores. The results indicate that, ranking risks according to this extension compared to traditional FMEA, leads to a more reliable and convincing prioritization.

1. Introduction

All organizations, companies and industries are bound to provide a safe and healthy workplace, which could be achieved by implementing HSE concepts. The final aim of HSE system implementation is to provide services, products and processes by taking into account health, safety and environmental considerations. Accomplishing HSE principles definitely results in workforce satisfaction and health, continued production, service delivery, prevention of excessive costs, elimination of wastes, and providing sustainable development which are the interest of manufacturers and decision makers. Therefore, in today's highly competitive world, the management of HSE is an indispensable part of any organization and managers should focus on HSE management principles more than other management fields. HSE principles have been defined based on a series of guidelines which usually follow the same structure, and are to be followed in order to prevent accidents and occupational diseases, since they can be significantly affected quantity and/or quality of production and services. HSE system management is an approach to provide the desirable standard working conditions along with methods to identify, assess, control or eliminate risks in workplace. In other words, hazardous risks identification and assessment is the heart core of any professional safety and health management system. Risk assessment is a systematic process to measure quantitative and qualitative risks associated with hazardous materials, processes, actions and/or accidents on people, material, equipment, and environment (Covello and Merkhoher, 2013). There are many risk assessment approaches, but a useful assessment method not only to be simple but also should be proportionate to the nature of activities, processes, culture, and other aspects of the intended organization.

Besides, safety, health, and environment management systems are required to be implemented based on the principle of prevention in order to conserve workforce in organizations. Failure modes and effect analysis (FMEA) method is one of the risk assessment methods available that its main difference with other qualitative techniques is being a proactive action (not reactive). In implementation of FMEA, corrective actions are defined and implemented by identifying potential problems and calculating the risk to eliminate or reduce their occurrence possibility. In most studies in which FMEA method is used (Arabian-Hoseynabadi et al., 2010; Feili et al., 2013; Trafialek and Kolanowski, 2014), risk identification and ranking is carried out based on traditional

* Corresponding author.
E-mail addresses: s.yousefi@ine.uut.ac.ir (S. Yousefi), a.alizadeh@ine.uut.ac.ir (A. Alizadeh), hayati.jamileh@ine.uut.ac.ir (J. Hayati), Bagheri@ppt.co.ir (M. Baghery).

http://dx.doi.org/10.1016/j.ssci.2017.10.015
Received 16 June 2017; Received in revised form 24 September 2017; Accepted 24 October 2017

risk priority number (RPN) score. This score focuses improvement effort on the risks that may have less severity with a higher RPN compared to other risks with lower RPN (Rezaee et al., 2017a). Additionally, conventional FMEA considers only three indices of severity (S), occurrence (O) and detection (D) (RPN determinant factors) in risks assessment which leads to inefficiency of traditional RPN score. Therefore, when using FMEA method to assess HSE risks, considering other indicators apart from three indices of SOD (the first letter of severity, occurrence and detection) is required. So in this study, in order to overcome the shortcomings of conventional FMEA, two additional factors including cost and duration (idle time of equipment) of treatments, have been considered which are directly associated with risks. However, these two extra mentioned factors can vary according to the personnel physical conditions, nature of risks and situation which risk occurred, which contaminated these indicators with inherent uncertainty. So considering deterministic values for these two factors may lead to uncertain, unrealistic and unreliable results and prioritization. Therefore, it is necessary to consider uncertainty in the two mentioned factors in order to get closer to the real world problems.

This study aims at providing a new score for HSE risks. This score integrate the two new parameters of cost and duration of treatments with RPN determinant factors and also can consider uncertainty of mentioned parameters, simultaneously. For simultaneous consideration of these indicators for each risk in the process of risk prioritization, conventional data envelopment analysis (DEA) can be used and provide a score accordingly (Rezaee et al., 2017b). However, a vital assumption in linear programming models such as DEA is that whole data is deterministic and equal to the nominal values. This assumption considers no effects of uncertainty on data on the quality and feasibility of model or solution, where a small perturbation could make a big change in feasibility, ranking and evaluation (Sadjadi and Omrani, 2008). This problem led researchers to extend optimization approaches which are immune in dealing with uncertainty and named as so-called robust optimization. Stochastic programming and sensitivity analysis are two classic methods to deal with uncertainty, however capability of robust optimization to meet uncertainty in high number of data and generation a robust solution makes this model an alternative to mentioned classic methods (Ben-Tal and Nemirovski, 2000; Bertsimas and Sim, 2004; Bertsimas and Sim, 2006).

So, in order to cover the disadvantages of traditional RPN, this study suggests new scores obtained from robust data envelopment analysis (RDEA) method based on RPN determinant factors and important indicators in the HSE management for risk prioritization; so that RPN factors are considered as inputs of RDEA method, and treatment's cost and duration (HSE indicators) as uncertain undesirable outputs in this method. Furthermore, in RDEA method, each indicator's weight is determined using mathematical models due to which result dependency on individual's opinion of risk prioritization can be reduced. It should be noted that the RDEA method can provide the necessary score for decision making when probability distribution function for data is not clear. The proposed approach was applied to evaluation of HSE risks in a company active in manufacturing automotive spare parts and then results were analyzed. Examining the rules of safety, health, and environment is one of the most important factors in automotive industry in which HSE management system requirements can be effective in elimination of problems. Since, in automotive industry, workers are exposed to many hazardous chemical and physical factors including inappropriate lighting, unpleasant smell, inhalation of chemicals, high frequency sound, electricity shocks, poor ergonomics, carry heavy load, falling mold during work, falling parts during carriage, Burr/chip projected while working and etc. that may lead to an accident or chronic occupational diseases which present the importance of HSE in this industry. Afterwards, after prioritization of identified risks, solutions were provided to reduce and/or eliminate the effects of critical risks as well as to improve HSE management process.

The rest of the paper is as follows: in Section 2, literature of related works on FMEA and HSE are reviewed. Sections 3 and 4 provides the methodology of the FMEA and RDEA methods respectively. In Section 5, the proposed approach is described. A case study has been investigated in Section 6. In Section 7, results of implementing proposed approach are presented and analyzed. Finally, in Sections 8 and 9, executive solutions and conclusions of the present study are provided.

2. Literature review

In recent years, world has experienced an increasing growth in technology and industrial development. Although this rapid development has great effects on productivity and economic prosperity, it brings challenges including problems of health, safety, and environment. According to the international labor organization (ILO) statistics (ILO, 2017), 317 million occur annually in the world which leads to irreparable financial and human life losses. More than 2.3 million people die around the world each year due to the consequences of occupational accidents and/or work-related illnesses. Also occupational accidents cause financial losses up to 4% of global gross domestic product (GDP) (ILO, 2017).

HSE management implementation by reducing consequences of HSE risk effects such as employee absenteeism, human resources disabilities, and poor quality of product can increase the organization's income. The importance of this issue has led to increasing researches in the field of safety, health, and environment. These studies have been carried out either qualitatively or mathematically methods in various fields. Some of these issues include the management of HSE (Duijm et al., 2008; Nassiri et al., 2016), study of the conditions and factors affecting the occupational health and safety (Høivik et al., 2009; Nordlöf et al., 2017; Moussiopoulos, 2017; Baguma, 2017), assessment of HSE (Azadeh and Sheikhalishahi, 2015; Azadeh et al., 2015; Işık and Atasoylu, 2017; Yan et al., 2017), and preventive management of HSE (Griffith, 2002; Motter and Santos, 2017). Methods used in these studies include fuzzy logic, FMEA method, economic models, statistical analysis, Taguchi method and meta-heuristic algorithms. Amongst methods used in risk identification, FMEA is one of the widely used methods in literatures.

Oraee et al. (2011) evaluated risks associated with health, safety and environment using fuzzy FMEA in underground mining. Fuzzy FMEA can perform better in the absence of sufficient information on conventional FMEA. Results obtained from implementation of FMEA method in Tabas coalmine indicate that rock explosion is the most dangerous parameter. Sarkheil and Rahbari (2016) examined HSE key indicators using FMEA and analytical hierarchy process (AHP). HSE management system is considered as a critical system in the field of career to achieve economic considerations, sustainable development, society and the environment. Weakness of RPN score in risk prioritization in some cases encourages researchers to use hybrid methods. Amongst these methods is the use of mathematical techniques such as FMEA method combined with DEA. In order to determine ranking indices, Garcia and Schirru (2005) provide a DEA approach in which the conventional parameters of FMEA are modeled as fuzzy sets. In this study, the rules of “if-then” can be eliminated. The proposed approach was implemented to a typical drinking water system. The results indicate potential combination of fuzzy logic and DEA for these types of problems. Chin et al. (2009), in their study, present a type of FMEA method which utilizes DEA. The proposed method measures minimum and maximum risk for each failure mode. In order to measure the overall risk of failure modes, geometric mean of both risks is calculated. Risk prioritization in terms of general risks is calculated instead of maximum and minimum risks. Chang and Paul Sun (2009), to enhance the ability to assessment of FMEA method, have used DEA method. In this approach, through the DEA and its expansion, the proposed method prioritizes failure modes using the SOD factors instead of RPN. Through a proposed example, it was indicated that not only DEA could be complement of the traditional FMEA method, but also it provides corrective information considering failure, severity, occurrence and