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Risk analysis of sequential processes in food industry integrating multi-stage fuzzy cognitive map and process failure mode and effects analysis

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ABSTRACT

Since managers and staff have not understood the actual consequences of risks in the food industry well, risk management methods practically are limited to identification of the type of risks. In addition, created changes in the business environment have led to change in the attitude of risk management to a process-oriented and systematic view. Because managers cannot decide based on the output of risk management process to implement improvement projects and allocate resources to them. This study has been tried to exactly identify and prioritize potential failures of the production process by using an approach based on the multi-stage Fuzzy Cognitive Map (FCM) method and Process Failure Mode and Effects Analysis (PFMEA) technique with the help of the cross-functional team. In this approach, failures are prioritized according to the amount of impact of each failure on other failures, as well as the amount of three factors as severity, occurrence, and detection (outputs of PFMEA). This approach considers process-oriented view in manufacturing system through internal-stage and external-stage relationships between production process failures and covers disadvantages of traditional Risk Priority Number (RPN) score such as disregarding internal relationships between failures. Hence, prioritization of potential failures based on the score which includes RPN determinant factors and causal relationships between failures is performed using the multi-stage FCM and learning algorithm based on extended Delta rule. The results of the proposed approach's implementation in an active company in the food industry show that prioritization of failures is closer to reality and presents more full prioritization in comparison with approaches such as traditional RPN. The real case study in the food industry has been used to show the ability of the proposed approach.

1. Introduction

Due to today's competitive environment, businesses are changed continuously. Such changes and dynamic conditions which are affected by technological, economic, political, and other issues, create new and susceptible opportunities for production units. Therefore, in this situation, the quick adaptation ability with created changes is necessary for their survival (Berjis, Shirouyehzad, & Tavakoli, 2015). The parameters of time, cost, human resources and the quality of goods play an important role in the success of any business. Inefficiencies or failures in each of these fields can lead to business failure (Shenhar, 2001). Therefore, risks associated with goods production should be evaluated and if they have priority, be corrected at the first step of production. Decision making to choose the most important risk factors plays an important role in the industry. Among the production industries, the food industry is exposed to more risks with higher coefficients in their processes. Direct connection with human life on the one hand and income of food selling and job creation, on the other hand, have led the food industry to become one of the key industries in each region (Maloni & Brown, 2006). In the food industry, products from converting raw materials until final packing may be affected by various risk factors that led to producing unsafe products which can affect consumers' health and have irreparable economic consequences for the food industry (Gao, Shao, & Chi, 2013). Therefore, risk assessment in the food industry is very vital.

One of the risk assessment techniques is Failure Mode and Effects Analysis (FMEA), which has been introduced as a valid technique among risk assessment techniques (Oldenhof et al., 2011). In the conventional FMEA technique, Risk Priority Number (RPN) is used to calculate the risks of various system failure modes. RPN is a multiplication of the three risk factors as Severity (S), Occurrence (O) and Detection (D) (Liu, Liu, & Liu, 2013). The purpose of calculating RPN is to prioritize the failure modes so that, each failure with the highest RPN score is located in top priority (Stamatis, 2003). But this indicator has some shortcomings. In the traditional RPN score, the relative importance of the S, O, and D (SOD) factors are not included in the

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calculation of this score and their weights are considered same. However, in reality, this can be a limitation (Chanamool & Naenna, 2016). The computational formula of RPN is unreliable and does not have a strong scientific foundation. In other words, there is no specific logic about the cause of multiplication of the SOD factors in calculating RPN (Kutlu & Ekmekçioğlu, 2012; Liu, Liu, Liu, & Mao, 2012). Also, RPN is the multiplication of three descriptive factors that cannot be used as a precise measurement indicator. So the results are not only meaningless but also misleading (Yang, Huang, He, Zhu, & Wen, 2011). Furthermore, one of the basic problems of RPN is determining SOD factors for each failure independently and disregarding causal relationships between failures which can lead to change in the priority of survey on failures (Liu et al., 2013). Because in reality and according to the process-oriented view, production stages are not implemented simultaneously, and also potential failures do not occur simultaneously; in fact, some failures are affected by the failures of previous stages and affect failures of subsequent stages (Rezaee, Yousefi, & Babaei, 2017).

Due to the mentioned problems, to overcome these problems, a novel score is needed to prioritize failures based on the three mentioned determinative factors of RPN in the FMEA and causal relationships between failures. Also, since in the studied process, all activities are affected by previous stages (processes) activities, it is necessary to consider relationships between stages with a multi-stage approach. Hence, in this study, to improve the accuracy of prioritization, the score obtained from the multi-stage Fuzzy Cognitive Map (FCM)-Process Failure Mode and Effects Analysis (PFMEA) approach, is used to prioritize failures instead of conventional RPN score. Actually, this approach prioritizes failures according to the amount of impact of each failure on other failures (through the occurrence of that failure or occurrence of previous stage failure), as well as the amount of the SOD factors. In this approach, in addition to considering causal relationships between failures using FCM, it is possible to consider the connections among stages with a multi-stage view. In order to validate this score, potential failures in the production processes of food industry which have been identified by systematic failure analysis, prioritize by the score obtained from the proposed multi-stage FCM-PFMEA approach and learning algorithm based on modified extended Delta rule.

The rest of this study is organized as follows: In Section 2, some studies are reviewed in three subsections as FMEA applications, FMEA in the food industry, and FCM applications. In Section 3, supplementary explanations of the PFMEA technique, multi-stage FCM method and learning algorithm based on Delta rule are presented. In Section 4, the proposed approach of this study is provided. In Section 5, a case study is introduced and in Section 6, the analysis of results from the implementation of multi-stage FCM-PFMEA approach is carried out. Finally, in Section 7, the conclusions and development suggestions of this study are expressed.

2. Literature review

In recent years, different risk assessment techniques have been developed that one of them is FMEA. This technique was first used for systematic analysis of failures modes and their subsequent consequences in the aeronautical industry (Bowles & Peláez, 1995). This technique focuses on preventing the occurrence of failures and defects, increasing safety and customer satisfaction (Wang, Chin, Poon, & Yang, 2009). Because FMEA is introduced as a supportive tool for designers, it has been widely used in a wide range of industries (Chang & Cheng, 2011; Rakesh, Jos, & Mathew, 2013; Rezaee, Salimi, & Yousefi, 2017; Wang et al., 2009). One of the most important applications of this technique is in the food industry. Hence, today FMEA has become one of the most popular and common methods among managers because of its applications in various fields. But, due to the mentioned limitations of FMEA in the previous section, some researchers have combined FMEA technique with Multi-Criteria Decision Making (MCDM) techniques to improve the process of determining, analyzing and reducing the failures in various industries. On the other hand, in the real world, there are many factors that have complex relationships with other factors, so many of them are affected by some factors and affected some others. One of the methods to consider these relationships and cover some disadvantages of MCDM techniques is the FCM method (Kosko, 1986; Rezaee & Yousefi, 2018). Due to a large number of researches and for a better understanding of studies which have been carried out in these fields, they are reviewed in three subsections as FMEA applications, FMEA in the food industry, and FCM applications.

2.1. FMEA applications

As mentioned, the FMEA technique is one of the popular techniques in risk assessment. In order to risk prioritization in FMEA, Garcia, Junior, Curty, and Oliveira (2013) proposed a weight restricted Data Envelopment Analysis (DEA) approach and performed this method in a pressurized water reactor power plant. A combination of fuzzy belief Technique for Order Preference by Similarity to Ideal Solution) TOPSIS) with FMEA and presented a belief structure FMEA model to improve risk assessment in steel production was done by Vahdani, Salimi, and Charkhchian (2015). Baghery, Yousefi, and Rezaee (2016) proposed a hybrid approach based on process failure analysis, interval DEA and Grey Relational Analysis (GRA) for risk assessment and prioritization of auto parts manufacturing processes. Another study about risk assessment is a new hybrid model based on FMEA, fuzzy Analytic Hierarchy Process (AHP), TOPSIS, and GRA to risk assessment of automotive dust cap production in manufacturing industry (Sakthivel & Ikua, 2017). Razi and Hoseini (2017) carried out a study about clustering and ranking in a manufacturing process (the Paper Machine Type) and presented a new method of FMEA. They clustered failures modes via KOHNEN neural network and evaluated them in own classes using the SBM-DEA model.

Ahmadi, Molana, and Sajadi (2017) evaluated risks of the Steel Company in Iran proposing a combined method based on FMEA and TOPSIS. In order to classify failure modes in the dairy manufacturing processes, Certa, Enea, Galante, and La Fata (2017) presented an ELECTRE TRI-based approach. Their method which has been used instead of traditional RPN for the assessment of process/system failure modes, classify risks with considering the relative importance and of risks factors and their uncertainty. Another study about risks evaluation in steel industries was done by Fattahi and Khalilzadeh (2018). Authors proposed a new method which is a combination of FMEA, extended MULTIMOORA, and AHP methods under fuzzy environment. Peeters, Basten, and Tinga (2018) presented a hybrid method with using Fault tree analysis (FTA) and FMEA in a recursive manner and performed this method in an additive manufacturing system for metal printing. Also, integrating FMEA and robust DEA with undesirable outputs to HSE risk management is one of the other hybrid methods that has been used (Yousefi, Alizadeh, Hayati, & Baghery, 2018). Baynal, Sarı, and Akpınar (2018) applied a combination of GRA and FMEA to enhance productivity in the automotive manufacturing process. A combined method with using VSM, plant layout, fuzzy QFD and fuzzy FMEA techniques to select lean tools in manufacturing organization was introduced by Bhuvanesh Kumar and Parameshwaran (2018).

2.2. FMEA in the food industry

Another application of FMEA is in the analysis of risks in the food industry. Varzakas and Arvanitoyannis (2007) applied FMEA, cause and effect analysis, and Pareto diagram in conjunction with Hazard Analysis and Critical Control Points (HACCP) system to risk assessment in corn curl manufacturing. Also in another study, they used a combination of FMEA and ISO 22,000 system to risk evaluation of salmon processing and packing (Arvanitoyannis & Varzakas, 2008). To risk evaluation, Ozilgen (2012) used FMEA in confectionery manufacturing to improve the quality and safety of final products and Kurt and Ozilgen (2013)