Engineering Failure Analysis 31 (2013) 211–224

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

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

Enhancing FMEA assessment by integrating grey relational analysis and the decision making trial and evaluation laboratory approach

Kuei-Hu Chang [a,*], Yung-Chia Chang [b], I-Tien Tsai [b]

[a] *Department of Management Sciences, R.O.C. Military Academy, Kaohsiung 830, Taiwan*
[b] *Department of Industrial Engineering and Management, National Chiao Tung University, Hsinchu 300, Taiwan*

ARTICLE INFO

Article history:
Received 23 November 2012
Received in revised form 8 February 2013
Accepted 8 February 2013
Available online 26 February 2013

Keywords:
Failure modes and effects analysis
Risk priority number
Grey relational analysis
Decision making trial and evaluation laboratory

ABSTRACT

Failure modes and effects analysis (FMEA) is used widely to improve product quality and system reliability, employing a risk priority number (RPN) to assess the influence of failures. The RPN is a product of three indicators—severity (*S*), occurrence (*O*), and detection (*D*)—on a numerical scale from 1 to 10. However, the traditional RPN method has been criticized for its four chief shortcomings: its (1) high duplication rate; (2) assumption of equal importance of *S*, *O*, and *D*; (3) not following the ordered weighted rule; and (4) failure to consider the direct and indirect relationships between failure modes (FMs) and causes of failure (CFs). To resolve these drawbacks, we propose a novel approach, integrating grey relational analysis (GRA) and the decision-making trial and evaluation laboratory (DEMATEL) method, to rank the risk of failure, wherein the GRA is used to modify RPN values to lower duplications and the ordered weighted rule is followed; then, the DEMATEL method is applied to examine the direct and indirect relationships between FMs and CFs, giving higher priority when a single CF causes FMs to occur multiple times. Finally, an actual case of the TFT-LCD cell process is presented to verify the effectiveness of our method compared with other methods in providing decision-makers more reasonable reference information.

1. Introduction

In the process of risk control, the first step is to eliminate the risks, which can be forecasted and removed, or to lower the possibility of the risk occurrence. Failure mode and effects analysis (FMEA) is primarily a risk assessment tool in risk control [1]. FMEA is used widely because it is simple to apply and understand, and it can be modeled using real situations. Many reports have discussed FMEA as a related subject. Ahmad et al. [2] proposed a new failure analysis method by integrating FMEA and failure time modeling that is based on the proportional hazard model to help engineers devise more effective maintenance strategies. Yang et al. [3] modified the Dempster–Shafer evidence theory under uncertainty to aggregate evaluation data by considering experts' opinions to solve risk evaluation problems. Chang and Cheng [4] combined fuzzy ordered weighted averaging (OWA) and the decision-making trial and evaluation laboratory (DEMATEL) approach to rank the causes of failure (CFs). However, the traditional FMEA method has several shortcomings. For instance, the severity (*S*), occurrence (*O*), and detection (*D*) indicators are discrete ordinal scales of measure; the calculation by multiplication is inappropriate [4–7]; and it ignores the relative importance between *S*, *O*, and *D* and assumes that they are assigned equal weight, which might not be true in practice [4–9]. Further, the FMEA method assumes that the risk priority number (RPN) is distributed

* Corresponding author. Tel.: +886 77403060.
E-mail address: evenken2002@yahoo.com.tw (K.-H. Chang).

1350-6307/$ - see front matter
http://dx.doi.org/10.1016/j.engfailanal.2013.02.020

evenly from 1 to 1000, but only 120 numbers can be generated—that is, certain disparate combinations of *S*, *O*, and *D* have equal RPN values [6,7]. FMEA only considers the *S*, *O*, and *D* indicators, but other factors, such as failure cost, might have to be included to approximate the actual situation [6]. Lastly, FMEA fails to consider the direct and indirect relationships between failure modes (FMs) and CFs [10] and does not follow the OWA criteria [4,11], which were proposed by Yager [12], prioritizing attributes based on the ranks of these weighting vectors after aggregation.

Many scholars have made improvements with regard to these shortcomings. Sankar and Prabhu [13] proposed a new technique to prioritize failures for corrective actions in FMEA, called risk priority ranks (RPRs), which uses expert knowledge and the if-then rule to analyze CFs and FMs and ranks RPRs from the highest to lowest. RPR values, ranked 1 through 1000, are used to represent the 1000 possible combinations of *S*, *O*, and *D*. This approach mitigates the problems of high duplication rate and the assumed equal importance of *S*, *O*, and *D*, but ranking 1000 possible combinations of *S*, *O*, and *D* is difficult and time-consuming. Gilchrist [14] proposed an expected cost model as the basis for ranking FMs, using $EC = Cnp_fp_d$ to calculate the expected cost of failures, where C is the failure cost, n is the annual production quantity, and p_f is the probability of failure; p_d means that the probability is not detected. Chin et al. [6] used the group-based evidential reasoning approach to capture FMEA team members' opinions and employed the minimax regret approach to rank expected risk scores. Braglia [15] adopted the analytic hierarchy process (AHP) technique to develop a multiattribute failure mode analysis approach, which integrates four factors—chance of failure, chance of nondetection, severity, and expected cost—to rank causes of failure. Shahin [16] concluded that the severity indicator of traditional FMEA is determined by the designers' perspective, not according to the customers, and used the Kano model to convert it to a customer-oriented model.

Bowles and Pelaez [17] were the first to use a fuzzy logic-based approach for criticality analysis. Since its appearance, the fuzzy logic-based approach has been analyzed extensively by many groups. Chang et al. [8] applied a fuzzy logic approach to evaluate linguistic *S*, *O*, and *D* indicators directly and used grey theory to determine the risk priority of potential causes. Braglia et al. [5] combined the technique for order preference by similarity to ideal solution (TOPSIS) and triangular fuzzy numbers for failure criticality analysis. In this approach, fuzzy logic was used to assess *S*, *O*, and *D* and their relative weights of importance rather than generating precise numerical values. Other groups have used fuzzy logic to improve the traditional FMEA method [7,18], but these methods do not consider the direct and indirect relationships between FMs and CFs, which might cause biased conclusions.

Recently, Seyed-Hosseini et al. [10] first used the DEMATEL approach to analyze relationships between components and assigned new priorities to CFs and FMs. But, if all FMs are due to distinct causes (CFs), such ranking will equal the traditional RPN method. This study reports a novel approach to overcome these shortcomings, using the GRA to lower the high duplication rate and mitigates the violation of the ordered weighted rule in the RPN method and inputs the analysis results into DEMATEL to examine the relationships between components in a system.

In Section 2, the literature is reviewed briefly. A novel approach that integrates grey relational analysis and the DEMATEL method is proposed in Section 3. An actual case of FMEA of the thin-film transistor liquid crystal display (TFT-LCD) cell process is analyzed to demonstrate the effectiveness and feasibility of the proposed approach in Section 4. Finally, Section 5 discusses our conclusions.

2. Related work

2.1. FMEA overview

FMEA was developed by the US military in the late 1940s as an assessment method to improve the evaluation of the reliability of weapons and military systems, culminating in the publication of the military standard MIL-STD-1629 in 1949. However, it did not suit military requirements completely and was revised in 1980 to MIL-STD-1629A [19]. This method was adopted by the National Aeronautics and Space Administration (NASA) during the Apollo space missions in the 1960s. In 1985, the International Electrotechnical Commission (IEC) published an international standard of FMEA, IEC 60812, to analyze system reliability [20]. The automotive industry used FMEA as a risk assessment method in the product design stage and manufacturing process. In 1993, the Automotive Industry Action Group (AIAG) and American Society for Quality (ASQ) united Daimler Chrysler Corporation, Ford Motor Company, and General Motors Corporation to create an FMEA reference manual to meet QS-9000 requirements [21]. FMEA is viewed as a risk assessment tool for improving the analysis of quality, except by the military and automotive industry. Certain international quality organizations, such as the International Organization for Standard (ISO), use FMEA as an important analysis measure in the ISO-9000 series. Today, FMEA is used extensively in industries, such as the aviation, automotive, machinery, medical, food industry, and semiconductor industry.

Traditionally, FMEA uses the risk priority number (RPN) to evaluate the risk of failure. The RPN value is the product of *S*, *O*, and *D* on a scale from 1 to 10. When a CF has a higher RPN value, this failure influences the system more significantly and requires a higher priority. A typical set of failure factor rankings and criteria are defined in Table 1 [16].

2.2. Grey theory

Nearly all systems fail to capture information perfectly, and some existing information is uncertain due to limited knowledge and cognition. Deng [22] first proposed the grey theory in 1982 to deal with the analysis of systems that are plagued by