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Generalized multi-attribute failure mode analysis

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ABSTRACT

Modern technology products are becoming more advanced, complex, and expensive, necessitating the use of failure mode and effects analysis (FMEA) to stabilize production and enhance market competitiveness. Traditional FMEA adopts the risk priority number (RPN) to stabilize production and monitor risks of failure. The RPN has 3 parameters—severity (*S*), occurrence (*O*), and detection (*D*)—which are used to assess and prioritize potential risks in production. Although the traditional RPN is efficient, it has several shortcomings. For example, it assumes that weighting factors have equal weight, it fails to examine the nature of problems stepwise and structurally, available information can be lost easily, and priority orders are assessed identically with high frequency. Thus, to improve the RPN, we propose an integrated method, combining multiattribute failure mode analysis (MAFMA) and 2-tuple representation, called generalized multiattribute failure mode analysis (GMAFMA). This study uses a TFT-LCD product of a technology company in Taiwan as an actual case study and compares the RPN, MAFMA, and GMAFMA by numerical verification, demonstrating that the disadvantages above are improved and obtaining a more reasonable assessment of risk priority. This method provides references that enhance process stability and reduce the risk of failure for managers.

1. Introduction

Failure mode and effects analysis (FMEA) originated from the National Aeronautics and Space Administration (NASA). It is primarily a proactive technique in risk control that identifies critical risk events to avoid potential failure modes. FMEA has been used in the development of electronics and weapon systems by the Department of Defense since 1963 and was introduces into vehicle-related product development management systems by the Automotive Industry Action Group (AIAG) in 1977 to enhance vehicle safety, satisfy customers' needs, and improve overall vehicle quality [1]. FMEA stresses the following 4 items: (1) prior prevention, (2) minimizing quality deviations of automobile components, (3) lowering poor production, and (4) preventing rising production costs, all of which in turn increase market competitiveness [2].

FMEA usually adopts 2 criticality evaluation methods: a criticality number (CN) and risk priority number (RPN). The most popular method is the RPN, which uses 3 parameters—severity (*S*), occurrence (*O*), and detection (*D*)—to assess and prioritize possible risks during production. The RPN is customized to identify discrepancies in the overall system design by identifying critical factors. Further, advances in computer technology have facilitated the solution process [2]. Consequently, FMEA is applied in military [3,4], academia, and production industries, such as autonomous aircraft [5], automobiles [6], electricity [7,8], knitting [9], color super-twisted nematic (CSTN) [10], medicine [11] and semiconductors [12–14].

However, the RPN has drawbacks in identifying solutions, such as determining the relevance between *S*, *O*, and *D* factors and assuming that these factors are equally weighted [15], a high duplication rate [1], and its failure to address problems by hierarchical analysis [2]. These shortcomings affect the accuracy of the solutions—for example, some RPN values in certain scenarios are lower than in others, creating potential danger.

The analytical hierarchy process (AHP) was developed by Saaty in 1980. It is a powerful and flexible multicriteria decision-making tool. Many studies have demonstrated that the AHP considers qualitative and quantitative aspects for complex problems [16,17]. Through series of simple comparisons and rankings to address such problems, it provides a clear rationale for alternative options and judgments that have been made and helps decision-makers and analysts identify the best preference. The AHP can be decomposed in a hierarchical structure from high to low using these goals, factors, and alternative causes of failure and by evaluation through a series of pairwise judgments. By numerical analysis to determine the critical factors with a higher degree of influence, the relative weights of decisions are calculated at different hierarchies. The AHP can mitigate some of the drawbacks of the RPN by analyzing the *S*, *O*, and *D* variables,

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generating a result that is a more realistic and flexible reflection of the actual situation [18].

Many scholars have started using the AHP, which is an effective means of quantifying and ranking critical failures in FMEA. For example, Su and Chou [18] adopted the AHP with the FMEA method to address problems in the semiconductor wafer manufacturing industry in 2008, prioritizing and sorting 6 sigma items and assisting top-level management making decisions with regard to critical projects. Conversely, Kutlu and Ekmekcioglu [19] applied fuzzy TOPSIS-based fuzzy AHP to solve the problems of small and – medium-sized corporations in the automotive industry.

Traditional FMEA can not solve problems in different hierarchies and fails to consider important information comprehensively, often generating the same evaluation results during the solution phase. These weaknesses can cause biased conclusions to be made; FMEA can not perform a risk assessment of the advantages and disadvantages effectively or determine the relative importance of various evaluation parameters. In 2000, Herrera and Martinez [20] proposed a concept of linguistic 2-tuples that communicates through symbols, called the “2-tuple linguistic representation model”. This method can help generate information precisely and manage complicated semantic information simply [21]. During the last decade, many scholars proposed several methods that were based on the linguistic 2-tuple for many disciplines, such as multicriteria decision-making [22], group decision-making [23,24], consensus reaching processes [25], risk evaluation [26,27], agricultural information evaluation systems [28], recommender systems [29], human resources performance appraisal [30], product design and development [31], health-related web quality evaluation [32], and product concept selection projects [33].

Over the past decade, many scholars via combine different methods to improve the shortcomings of traditional FMEA method. For example, Seyed-Hosseini et al. [34] integrated the RPN and decision-making trial and evaluation laboratory (DEMATEL) approaching to reprioritization of failure modes in a FMEA. Chang and Sun [35] applied the DEA technique (CCR AR model) to enhance assessment capabilities of FMEA. Chang and Wen [36] integrated 2-tuple and the ordered weighted averaging (OWA) operator for prioritization of failures in a product design FMEA, and a case study on assess the risk of the color super twisted nematic (CSTN) in a midsized manufacturing factory has been reported. Rahimi et al. [37] proposes an integrated approach that combined fuzzy cost-based FMEA, grey relational analysis (GRA), and profitability theory for evaluating and improving the potential failures of Internal Medicine service of a hospital that located in Seoul, Korea. However, these methods had not been indicated that the hierarchical relationship between the objective of the problem, evaluation criteria, and solution. Recently, Braglia [2] developed an approach that was based on the AHP technique, called multi-attribute failure mode analysis (MAFMA), which uses 4 risk factors (*S*, *O*, *D*, and expected cost) as decision-making criteria. Based on the hierarchical relationship between the objective of the problem, evaluation criteria, and solution, MAFMA uses a pairwise comparison matrix to estimate criterion weights, by which it synthesizes local priorities into the global priority. Despite its usefulness, MAFMA uses the arithmetic mean to evaluate *S*, *O*, and *D* data from experts, like the RPN, losing valuable information and thus generating an incorrect result and affecting strategic decisions. To resolve the problems of evaluations by the RPN method above, we propose a novel method that integrates multiattribute failure mode analysis (MAFMA) and the 2-tuple representation method.

The remainder of this paper is organized as follows. Section 2 presents a review of the pertinent research methods, such as FMEA, MAFMA, and the 2-tuple representation method. In Section 3, the new approach is applied, integrating MAFMA and the 2-tuple representation method for risk assessment and prioritization. Section 4 presents a data analysis case of a 2-in. thin-film-transistor liquid crystal display (2-in. TFT-LCD) product and compares the methods from Section 2. Section 5 summarizes the main conclusions.

Table 1
Typical rankings of failure mode indices [38].

Level	Severity	Occurrence	Detection
1	No	Almost never	Almost certain
2	Very slight	Remote	Very high
3	Slight	Very slight	High
4	Minor	Slight	Moderately high
5	Moderate	Low	Medium
6	Significant	Medium	Low
7	Major	Moderately high	Slight
8	Extreme	High	Very slight
9	Serious	Very high	Remote
10	Hazardous	Almost certain	Almost impossible

Table 2
Nine-point scale of the pairwise comparison [2].

Intensity of relative importance	Definition
1	Equal
3	Moderately
5	Strongly
7	Very strongly
9	Extremely
2, 4, 6, 8	Intermediate judgment between two adjacent scores

2. Related work

2.1. FMEA

FMEA was developed to translate characteristics of production design to definite operation conditions and ensure that the final results and performance meet customers’ needs and expectations. After distinguishing potential failure modes and effects during production, potential failure risks can be eliminated through corrective measures. Consequently, the severity and occurrence of FMEA can be lowered, and its detectability of failures can be increased. In 1977, Ford Motor Company used FMEA in its standard operating procedures, generally for production. Because of the outstanding results with Ford Motor Company, the US automotive industry gradually adopted FMEA as a risk assessment tool [1].

Table 3
RI values for different matrix orders [16].

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59