Preface

Since its introduction by the NASA in 1960s, failure mode and effect analysis (FMEA) has been extensively used to help assure the safety and reliability of products in various industries. Central to FMEA is the prioritization of failure modes based on risk priority number (RPN), which is calculated by the product of the risk factors occurrence (O), severity (S), and detection (D) scaled by experts with an integer number from 1 to 10. However, the conventional RPN method has been criticized as having many inherent deficiencies, thus affecting its effectiveness and limiting its actual applications. In the processes of risk assessment, FMEA team members may not possess a sufficient level of knowledge regarding the risk analysis problem due to the increasing complexity of products, designs, processes, and/or services. In such cases, they usually have some uncertainty in providing their judgments on the identified failure modes, which makes the results of risk evaluation exhibit the characteristics of uncertainty, fuzziness, and imprecision. Besides, the mathematical formula (i.e., multiplication) adopted for determining the failure priority is questionable and lacks adequate scientific basis. For example, the relative weights of risk factors are not taken into account; different combination of O, S, and D ratings may produce the same value of RPN, but their risk implications may be different; the risk factors are evaluated according to discrete ordinal scales of measure, but the calculation of multiplication is meaningless on ordinal scales.

Over the past decades, the improvement of FMEA has been receiving more and more attention from researchers, and a lot of alternative risk priority models have been suggested in the literature to resolve the shortcomings and enhance the performance of the traditional FMEA. First, many uncertainty theories, such as fuzzy set, Dempster–Shafer (D–S) theory, and intuitionistic fuzzy set (IFS), have been utilized to deal with the vagueness and uncertainty in making the criticality assessment. On the other hand, multi-criteria decision-making (MCDM) methods are one of the most popular approaches employed to prioritize the failure modes recognized in FMEA, which can enhance the efficacy and empirical validity of risk assessment results. We remark, despite the existence of other types of FMEA models (such as mathematical programming and artificial intelligence), that the

MCDM-based FMEA under uncertain environment has a series of unique advantages.

The FMEA theory is undergoing continuous in-depth study as well as continuous expansion of the scope of its applications. As such, it has been found that effective assessment and ranking of the failure modes that have been individuated in FMEA becomes increasingly important. Evaluation information modeling and decision-making tools, including uncertainty theories for modeling the ambiguities of risk assessments and MCDM techniques for the priority ranking of failure modes, have broad prospects to improve the criticality analysis process of FMEA, but pose many interesting yet challenging topics for research.

In this book, we will offer a thorough and systematic introduction to the modified FMEA models based on uncertainty theories (e.g., fuzzy logic, IFS, *D* numbers and 2-tuple linguistic variables) and various MCDM methods such as distance-based MCDM, compromise ranking MCDM, hybrid MCDM, etc. The book is structured as the following five parts, which contain 13 chapters.

Part I consists of two chapters (Chaps. 1 and 2), which introduce the traditional FMEA and review the risk evaluation approaches based on uncertainty theories and MCDM methods in FMEA literature. Concretely speaking, Chap. 1 introduces the basics of FMEA, covering its development, implementing procedure, and basic terminology, and summarizes the major shortcomings of the conventional RPN method when applied in practical situations. Chapter 2 makes a comprehensive review of the academic works employing uncertainty theories and MCDM methods to overcome the deficiencies of the traditional FMEA, based on which the current research trends and future research directions in this field of study are also highlighted.

Part II consists of four chapters (Chaps. 3–6), which introduce the FMEA models by using distance-based MCDM methods. Specifically, Chap. 3 introduces the risk assessment methodology for FMEA using intuitionistic fuzzy hybrid weighted Euclidean distance (IFHWED) operator, and illustrates it with an example of developing new horizontal directional drilling (HDD) machine. Chapter 4 introduces the risk priority model for FMEA using interval 2-tuple hybrid weighted distance (ITHWD) measure, and gives its illustration with a case study of blood transfusion. Chapter 5 presents the risk priority model for FMEA based on fuzzy evidential reasoning (FER) and grey relation analysis (GRA) method, and illustrates it by a numerical example. Chapter 6 presents an improved FMEA using *D* Numbers and grey relational projection (GRP) method, and applys it to a case of rotor blades for an aircraft turbine.

Part III consists of two chapters (Chaps. 7–8), which introduce the FMEA models based on compromise ranking MCDM methods. Concretely speaking, Chap. 7 introduces the risk ranking method for FMEA problems, in which fuzzy linguistic terms are used to assess the ratings and weights for risk factors and an extended VIKOR method is used to determine the risk priorities of failure modes. Also, this method is demonstrated with a numerical example concerning the risk analysis in general anesthesia process. Chapter 8 introduces the intuitionistic fuzzy hybrid TOPSIS (IFH-TOPSIS) approach to determine the risk priorities of the

failure modes identified in FMEA, and gives a product example of the color super-twisted nematic to show its feasibility and effectiveness.

Part IV consists of three chapters (Chaps. 9–11), which introduce the FMEA frameworks based on other MCDM methods. In Chap. 9, we introduce the risk assessment methodology based on fuzzy decision-making trial and evaluation laboratory (DEMATEL) for the prioritization of failures in system FMEA, and show its application in the thin-film transistor liquid crystal display (TFT-LCD) product. Chapter 10 introduces the risk priority method for FMEA, which uses fuzzy digraph and matrix approach for the risk evaluation of failure modes, and verifies its practicality via a case study of steam valve system. In Chap. 11, we present the FMEA model by applying fuzzy set theory and MULTIMOORA method for failure modes assessment and ranking, and apply it for the prevention of infant abduction in a healthcare facility.

Part V consists of two chapters (Chaps. 12–13), which introduce the FMEA approaches by utilizing hybrid MCDM methods. Specifically, Chap. 12 introduces the hybrid MCDM method for risk analysis based on combination weighting and fuzzy VIKOR method, in which fuzzy analytic hierarchy process (AHP) is combined with entropy method for risk factor weighting. Furthermore, this FMEA method is applied for analyzing the risk of general anesthesia process to illustrate its feasibility and applicability. Chapter 13 introduces the hybrid MCDM method for FMEA that uses a modified VIKOR to determine the effects of failure modes, the DEMATEL to construct the influential relations among failure modes and causes of failures, and the AHP approach to obtain the prioritization levels for failure modes. Finally, a numerical example concerning diesel engine turbocharger system is given to demonstrate the FMEA approach being proposed.

This book is useful for practitioners and researchers working in the fields of quality management, decision making, information science, and management science and engineering. It can also be used as a textbook for postgraduate and senior undergraduate students.

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