# Preface

Decision making always happens in our daily life, for example, choosing a car to buy, or selecting an electronic product from Amazon or Ebay. In the traditional multiple criteria decision making models, all evaluation values are precise, which is too ideal to match our daily life. To make it more applicable and efficient, the decision making models should depict the situation as close as possible to the real-world, but sometimes it is very difficult or impossible due to the incomplete information or knowledge and the complexity and uncertainty involved in the practical decision making problems. Many different theories and tools were proposed in the realm of decision making, such as the probability theory. However, in many cases, uncertainty is not probabilistic in nature but rather imprecise or vague, for example, "fast" speed, "cheap" price, "good" student, and so forth. The fuzzy set theory, which was originally introduced by Zadeh (1965), is one of the most efficient decision aid techniques providing the ability to deal with imprecise and vague information. Nonetheless, to cope with imperfect or imprecise information that two or more sources of vagueness appear simultaneously, the traditional fuzzy set shows some limitations. Hence, it has been extended into several different forms, such as the type 2 fuzzy set, the type $n$ fuzzy set, the interval-valued fuzzy set, the fuzzy multisets, and so on. All these extensions are based on the same rationale that it is not clear to assign the membership degree of an element to a fixed set. Recently, Torra (2010) proposed a new generalized type of fuzzy set called hesitant fuzzy set. The motivation of introducing such a set is that sometimes the uncertain membership degree is not due to possibility distribution (as in type 2 fuzzy set), or a margin of error (as in interval fuzzy set), but because of a set of possible values. The hesitant fuzzy set shows many advantages over the traditional fuzzy set and its extensions, especially in group decision making with anonymity. It opens new perspectives for research on decision making under hesitant fuzzy environments.

In this book, we give a thorough and systematic introduction to the latest research results on hesitant fuzzy decision making theory, which include the operational laws of hesitant fuzzy sets, the correlation and entropy measures of hesitant fuzzy sets, the hesitant fuzzy hybrid weighted aggregation operators,

the hesitant fuzzy multiple criteria decision making methods with complete or incomplete weights, the hesitant fuzzy preference relation theory, etc. We apply these methodologies to various fields such as decision making, medical diagnosis, cluster analysis, service quality management, e-learning management, environmental management, etc. The book is constructed into six chapters that deal with different but related issues, which are listed as follows:

Chapter 1 mainly introduces the state of the art of hesitant fuzzy sets. The chapter first defines the concept of hesitant fuzzy set. The mean and hesitant degrees of a hesitant fuzzy element are also defined. Then the chapter defines the operational laws of hesitant fuzzy elements, especially the subtraction and division operations. A theorem is given to show that the dimension of the derived hesitant fuzzy element may increase as the addition or multiplication operations are done, and thus, some adjusted operations are given. The comparison laws of hesitant fuzzy elements are given based on the score function and variance function of the hesitant fuzzy element. We also introduce the extensions of hesitant fuzzy sets, including the interval-valued hesitant fuzzy set, the dual hesitant fuzzy set and the hesitant fuzzy linguistic term set.

Chapter 2 introduces some novel correlation and entropy measures of hesitant fuzzy sets and applies them to hesitant fuzzy decision making. The chapter first points out the weakness of the existing correlation measures of hesitant fuzzy sets, and then introduces a novel correlation coefficient formula to measure the relationship between two hesitant fuzzy sets. The definitions of mean and variance of a hesitant fuzzy set are introduced. The weighted correlation coefficients are also defined. This chapter then applies the correlation coefficients to medical diagnosis and cluster analysis. After analyzing the existing entropy measures of hesitant fuzzy sets, this chapter introduces some novel two-tuple entropy measures of hesitant fuzzy sets.

Chapter 3 mainly introduces the hesitant fuzzy hybrid weighted aggregation operators for hesitant fuzzy information. The chapter first introduces the hesitant fuzzy weighted aggregation operators, such as the hesitant fuzzy weighted averaging operator, the hesitant fuzzy weighted geometric operator, the adjusted hesitant fuzzy weighted averaging operator, the adjusted hesitant fuzzy weighted geometric operator, the hesitant fuzzy ordered weighted averaging operator, the hesitant fuzzy ordered weighted geometric operator, the hesitant fuzzy hybrid averaging operator and the hesitant fuzzy hybrid geometric operator. Then the chapter points out the drawbacks of the existing hesitant fuzzy hybrid operators that they do not satisfy the desirable property, i.e., idempotency. To circumvent this flaw, a sort of new hesitant fuzzy hybrid weighted aggregation operators are introduced, such as the hesitant fuzzy hybrid weighted averaging operator, the hesitant fuzzy hybrid weighted geometric operator, the quasi hesitant fuzzy hybrid weighted averaging operator, the quasi hesitant fuzzy hybrid weighted geometric operator, and their generalized and induced forms. The properties of these operators are investigated in-depth. Finally, we apply these hesitant fuzzy weighted aggregation operators to multiple criteria decision making with hesitant fuzzy information.

Chapter 4 introduces the hesitant fuzzy multiple criteria decision making methods with complete weight information. After describing the hesitant fuzzy multiple criteria decision making problem and the basic idea of the VIKOR method, the chapter introduces the procedure of hesitant fuzzy VIKOR method to handle the problems where the assessments of alternatives on different criteria are given as hesitant fuzzy element and the weights of criteria are completely given as crisp values. This chapter applies the hesitant fuzzy VIKOR method to a service quality management problem. In addition, we also introduce the hesitant fuzzy ELECTRE methods, including the hesitant fuzzy ELECTRE I and the hesitant fuzzy ELECTRE II, for hesitant fuzzy multiple criteria decision making and apply these two methods to solve practical decision making problems.

Chapter 5 introduces the hesitant fuzzy multiple criteria decision making methods with incomplete weight information. Based on the definitions of hesitant fuzzy positive ideal solution and the hesitant fuzzy negative ideal solution, the satisfaction degree of an alternative is introduced. Then, we construct several optimization models to derive the weights of criteria, and discuss the interactive method for multiple criteria decision making problems with hesitant fuzzy information. In addition, we introduce the minimum deviation methods for hesitant fuzzy multiple criteria decision making with incomplete weight information and address the corresponding interval-valued cases. This chapter also presents how to solve the hesitant fuzzy multiple stages multiple criteria decision making problems where the weights of different stages are unknown.

Chapter 6 introduces the hesitant fuzzy preference relation and its multiplicative consistency as well as its consistency index. The chapter defines the concept of hesitant fuzzy preference relation and investigates its desirable properties. The concepts of multiplicative consistency, perfect multiplicative consistency and acceptable multiplicative consistency of a hesitant fuzzy preference relation are defined. Then the chapter introduces two algorithms to improve the consistency level of a hesitant fuzzy preference relation. The chapter provides a method to determine the values of the consistency index of hesitant fuzzy preference relations with different orders. Afterwards, we investigate the consensus reaching process of group decision making based on the hesitant fuzzy preference relations. Finally, the chapter presents how to use interval-valued hesitant fuzzy preference relation in group decision making.

This book is suitable for the engineers, technicians, and researchers in the fields of fuzzy mathematics, operations research, information science, management science and engineering, etc. It can also be used as a textbook for postgraduate and senior-year undergraduate students of the relevant professional institutions of higher learning.

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