Preface

The book has a monographic nature and contains scientific results in the field of contemporary approaches to adaptive decision-making and decision. Its purpose is to present an application and demonstration of a new mathematical technique and possibilities for mathematical descriptions of complex systems, in which human speculative knowledge is decisive for the final solution. The aspiration for quantity measurements, estimations, and prognosis at all phases of decision-making and problem solving is natural. However, this task is carried out with very scarce initial information, especially in the initial development phase in complex problems and situations. In the initial stage of a decision process, the heuristic of the investigator is very important, because in most of the cases there is a lack of measurements or even clear scales under which to implement these measurements and computations. This stage is often outside of the strict logic and mathematics and is close to the art, in the widest sense of the word, to choose the right decision among a great number of circumstances and often without associative examples of similar activity. The correct assessment of the degree of informativity and usability of this type of knowledge requires careful analysis of the terms measurement, formalization, and admissible mathematical operations under the respective scale, which do not distort the initial empirical information.

In the book, we propose approaches and methods for measurement and analytical presentations of empirical and scientific knowledge expressed as preferences. The problem of human preference and their implementation in information systems is certainly one of the important topics in decision-making for the forthcoming years, as witnessed by some current activity in this area, from the standpoint of utility theory. According to social-cognitive theories, people’s strategies are guided both by internal expectations about their own capabilities of getting results and by external feedback. Internal human expectations and assessments are generally expressed by qualitative preferences. Following the ideas of Professor Ralph Keeney, the main assumption in each management or control decision is that the values of the subject making the decision are the locomotive force, and as such, they are the main moment in supporting the decisions. The values are the guiding force in supporting the decisions and due to this are determining the formation of the decisions. In information systems in general and especially in the expert systems, the values are implicitly and heuristically included.

The productive merger of the mathematical exactness with the empirical uncertainty in the human notions is the main challenge here because people’s preferences contain uncertainty due to the qualitative type of the empirical information and the qualitative nature of the human notions. This uncertainty is of subjective and probability nature. The uncertainty of the subjective preferences could be eliminated, as is typical in the stochastic approximation procedures and machine-learning based on the stochastic programming.
Due to multidisciplinary nature of the cognitive process and to the multidisciplinary nature of the fields of applications, our choice of scientific methods is oriented toward the utilization of the stochastic programming, the theory of measurement, the utility theory, and on some flexible techniques for extrapolation and prognosis based on the multilinker extrapolation and pseudo inverse matrices. In this manner, we have posed the decision-making problem as a problem of constructing value and utility functions based on stochastic recurrent procedures as machine learning, which can later be used in optimization problems. Following from this choice, the orientation of the book is toward the branch of model-driven decision-making. Model-driven decision-making emphasizes access to and manipulation of a statistical, financial, optimization, or simulation model. Model-driven decision-making uses data and parameters provided by users to assist decision makers in analyzing a situation.

While the role of knowledge management for decision support is well acknowledged, there is a socio-technical gap between existing theory and actual practice in real-life decision-making. In recent years, bridging this gap has been a challenge in many areas of research. This is a great divide between the social aspects aimed to be supported and those that are actually supported. In decision support, this challenge has raised several important questions concerned with the account and encapsulation of social aspects of managerial decision-making as well as with the representation of certain human cognitive aspects, such as intuition or insights within computational systems. In this manner the problem of constructing analytically valuable utility functions with flexible mathematical techniques is now a problem and a challenge. Model-driven value-driven design can be defined as a software development paradigm, in which required human value considerations are importantly and equally engineered into best practices, activities, and management. Value-driven design creates an environment that enables design optimization by providing designers with an objective function. The objective value function inputs all the important attributes of the system being designed and outputs a score. The purpose is to enable the assessment of a value for every design option so that options can be rationally compared and a choice taken. At the whole system level, the objective function that performs this assessment of value is called a value model.

Value-Based Management (VBM) concepts are prevalent in theory and practice, since value creation is commonly considered the paramount business goal. However, VBM mainly applies data-driven concepts to support decision-making, disregarding model-driven approaches. Validate mathematical preferences value evaluation could be the first step in realization of a human-adapted design process and decision-making in VBM. The objective is to avoid the contradictions in human decisions and to permit mathematical calculations in these fields and rational management and control decisions. The analytical description of the expert’s preferences as value or utility function will allow mathematically the inclusion of the decision maker in the description of the complex system “technologist or manager-process.” Value-based decision enables the assessment of a value for every design option so that options can be rationally compared and a choice taken. At the whole system level, the objective function that performs this assessment of value is called a value model. The rational and logical description of value-based decisions requires basic analytical description and representation of the DM’s preferences. The mathematical description on such a socio-technical fundamental level requires basic mathematical terms as well, as equivalent of this description with respect to a given real object. In the last aspect of equivalency of the mathematical descriptions, we enter the theory of measurements and scaling.

The book has two aspects of orientation. In the first aspect, it suggests a common mathematical conception and appropriate numeric methods for development of model-driven decision-making based on value models. This approach realizes the concepts of value modeling in decision-making on the basis of the achievements of the utility theory, stochastic programming, and multilinker extrapolation. In that
aspect, the book provides the general mathematical paradigm and lots of numerical methods the practitioners for development of value-driven models in new applications in sociology, medicine, agriculture, control design in economics. It will be of interest to advanced students and professionals working in the subject of decision theory, control and management of complex systems, developers of information systems, as well as to economists and other social scientists. The proposed methods are unique and permit incorporation of machine learning with mathematical exactness in the decision-making and decision support practices.

In the second aspect, whenever deemed necessary, the mathematical proofs are provided in detail so that the reader with mathematical experience and mathematical background can study in depth the principles and methods outlined in this book and to eventually develop some of them. The reason is that the used stochastic programming approach, the theory of potential function method, is not well-known to the wide scientific community.

The practitioners could omit the proofs of the theorems and could follow only the examples of applications of the mathematical methods. They could follow, based on these examples, the ways of development of value-driven modeling and models in the different chapters. In this manner, the book is not a simple enumeration of value-driven models in different areas of human activities, but a guidance of how to design value-driven models and value-driven decision-making in complex processes.

Chapter one presents a conceptual framework of decision-making domain. Decision-making is the major component of a problem-solving system based on the principles of decision theory. The important factors that influence decision-making activity are decision environment and decision situation (decision context) that is interpreted usually as a complex adaptive system. Decision support is based on the idea that many important classes of decision situations can be supported by providing decision makers with a decision support environment. The construction of such environments concerns the development of Decision-Making Support Systems (DMSS). The main strategies in their development are determined in the framework of a generalized decision-making process. The development of DMSS depends on the accepted implementation method, architectural representation of these systems, implementation approaches, and used information, communication, and computer technologies.

Chapter two has an introductory nature for the principles and some concepts from probability theory. We consider the concept probability in two aspects: objective probability as frequency of occurrence and in the aspect of human expectation. Special attention is devoted to the concept “generalized gradient” because we discuss recurrent procedures based on it, and theorems and proofs regarding the convergence of the recurrent procedures are provided. Presenting strict mathematical proofs, we give the mathematically prepared reader an opportunity to enter in the mechanisms of the proposed approaches and methods for evaluating subjective knowledge, empirical, and verbally expressed as preferences.

Chapter three has an introductory nature with respect to the decision-making theory. It begins with description of the notion measurement and scale. The concepts of “value” and “utility” are interpreted from the point of view of the theory of measurement (scaling). Special attention is paid to the concept “subjective probability.” The chapter ends with an example for evaluation of subjective probabilities and examples of utility functions that have methodological generality.

Chapter four takes into consideration the main results and theorems for the existence of value and utility function. Our choice of theoretical results and theorems is conditioned methodologically by the respect to the utility theory’s use and application in practical problems. This section concludes with three examples of the application of utility theory in practice. The chapter requires certain persistence and mathematical inclination with clear definitions and description of the used mathematical concepts.
Chapter five considers in detail a direction of the stochastic programming used in the stochastic procedure for analytical construction of value and utility functions, and subjective probabilities. The question of special interest is an important topic from the so-called “potential function method.” This theory is relatively unknown in the scientific literature, in particular in the field of decision-making. Because of this, we have provided the used theoretical results with detailed proofs.

Chapter six presents the main theorems and methods for analytical representation of utility functions and a theorem for the convergence of the proposed recurrent procedures. The use of the proposed stochastic procedures for utility function construction is described from the viewpoint of Kahneman and Tversky and their Prospect Theory. Their understanding is based on the techniques given in chapters two, four, and five at the level of applicability of the discussed mathematical notions and methods.

Chapter seven takes into consideration stochastic procedures for the evaluation of subjective probability. They are based on the theoretical results outlined in chapter five. The described stochastic procedures are used for the decomposition of the multiattribute utility function to functions of fewer variables. This decomposition is fundamental for the use of utility theory in practice and in the modeling of more complex and difficult for formalization processes.

Chapter eight is devoted to the theoretical description of the Multilinear Extrapolation (MLE) approach of Rastrigin. This method is effective and suitable for making prognosis and evaluations in complex systems, including as analytical mathematical relationships. It allows adaptation of the prognoses with easy to implement iterative procedures and easy generation of training samples with applied significance. Such adaptation is also allowed by stochastic recurrent procedures. This makes the methods convenient as a basis for the development of adaptive, complex systems with human participation in the final decision.

Chapters nine, ten, and eleven are devoted to examples of application of the previously presented approaches and methods. Each of them may be read independently of the others according to the interests and orientation of the reader. Chapter nine shows the applicability of the proposed approaches and methods for complete description of the complex system “human-biotechnologist, bio-process.” It presents a complete solution of a practically significant problem, which has not been formally described. Chapter ten regards the teaching/learning process as decision-making process where the teacher plays the role of decision maker. Determining the competence of a learner to use learning resources in one way or another is done on the basis of measuring his/her preferences. This chapter demonstrates the capabilities of the new approach to describe complex, socially determined concepts and processes with the formal methods of the decision-making theory. The next chapter is a demonstration of modeling and managing complex process from stockbreeding. It includes an evaluation of the scale by which the initial information is obtained, factor analysis for eliminating the overlapping, formal model based on MLE, and the utility theory for description of the processes of the considered field of stockbreeding.

Chapter twelve together with chapter one describes the structure and methods for the development of DMSS (on the base of data mining and knowledge discovery) using decision-aiding tools in the data mining process. It gives a brief description of the decision support system, which allows the construction of value and utility functions of the individual user. It describes a prototype of an information decision support system for the individual’s utility evaluation as proposed by Professor Ralph Keeney. Mathematically it is backed up by the methods from the preceding chapters. The prototype of the information system is developed on the basis of the mathematical methods from chapters five, six, and seven.