Engineering Design

Products, Processes, and Systems

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Preface

For many years, engineering design has been considered art rather than science. Over the past decade, research and industrial communities have actively pursued a science-based approach to design. The volume of new knowledge is quite impressive. It may take many years to build a comprehensive and complete design model; however, existing knowledge can be organized from a number of perspectives. This book deals with a process view of engineering design. Material included here will allow the research and practice community to gain a clear understanding of various phases of the engineering design process. Some may be interested in applying the concepts presented in practice, while others may be encouraged to fill the gaps discovered with new results.

This book is written to meet the needs of senior undergraduates and graduate engineering students, designers, systems analysts, managers, and other practitioners. Because of its emphasis on modeling and analysis of design process, the book will be of interest to those working in numerous disciplines, including industrial, mechanical, electrical, and systems engineering. Significant portions of the material apply to the service sector, including health care. Design is interdisciplinary and the design process links the activities of various disciplines. The main motivation for writing this book comes from multiyear collaboration with various industries. Many examples and case studies are based on these experiences, and the models and algorithms presented have been widely used in practical applications.

The contents are organized into 16 chapters. The first chapter introduces process modeling. The emphasis is on the Integration DEFinition methodology. Chapters 2 through 5 discuss methods of analysis of process models, aiming at their improvement. Methods for process reengineering, reducing process cycle, reliability, and risk analysis are covered. Chapter 6 discusses the quality function deployment in the context of analysis of process models. A process model is always built for a purpose. The most common goal is an increased understanding of the underlying process and its improvement. One can use a process model to improve the execution of its activities. Chapter 7 discusses scheduling activities based on the example of a design process model. Design cannot take place without interdisciplinary teams. The method for team formation is discussed in Chapter 8. Because the book emphasizes engineering design process, Chapters 9 through 13 reflect details of this process. Design requirements and specifications are discussed in Chapter 9, followed by design synthesis in Chapter 10. The decomposition concept applied at different levels of design is presented in Chapter 11 and extended to the modularity of products in Chapter 12. Issues related to design of parts, including analysis and synthesis of tolerances, are discussed in Chapter 13. Chapter 14 introduces decision-making aspects of engineering design. Products and components should be designed for a multitude of constraints imposed on the environment that the design is to serve. Many of these constraints and ways of designing for them are discussed in Chapter 15. Conflicts arise in designing to meet different goals and constraints. Chapter 16 introduces innovative methods to resolve these conflicts.

I express appreciation to many colleagues, visiting researchers, and graduate students with whom I have collaborated in recent years. Numerous chapters in this book are results of joint work with my former graduate students and collaborators. Three recent graduate students, Dr. Jack Feng, Dr. David He, and Dr. Armen Zakarian, have joined my research team following different career paths. Professor Feng, who gained his background at Arizona State University and the People's Republic of China, has introduced me to the area of designing experiments and feature-based design, both of which are reflected in this book. Professor David He's research has been instrumental in expanding the scope of design for manufacturing. Professor Zakarian has contributed useful concepts following his education in Armenia and at the University of Southern California. Dr. Gun-Ho Lee's work on reconfigurabilty of manufacturing systems and design for a manufacturing environment was most valuable. I cannot think of words to describe the contributions of two of my former Ph.D. students, now Professors Chun-Che Huang and Juite Wang, whose hard work has motivated me to write this book. Prior to joining the Laboratory of Intelligent Systems, Dr. Huang spent a number of years at the University of Southern California and Columbia University. Dr. Upendra Belhe and Nick Larson are the only two of my recent graduate students who have decided to pursue industrial careers. Both have done remarkable research that can be easily identified by references in various chapters of this book.

The content presented here was created over many years. In earlier years, I collaborated with Dr. Edward Szczerbicki, then a visiting faculty member from the Gdansk Technical University, Poland, and now a faculty member in Australia. I appreciate his contributions in conceptual design and design synthesis. Dr. Ranko Vujosevic joined my research team after M.S. studies at Vanderbilt University. He has done innovative work in object-oriented programming. The research of my two collaborators Drs. Jun Park and Moon Cho can be traced in the body of knowledge incorporated in this book. Finally, thanks go to my undergraduate and

graduate students, industrial corporations, many colleagues from industry working in the Consortium for Advanced Manufacturing–International, and participants in professional seminars and workshops for discussing various ideas incorporated in this book.

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Chapter 1

Fundamentals of Process Modeling

1.1. INTRODUCTION

A model may represent a system (e.g., a manufacturing system), an object (e.g., designed artifact), or a problem (e.g., designing a shaft) and is typically constructed for the purpose of analysis. Models are used to describe existing systems as well as to evaluate the feasibility and anticipated performance of proposed systems. Although models must capture enough details to facilitate reliable experimentation, the purpose of modeling must not be violated. Such a violation may be caused by including unnecessary information at a cost exceeding the cost of building and/or experimenting with the actual system. The motivation and potential drawbacks of modeling efforts vary considerably between applications and methods. A thorough understanding of functions, data, resources, and the organizational structure is essential in modeling processes. A model can provide a sufficient understanding of the system being modeled without disturbing the actual environment. For example, in manufacturing, models can be used to analyze the manufacturing system ability to respond to the market changes. This enables rapid and accurate reconfiguration when new products are demanded. Ultimately, an executable version of the model can simulate and even control the actual process.

Once a process model has been developed, one should be able to perform various analyses of the underlying processes by presenting a user with different perspectives (see Fig. 1). The time (temporal) perspective optimizes the process duration and distribution of cycles among activities and it determines critical activities. It also enables the validation of process models. The other perspectives consider quality, reliability, risks, costs, and performance. A negotiation perspective (module) evaluates the conflicts from decisions made by the individual perspectives.