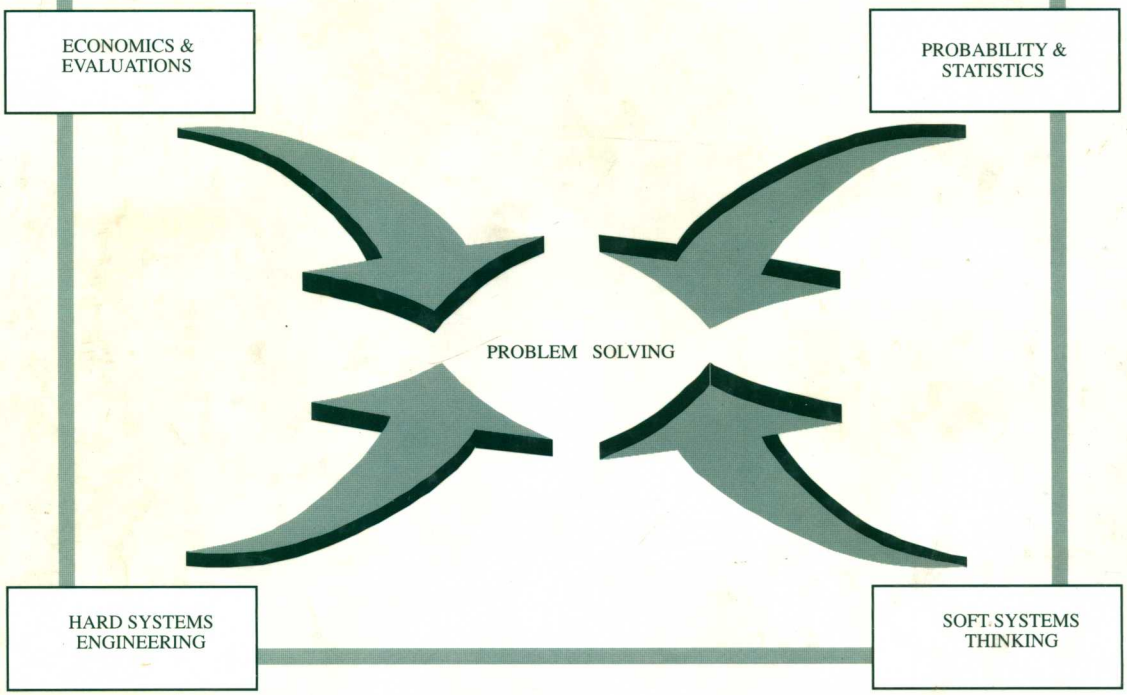
FUNDAMENTALS OF SYSTEMS ENGINEERING

WITH ECONOMICS, PROBABILITY, AND STATISTICS



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Fundamentals of Systems Engineering
with Economics, Probability, and Statistics

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Fundamentals of Systems Engineering

Dedication

To
Lena, Mohan, Suman, and Vijaya
CJK

Shar, Negar, and Cameron
JM

PREFACE

Society depends to a large extent on socio-political and managerial decisions made that rely, directly or indirectly, on the advice of engineers. In fact, the planning, design, construction, operation, and maintenance of engineering facilities, in the public and private sector, represents the expenditure of billions of dollars every year, and yet many engineers who are responsible for this massive expenditure have little or no formal training in the fundamentals of economics or systems analysis---both being essential for dealing with these kinds of decisions. With the revision of curricula for professional schools of engineering all over North America and abroad, however, this picture is rapidly changing.

The main objective of this book is to present the fundamental principles of economics, probability, statistics, and systems analysis to engineering sophomore, junior, or senior students. While there are scores of excellent textbooks dealing with all four components individually, there are comparatively few textbooks covering these areas in a single volume. Our experience has been that engineering students need to be exposed to these fundamental tools early on in their undergraduate training, so that they can apply the knowledge covered in each of these areas when they take advanced courses toward their bachelor's degree, or in some cases toward their master's degree. This textbook attempts to integrate the power of quantitative analysis with the conceptual richness of capital budgeting and microeconomics into the elements of systems engineering. It provides the reader with the basic concepts and tools that have proven most useful in engineering problem solving.

Some of the special features of the book need to be highlighted. First, a wide range of topics is covered, all drawn from the "systems approach" standpoint. Second, the emphasis is on presenting the fundamental concepts and their practical engineering applications, unobscured by complicated mathematics. Third, realizing that our best practice is far from perfect and our theories incomplete, we have included many open-ended, value-laden, real-world problems, at the end of every chapter. Fourth, although the conventional practice is for engineers to normally deal with natural and physical systems, we have included a chapter on "Soft Systems Thinking and Analysis." This inclusion was in response to the emergence of a range of formal methodologies, which aim not just to produce "optimal" solutions but to facilitate an enriched decision-making process, most suitable for application in an uncertain world. To our knowledge, this is the first attempt at including such material in an undergraduate textbook.

Material included in this book is organized as follows: Chapters 1 and 2 are introductory in nature, focussing on the natural, physical, and human systems and describing the nature of problems likely to be encountered in engineering practice. Chapters 3 and 4 cover the basic topics on engineering economics and the fundamental tools of microeconomics, respectively. The principles of probability are taken up next in Chapters 5, 6, and 7. Each of these chapters covers one of several basic topics in the theory of probability, while Chapters 8 and 9 deal with the principles of applied statistics. The application of probability and statistics in engineering is in such areas as decision-making, design under uncertainty, data analysis and interpretation, and system safety analysis. In this respect, we assume that engineering problem-solving practice, to a large extent, depends on engineering knowledge and the ability to interpret data. As such, the theory of probability and statistics plays an essential role in the decision-making process. Chapters 8 and 9 focus on applied statistics and discuss such topics as the analysis of engineering data, empirical estimation of statistical parameters, hypothesis testing, and correlation analysis. Even though courses in probability and statistics (usually offered by departments of mathematics/statistics) are included in engineering curricula, our experience has been that students taking such courses invariably end up having great difficulty in applying their knowledge to engineering problems. One objective in including chapters on probability and statistics is to emphasize the practical applications and relevance of the basic concepts in these two areas to engineering design.

Chapters 10 and 11 serve as introductory chapters on Hard Systems Engineering, while Chapter 12 deals with Soft Systems Thinking. As is well known, systems thinking developed out of wartime military operations planning, and has been the dominant traditional approach underlying systems engineering, systems analysis, and operations research for the last 50 years (Jackson, 1991). Soft systems thinking, on the other hand, is a more recent development, and in contrast to hard systems thinking, admits that there are multiple perceptions of reality, and of "solving" wicked, messy, complex, and ill-structured problems, characteristics of most contemporary engineering problems, particularly where the socio-economic and political ramifications are predominant.

We have presented the material through plenty of illustrative engineering and managerial worked examples. This will surely motivate practicing engineers and students to grasp the essential concepts for analysis and design. In view of the major worldwide thrust on distance learning and self-study by individuals who need a self-contained textbook dealing with the fundamentals of systems engineering with economics, probability and statistics, we are confident that this textbook will be ideal.

There are a number of audiences for this book. It is quite possible that students could complete the major topics included in this book in two-3 credit semester courses. Instructors in Architecture, Construction Management, Chemical, Electrical, Mechanical, Industrial Engineering, as well as in Urban Planning, in addition to Civil Engineering could formulate basic one- or two-semester course(s) to meet their own specific requirements. This textbook could very effective be used in graduate courses too, particularly in construction management and transportation engineering programs. A solutions manual is available.

Many people warrant acknowledgement, individually or jointly from the authors, and for personal or work-related reasons. We wish to thank our colleagues and students in the Department of Civil and Architectural Engineering, Illinois Institute of Technology (IIT), Chicago, for their help and advice. For the first author, this book began as a set of notes as early as 1978 when he was a faculty member at Washington State University (WSU), Pullman, WA. Many batches of graduate and undergraduate students at WSU and IIT have contributed in one form or another in the development of this book. In more recent years, four of my former students, Dr. P. S. Sriraj, Cemal Ayvalik, Turan Arslan, Raymond Tellis, and Sagar Sonar, helped this author to put the book together. My sincere thanks go to them. The second author expresses his gratitude to his colleagues, Dr. Anatol Longinow of Wiss, Janney, Elstner Associates of Northbrook, Illinois, and Joseph F. Braun of Systems & Electronics, Inc., of Elk Grove, Illinois, for providing an opportunity and reposing their trust in him to apply many of the statistical methods in Chapters 8 and 9 in realworld engineering data analysis problems. Finally, this book would not have taken shape without the admirable help, support, and advice provided by Laura Curless, Scott Disanno and their staff at Prentice Hall.

As with any textbook containing a vast amount of numerical work together with scores of examples and exercises, we would appreciate it very much if errors and inconsistencies are brought to our notice.

C. Jotin Khisty

Jamshid Mohammadi

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CHAPTER 3. BASIC ENGINEERING ECONOMICS & EVALUATION