Contents

Foreword to the Second Edition xvii
Foreword to the First Edition xix
Preface to the Second Edition xxi
Acknowledgments xxv
Thoughts for Instructors xxvii
Contributors xxxiii
Acronyms xli

1 Introduction 1
Gregory S. Parnell and Patrick J. Driscoll

1.1 Purpose 1
1.2 System 3
1.3 Stakeholders 3
1.4 System Life Cycle 7
1.5 Systems Thinking 10
1.6 Systems Engineering Thought Process 12
1.7 Systems Engineering 13
1.8 Engineering Management 15
1.9 Systems Decision Process 16
1.10 Overview 21
1.11 Exercises 21
References 23
References vii
PART I  SYSTEMS THINKING  25

2  Systems Thinking  27
   Patrick J. Driscoll

   2.1 Introduction  27
   2.2 Structure  32
   2.3 Classification  33
   2.4 Boundaries  35
   2.5 Visibility  39
   2.6 IDEF0 Models  40
   2.7 Mathematical Structure  50
   2.8 Spatial Arrangement  54
   2.9 Evolution  58
   2.10 Summary  58
   2.11 Exercises  59
   References  63

3  System Life Cycle  65
   Patrick J. Driscoll and Paul Kucik

   3.1 Introduction  65
   3.2 System Life Cycle Model  68
      3.2.1 Establish System Need  70
      3.2.2 Develop System Concept  70
      3.2.3 Design and Develop System  70
      3.2.4 Produce System  71
      3.2.5 Deploy System  72
      3.2.6 Operate System  72
      3.2.7 Retire System  73
   3.3 Other Major System Life Cycle Models  74
   3.4 Risk Management in the System Life Cycle  77
      3.4.1 Risk Identification  78
      3.4.2 Risk Assessment  83
      3.4.3 Risk Mitigation  88
   3.5 Summary  89
   3.6 Exercises  90
   References  92

4  Systems Modeling and Analysis  95
   Paul D. West, John E. Kobza, and Simon R. Goerger

   4.1 Introduction  95
   4.2 Developing System Measures  96
   4.3 Modeling the System Design  98
      4.3.1 What Models Are  99
CONTENTS

4.3.2 Why We Use Models 99
4.3.3 Role of Models in Solution Design 101
4.3.4 Qualities of Useful Models 102

4.4 The Modeling Process: How We Build Models 104
4.4.1 Create a Conceptual Model 105
4.4.2 Construct the Model 106
4.4.3 Exercise the Model 107
4.4.4 Revise the Model 108

4.5 The Model Toolbox: Types of Models, Their Characteristics, and Their Uses 109
4.5.1 Characteristics of Models 112
4.5.2 The Model Toolbox 114

4.6 Simulation Modeling 121
4.6.1 Analytical Solutions Versus Simulation; When It Is Appropriate to Use Simulation 122
4.6.2 Simulation Tools 123

4.7 Determining Required Sample Size 129

4.8 Summary 131
4.9 Exercises 132
References 134

5 Life Cycle Costing 137

Edward Pohl and Heather Nachtmann

5.1 Introduction to Life Cycle Costing 137
5.2 Introduction to Cost Estimating Techniques 139
5.2.1 Types of Costs 143

5.3 Cost Estimation Techniques 145
5.3.1 Estimating by Analogy Using Expert Judgment 145
5.3.2 Parametric Estimation Using Cost Estimating Relationships 146
5.3.3 Learning Curves 160

5.4 System Cost for Systems Decision Making 167
5.4.1 Time Value of Money 168
5.4.2 Inflation 168
5.4.3 Net Present Value 171
5.4.4 Breakeven Analysis and Replacement Analysis 172

5.5 Risk and Uncertainty in Cost Estimation 172
5.5.1 Monte Carlo Simulation Analysis 173
5.5.2 Sensitivity Analysis 177

5.6 Summary 178
5.7 Exercises 178
References 181
PART II  SYSTEMS ENGINEERING  183

6  Introduction to Systems Engineering  185
   Gregory S. Parnell
   6.1 Introduction  185
   6.2 Definition of System and Systems Thinking  185
   6.3 Brief History of Systems Engineering  186
   6.4 Systems Trends that Challenge Systems Engineers  186
   6.5 Three Fundamental Tasks of Systems Engineers  189
   6.6 Relationship of Systems Engineers to Other Engineering Disciplines  192
   6.7 Education, Training, and Knowledge of Systems Engineers  192
      6.7.1 Next Two Chapters  193
   6.8 Exercises  193
   Acknowledgment  194
   References  194

7  Systems Engineering in Professional Practice  197
   Roger C. Burk
   7.1 The Systems Engineer in the Engineering Organization  197
      The Systems Engineering Job  199
      Three Systems Engineering Perspectives  199
      Organizational Placement of Systems Engineers  199
   7.2 Systems Engineering Activities  200
      Establish System Need  201
      Develop System Concept  202
      Design and Develop the System  202
      Produce System  202
      Deploy System  203
      Operate System  203
      Retire System  203
   7.3 Working with the Systems Development Team  203
      The SE and the Program Manager  203
      The SE and the Client, the User, and the Consumer  203
      The SE and the CTO or CIO  205
      The SE and the Operations Researcher or System Analyst  205
      The SE and the Configuration Manager  206
      The SE and the Life Cycle Cost Estimator  206
      The SE and the Engineering Manager  206
      The SE and the Discipline Engineer  207
      The SE and the Test Engineer  207
      The SE and the Specialty Engineer  207
      The SE and the Industrial Engineer  208
## CONTENTS

### 7.4 Building an Interdisciplinary Team
- Team Fundamentals 208
- Team Attitude 209
- Team Selection 210
- Team Life Cycle 210
- Cross-Cultural Teams 211

### 7.5 Systems Engineering Responsibilities
- Systems Engineering Management Plan (SEMP) 212
- Technical Interface with Users and Consumers 213
- Analysis and Management of Systems Requirements 213
- System Architcting 216
- Systems Engineering Tools and Formal Models 217
- Interface Control Documents (ICDs) 218
- Test and Evaluation Master Plan (TEMP) 218
- Configuration Management (CM) 218
- Specialty Engineering 218
- Major Program Technical Reviews 220
- System Integration and Test 221

### 7.6 Roles of the Systems Engineer 221

### 7.7 Characteristics of the Ideal Systems Engineer 222

### 7.8 Summary 223

### 7.9 Exercises 224

### Acknowledgment 225

### References 225

### 8 System Reliability

*Edward Pohl*

8.1 Introduction to System Effectiveness 227
8.2 Reliability Modeling 228
8.3 Mathematical Models in Reliability 229
  - 8.3.1 Common Continuous Reliability Distributions 233
  - 8.3.2 Common Discrete Distributions 242
8.4 Basic System Models 244
  - 8.4.1 Series System 245
  - 8.4.2 Parallel System 245
  - 8.4.3 $K$-out-of-$N$ Systems 247
  - 8.4.4 Complex Systems 247
8.5 Component Reliability Importance Measures 249
  - 8.5.1 Importance Measure for Series System 249
  - 8.5.2 Importance Measure for Parallel System 250
8.6 Reliability Allocation and Improvement 250
8.7 Markov Models of Repairable Systems 253
  - 8.7.1 Kolmogorov Differential Equations 253
CONTENTS

10.3 Functional and Requirements Analyses 314
  10.3.1 Terminology 315
  10.3.2 Importance of Functional Analysis 315
  10.3.3 Functional Analysis Techniques 316
  10.3.4 Requirements Analysis 324
  10.3.5 At Completion 325
10.4 Value Modeling 326
  10.4.1 Definitions Used In Value Modeling 326
  10.4.2 Qualitative Value Modeling 327
  10.4.3 Quantitative Value Model 331
  10.4.4 At Completion of Value Modeling 340
10.5 Output of the Problem Definition Phase 340
  10.5.1 Discussion 340
  10.5.2 Conclusion 341
10.6 Illustrative Example: Systems Engineering Curriculum
    Management System (CMS)—Problem Definition 341
10.7 Exercises 350
References 350

11 Solution Design 353

  Paul D. West

11.1 Introduction to Solution Design 353
11.2 Survey of Idea Generation Techniques 355
  11.2.1 Brainstorming 355
  11.2.2 Brainwriting 358
  11.2.3 Affinity Diagramming 358
  11.2.4 Delphi 358
  11.2.5 Groupware 361
  11.2.6 Lateral and Parallel Thinking and Six Thinking Hats 361
  11.2.7 Morphology 361
  11.2.8 Ends–Means Chains 363
  11.2.9 Existing or New Options 363
  11.2.10 Other Ideation Techniques 363
11.3 Turning Ideas into Alternatives 365
  11.3.1 Alternative Generation Approaches 365
  11.3.2 Feasibility Screening 366
11.4 Analyzing Candidate Solution Costs 368
11.5 Improving Candidate Solutions 369
  11.5.1 Modeling Alternatives 369
  11.5.2 Simulating Alternatives 369
  11.5.3 Design of Experiments 370
  11.5.4 Fractional Factorial Design 376
  11.5.5 Pareto Analysis 386
11.6 Summary 388
11.7 Illustrative Example: Systems Engineering Curriculum Management System (CMS)—Solution Design 388
11.8 Exercises 390
References 391

12 Decision Making 395
Michael J. Kwinn, Jr., Gregory S. Parnell, and Robert A. Dees

12.1 Introduction 395
12.2 Preparing to Score Candidate Solutions 396
  12.2.1 Revised Problem Statement 396
  12.2.2 Value Model 397
  12.2.3 Candidate Solutions 397
  12.2.4 Life Cycle Cost Model 397
  12.2.5 Modeling and Simulation Results 397
  12.2.6 Confirm Value Measure Ranges and Weights 397
12.3 Five Scoring Methods 398
  12.3.1 Operations 398
  12.3.2 Testing 398
  12.3.3 Modeling 399
  12.3.4 Simulation 399
  12.3.5 Expert Opinion 399
  12.3.6 Revisit Value Measures and Weights 400
12.4 Score Candidate Solutions or Candidate Components 400
  12.4.1 Software for Decision Analysis 401
  12.4.2 Candidate Solution Scoring and Value Calculation 402
  12.4.3 Candidate Components Scoring and System Optimization 404
12.5 Conduct Sensitivity Analysis 409
  12.5.1 Analyzing Sensitivity on Weights 410
  12.5.2 Sensitivity Analysis on Weights Using Excel 411
12.6 Analyses of Uncertainty and Risk 412
  12.6.1 Risk Analysis—Conduct Monte Carlo Simulation on Measure Scores 413
12.7 Use Value-Focused Thinking to Improve Solutions 417
  12.7.1 Decision Analysis of Dependent Risks 419
12.8 Conduct Cost Analysis 423
12.9 Conduct Cost/Benefit Analysis 423
12.10 Decision-Focused Transformation (DFT) 424
  12.10.1 Transformation Equations 425
  12.10.2 Visual Demonstration of Decision-Focused Transformation 427
  12.10.3 Cost/Benefit Analysis and Removal of Candidate Solutions 427
12.11 Prepare Recommendation Report and Presentation 432
CONTENTS

14.2.4 Systems Engineers Have Key Roles Throughout the System Life Cycle 481

14.3 A Systems Decision Process Is Required for Complex Systems Decisions 481

14.3.1 Problem Definition Is the Key to Systems Decisions 481

14.3.2 If We Want Better Decisions, We Need Better System Solution Designs 482

14.3.3 We Need to Identify the Best Value for the Resources 482

14.3.4 Solution Implementation Requires Planning, Executing, and Monitoring and Controlling 482

14.4 Systems Engineering Will Become More Challenging 483

Appendix A SDP Trade Space Concepts 485

Index 491