

DECISION MAKING

IN SYSTEMS ENGINEERING AND MANAGEMENT

EDITED BY

GREGORY S. PARNELL PATRICK J. DRISCOLL DALE L. HENDERSON

Wiley Series in Systems Engineering and Management Andrew P. Sage, Series Editor

Contents

Fo	rewo	ord	xvii
Pr	eface	•	xix
Th	ough	ats for Instructors	xxiii
C	ontrib	outors	xxvii
A	cknov	vledgments	xxxiii
A	crony	ms	xxxv
1		oduction gory S. Parnell and Patrick J. Driscoll	1
	1.1	Purpose	1
	1.2	System	3
	1.3	Stakeholders	3
	1.4	System Life Cycle	5
	1.5	Systems Thinking	7
	1.6	Systems Engineering Thought Process	8
	1.7	Systems Engineering	10
	1.8	Engineering Management	11
	1.9	Systems Decision Process	12
	1.10	Overview	13
	1.11	Exercises	14
	Refe	rences	15

PART I SYSTEMS THINKING

2		tems Thinking ick J. Driscoll	19
	2.1	Introduction	19
	2.2	Structure	23
	2.3	Classification	24
	2.4	Boundaries	26
	2.5	Visibility	29
	2.6	IDEFφ Models	31
	2.7	Mathematical Structure	38
	2.8	Spatial Arrangement	44
	2.9	Evolution	47
		Summary	48
		Exercises	49
	Refe	prences	52
3	Syst	tem Life Cycle	55
	Patr	ick J. Driscoll	
	3.1	Introduction	55
	3.2	System Life Cycle Model	58
		3.2.1 Establish System Need	58
		3.2.2 Develop System Concept	60
		3.2.3 Design and Develop System	60
		3.2.4 Produce System	61
		3.2.5 Deploy System	61
		3.2.6 Operate System	62
		3.2.7 Retire System	63
	3.3	Other Major System Life Cycle Models	63
	3.4	Risk Analysis in the System Life Cycle	67
		3.4.1 Risk Assessment in the System Life Cycle	69
		3.4.2 Prioritizing Risks for Risk Management	71
	3.5	Summary	75
	3.6	Exercises	76
	Refe	erences	77
4		tems Modeling and Analysis	79
	Pau	l D. West, John E. Kobza, and Simon R. Goerger	
	4.1	Introduction	79
	4.2	Developing System Measures	80
	4.3	Modeling the System Design	82
		4.3.1 What Models Are	83
		4.3.2 Why We Use Models	83

				CONTENTS	ΙX
		4.3.3 4.3.4	Role of Models in Solution Design Qualities of Useful Models		85 85
	4.4	The M	Iodeling Process – How We Build Models		88
		4.4.2 4.4.3	Create a Conceptual Model Construct the Model Exercise the Model Revise the Model		88 90 90 92
	4.5		Iodel Toolbox: Types of Models,		
		Their	Characteristics, and Uses		92
		4.5.1 4.5.2	Characteristics of Models The Model Toolbox		95 98
	4.6	Simul	ation Modeling		105
		4.6.1	Analytical Solutions versus Simulation; When it is Appropriate to Use Simulation Simulation Tools		105 106
	4.7		mining Required Sample Size		111
	4.8	Summ	9 1		114
	4.9 Exercises			114	
	References				
5		Life Cycle Costing Edward Pohl and Heather Nachtmann			119
					110
	5.1 5.2		duction to Life Cycle Costing duction to Cost Estimating Techniques		119 121
	5.2	5.2.1	Types of Costs		125
	5.3		Estimation Techniques		126
	5.5		Estimating by Analogy Using Expert Judgment		127
			Relationships		128
		5.3.3	Learning Curves		141
	5.4	•	m Cost for Systems Decision Making		147
			Time Value of Money		147
			Inflation		148
		5.4.3 5.4.4	Net Present Value Breakeven Analysis and Replacement Analysis		151 152
	5.5		and Uncertainty in Cost Estimation		152
	5.5	5.5.1	Monte Carlo Simulation Analysis		153
		5.5.1	Sensitivity Analysis		157
	5.6	Sumn			158
	5.7	Exerc	· ·		159
	Ref	erences		161	

PART II SYSTEMS ENGINEERING

6		oductio gory S	n to Systems Engineering Parnell	165
	6.1	Introdu	ction	165
	6.2	Definit	ion of System	165
	6.3	Brief H	listory of Systems Engineering	166
	6.4	System	s Trends that Challenge System Engineers	166
	6.5		Fundamental Tasks of Systems Engineers	167
	6.6		nship of Systems Engineers to Other	
			ering Disciplines	170
	6.7		ion and Training of Systems Engineers	170
	6.8	Exercis	ses	171
	Refe	erences		172
7	-	t <mark>ems En</mark> er C. Bu	gineering In Professional Practice	173
	7.1	The Sy	stems Engineer in the Engineering Organization	173
		7.1.1	The Systems Engineering Job	173
			Three Systems Engineering Perspectives	174
			Organizational Placement of Systems Engineers	175
	7.2	System	as Engineering Activities	175
		7.2.1	Establish System Need	176
			Develop System Concept	177
		7.2.3	Design and Develop the System	177
		7.2.4	Produce System	178
		7.2.5	Deploy System	178
		7.2.6	Operate System	178
		7.2.7	Retire System	178
	7.3	The Sy	stems Engineer and Others	178
		7.3.1	The SE and the Program Manager	178
		7.3.2	The SE and the Customer, the User, and the Consumer	180
		7.3.3	The SE and the CTO or CIO	180
		7.3.4	The SE and the Operations Researcher or System Analyst	181
		7.3.5	The SE and the Configuration Manager	181
		7.3.6	The SE and the Life-Cycle Cost Estimator	181
		7.3.7	The SE and the Engineering Manager	181
		7.3.8	The SE and the Discipline Engineer	182
		7.3.9	The SE and the Test Engineer	182
			The SE and the Specialty Engineer	182
			The SE and the Industrial Engineer	183
		7.3.12	The SE and Quality Assurance	183

	7.4	Building an Interdisciplinary Team	183
		7.4.1 Team Fundamentals	183
		7.4.2 Team Attitude	184
		7.4.3 Team Selection	185
		7.4.4 Team Life Cycle	185
	7.5	Systems Engineering Responsibilities	186
		7.5.1 Systems Engineering Management Plan (SEMP)	186
		7.5.2 Technical Interface with Users and Consumers	187
		7.5.3 System Requirements Analysis and Management	187
		7.5.4 System Architecting	188
		7.5.5 Interface Control Documents (ICDs)7.5.6 Test and Evaluation Master Plan (TEMP)	189
		7.5.6 Test and Evaluation Master Plan (TEMP)7.5.7 Configuration Management (CM)	189 190
		7.5.8 Specialty Engineering	190
		7.5.9 Major Program Technical Reviews	190
		7.5.10 System Integration and Test	192
	7.6	•	192
		Characteristics of the Ideal Systems Engineer	193
	7.8	Summary	194
	7.9	Exercises	195
	Refe	prences	196
8	Syst	em Effectiveness	197
-	-	vard Pohl	
	8.1	Introduction to System Effectiveness	197
	8.2	Reliability Modeling	198
	8.3	Mathematical Models in Reliability	199
		8.3.1 Common Continuous Reliability Distributions	203
		8.3.2 Common Discrete Distributions	210
	8.4	Basic System Models	214
		8.4.1 Series System	214
		8.4.2 Parallel System	215
		8.4.3 K-out-of-N Systems	215
		8.4.4 Complex Systems	216
	8.5	Component Reliability Importance Measures	218
		8.5.1 Importance Measure for Series System	218
		8.5.2 Importance Measure for Parallel System	219
	8.6	Reliability Allocation and Improvement	219
	8.7	Markov Models of Repairable Systems	222
		8.7.1 Kolmogorov Differential Equations	222
		8.7.2 Transient Analysis	223
		8.7.3 Steady State Analysis	225

CONTENTS xi

	CONTENTS
XII	COMPTIME

		8.7.4	CTMC Models of Repairable Systems	225
			Modeling Multiple Machine Problems	227
		8.7.6	Conclusions	232
	8.8	Exercise	es	232
	Refe	rences		240
PA	RT II	I SYS	TEMS DECISION MAKING	
9	Syst	ems Dec	ision Process Overview	243
	Greg	gory S. F	Parnell and Paul D. West	
	9.1	Introdu	ction	243
	9.2		Focused Versus Alternative-Focused Thinking	244
	9.3		on Quality	246
	9.4		s Decision Process	247
	9.5		Stakeholders	249
	9.6		Decision Makers	250
	9.7	Enviror		251
	9.8		rison with Other Processes	253
	9.9		o Use the Systems Decision Process	253
			Need	254
			Resources	254
			Decision Maker and Stakeholder Support	254
	9.10		ng the Systems Decision Process to the	
		System	s Engineering Project	254
			le of Use of the Systems Decision Process	257
	9.12		tive Example: Systems Engineering Curriculum	
			ement System (CMS)—Summary and Introduction	258
		Exercis	es	260
	Ref	erences		261
10	Prob	lem Defi	inition	263
	Time	othy Trai	inor and Gregory S. Parnell	
	10.1	Introd	uction	263
		10.1.1	Introduction to the Problem Definition Phase	264
		10.1.2	Comparison with Other Systems Engineering Processes	266
		10.1.3	Purpose of the Problem Definition Phase	266
		10.1.4	Chapter Example	266
	10.2	Stakeh	older Analysis	267
		10.2.1	Introduction	267
		10.2.2	Techniques for Stakeholder Analysis	268
		10.2.3		
			System Decision Problem	278
		10.2.4	Conclusion	279
	10.3	Functi	onal Analysis	279

		CONTENT\$	Xiii
	10.3.1 Terminology		279
	10.3.2 Importance of Functional Analysis		280
	10.3.3 Functional Analysis Techniques		280
	10.3.4 Conclusion		288
10.4	Value Modeling		289
	10.4.1 Introduction		289
	10.4.2 Definitions Used in Value Modeling		289
	10.4.3 Qualitative Value Modeling		290
	10.4.4 Quantitative Value Model 10.4.5 Conclusion		294
10.5			301
10.5	Output of the Problem Definition Phase: Problem Statement, Screening Criteria, and Value Mode	1	200
	10.5.1 Introduction	1	303
	10.5.2 Discussion		303
	10.5.3 Conclusion		303 304
10.6	Illustrative Example: Systems Engineering Curriculum		304
10.0	Management System (CMS)—Problem Definition		304
10.7	Exercises		313
	rences		313
	tion Design D. West		317
11.1	Introduction to Solution Design		317
11.2	Survey of Idea Generation Techniques		319
	11.2.1 Brainstorming		319
	11.2.2 Brainwriting		322
	11.2.3 Affinity Diagramming		322
	11.2.4 Delphi 11.2.5 Groupware		322
	11.2.6 Chotapware 11.2.6 Lateral and Parallel Thinking and Six Thinking	Unto	324 325
	11.2.7 Morphology	11418	325
	11.2.8 Ends-Means Chains		327
	11.2.9 Existing or New Options		327
	11.2.10 Other Ideation Techniques		327
11.3	Turning Ideas into Alternatives		328
	11.3.1 Alternative Generation Approaches		329
	11.3.2 Feasibility Screening		330
11.4	Enhancing Solution Candidates		332
	11.4.1 Modeling Alternatives		332
	11.4.2 Simulating Alternatives		332
	11.4.3 Design of Experiments		333
	11.4.4 Fractional Factorial Design		339
	11.4.5 Pareto Analysis		349

xiv CONTENTS

11.5	Summary	350
11.6	Illustrative Example: Systems Engineering Curriculum	
	Management System (CMS)—Solution Design	351
11.7	Exercises	353
Refere	ences	354
	sion Making nael J. Kwinn, Jr. and Gregory S. Parnell	357
12.1	Introduction	357
12.2	Preparing to Score Candidate Solutions	358
	12.2.1 Revised Problem Statement	358
	12.2.2 Value Model	359
	12.2.3 Candidate Solutions	359
	12.2.4 Modeling and Simulation Results	359
	12.2.5 Confirm Value Measure Ranges and Weights	359
12.3	Four Scoring Methods	360
	12.3.1 Operations	360
	12.3.2 Testing	360
	12.3.3 Modeling	360
	12.3.4 Simulation	361
	12.3.5 Expert Opinion	361
	12.3.6 Revisit Value Measures and Weights	362
12.4	Score Candidate Solutions or Candidate Components	362
	12.4.1 Software for Decision Analysis	363
	12.4.2 Candidate Solution Scoring and Value Calculation12.4.3 Candidate Components Scoring and	364
	System Optimization	366
12.5	Conduct Sensitivity Analysis	371
	12.5.1 Analyzing Sensitivity on Weights	372
	12.5.2 Sensitivity Analysis on Weights Using Excel	373
	12.5.3 Conduct Monte Carlo Simulation on Measure Score	s 377
12.6	Use Value-Focused Thinking to Improve Solutions	380
12.7	Conduct Cost Analysis	383
12.8	Conduct Cost/Benefit Analysis	384
12.9	Prepare Recommendation Report and Presentation	385
	12.9.1 Develop Report	385
	12.9.2 Develop Presentation	386
12.10	Prepare for Solution Implementation	391
12.11	Illustrative Example: Systems Engineering Curriculum	
	Management System (CMS)—Decision Making	391
12.12	2 Exercises	394
Refer	rences	397

13		on Impl rt Powel	ementation /	399
	13.1	Introduc	ction	399
	13.2	The Sol	ution Implementation Phase	400
	13.3		g for Action: The Work Breakdown Structure	403
	13.4	System	Performance Measurement	405
		13.4.1	Monitoring	406
		13.4.2	Assessing	406
		13.4.3	Controlling	406
	13.5		n Implementation Strategy	407
	13.6	Implem	entation for the "Produce the System" Life Cycle Stage	408
			Planning for Action	409
			Developing the Organization	409
			Execution	412
		13.6.4		413
	13.7		entation for the "Deploy the System" Life Cycle Stage	414
		13.7.1	8	415
			Execution	416
	10.0		Assessment and Control	416
	13.8		entation in the "Operate the System" Life Cycle Stage	417
			Planning for Action	417
			Execution Assessment and Control	418
	10.0	13.8.3	Assessment and Control	418
	13.9	Summa		419
	15.10		ive Example: Systems Engineering Curriculum ment System (CMS)—Implementation	422
	13 11	Exercise		426
	Refere			427
14	Sumn	nary		429
	Grego	ory S. Pa	arnell	
	14.1		s Thinking is the Key to Systems Engineering	
		•	etems Decision Making	430
		14.1.1	Systems Thinking Focuses on System Behavior	100
		1410	in the Current and Future Operating Environment	430
		14.1.2 14.1.3	System Managers Must Consider the System Life Cycle Modeling and Simulation are Important Tools	430
		14,1.3	for Systems Engineers	430
		14.1.4	The System Life Cycle is a Key Risk Management Tool	430
		14.1.5	Life Cycle Costing is an Important Tool for	150
			Systems Engineering	431
	14.2	System	s Engineers Play a Critical Role in the System Life Cycle	431

xvi CONTENTS

14.4	System	s Engineering will Become More Challenging	434
111	14.3.4	1 8	433
		We Need to Identify the Best Value for the Resources	433
		System Solution Designs	433
		If We Want Better Decisions, We Need Better	
	14.3.1	Problem Definition is the Key to Systems Decisions	433
		s Decisions	432
14.3	A Syste	ems Decision Process is Required for Complex	
		the System Life Cycle	432
	14.2.4	Systems Engineers Have Key Roles Throughout	
		System Effectiveness	432
	14.2.3	Systems Engineers Define Value and Manage	751
	17,2,2	to System Functions and Requirements	431
	14.2.2	Makers and Stakeholders Systems Engineers Convert Stakeholder Needs	431
		Obtain System Solutions That Create Value for Decision	40.
	14.2.1	Systems Engineers Lead Interdisciplinary Teams to	