

Contents

1	Maintenance Systems	1
1.1	Introduction	1
1.2	Strategic Holistic System Approach	2
1.3	Planning Activities	4
1.3.1	Strategic Systems Alliance	4
1.3.2	Maintenance Strategies	5
1.3.3	Maintenance Load Forecasting	8
1.3.4	Maintenance Capacity Planning	8
1.3.5	Maintenance Organization	9
1.3.6	Maintenance Scheduling	9
1.4	Organizing and Designing Activities	10
1.4.1	Job Design	11
1.4.2	Time Standards	11
1.4.3	Project Management	11
1.5	Control Activities	12
1.5.1	Work Control	12
1.5.2	Inventory Control	12
1.5.3	Cost Control	13
1.5.4	Quality Control	13
1.6	Managing for Quality and Training	13
1.7	Reliability-Centered Maintenance (RCM)	14
1.8	Total Productive Maintenance (TPM)	14
1.9	Intelligent Maintenance	14
1.10	Human Behavior	15
1.11	Maintenance Terms	15
1.12	Summary	16
	Exercises	17
	References	17

2	Maintenance Strategic and Capacity Planning	19
2.1	Introduction	19
2.2	Forecasting Preliminaries	20
2.3	Qualitative Forecasting Techniques	22
2.4	Quantitative Forecasting Techniques	22
2.4.1	Simple Moving Average	22
2.4.2	Weighted Moving Average	23
2.4.3	Regression Analysis	24
2.4.4	Exponential Smoothing	27
2.4.5	Seasonal Forecasting	30
2.5	Error Analysis	32
2.6	Forecasting Maintenance Work	34
2.7	Maintenance Strategic Planning	35
2.7.1	Maintenance Strategic Issues	36
2.8	Maintenance Capacity Planning	36
2.9	Deterministic Approaches for Capacity Planning	37
2.9.1	Heuristic Tableau Method	37
2.9.2	Linear and Integer Programming for Maintenance Capacity Planning	42
2.10	Stochastic Techniques for Capacity Planning	46
2.10.1	Queuing Models	47
2.10.2	Stochastic Simulation	49
2.11	Contract Maintenance	52
2.12	Summary	53
	Exercises	53
	References	55
3	Preventive Maintenance, Concepts, Modeling, and Analysis	57
3.1	Introduction	57
3.2	Preventive Maintenance	59
3.3	Diagnostic Technologies	62
3.3.1	Vibration Monitoring and Analysis	62
3.3.2	Oil Analysis	63
3.3.3	Thermography	63
3.3.4	Ultrasonic	64
3.3.5	Electrical Effects Monitoring	64
3.3.6	Penetrants	64
3.4	Replacement Decision Models	64
3.5	Elements of Planned Maintenance	67
3.5.1	Plan Administration	67
3.5.2	Facility Inventory	67
3.5.3	Identification of Equipment	67
3.5.4	The Facility Register	68
3.5.5	Maintenance Schedule	68

3.5.6	Job Specification	68
3.5.7	The Maintenance Program	68
3.5.8	Program Control	69
3.6	Mathematical Models for Optimum Preventive Policies	69
3.6.1	Optimal Age Preventive Replacement (Type I Policy)	69
3.6.2	The Golden Section Method	71
3.6.3	Optimal Constant Interval Preventive Replacement Policy (Type II Policy)	75
3.6.4	Extension of Policies I and II	77
3.7	Inspection Models	78
3.7.1	Optimal Inspection Schedule Minimizing Expected Cost for a Single Machine	79
3.7.2	A Profit Maximization Model for a Single Machine Inspection	80
3.7.3	Inspection Model to Minimize Expected Cost with Minimal Repair	81
3.7.4	A Model for Coordinating the Inspection of a Group of Machines	83
3.8	Imperfect Preventive Maintenance	85
3.8.1	Models Assumptions and Notation	86
3.8.2	Approach One Model	86
3.8.3	Approach Two Model	88
3.8.4	Approach Three Model	88
3.9	Delay Time Modeling	90
3.10	Summary	92
	Exercises	92
	References	94
4	Maintenance Work Measurement	95
4.1	Introduction	95
4.2	Work Measurement Techniques	96
4.2.1	Time Study	97
4.2.2	Time Study Procedures	97
4.3	Work Sampling	100
4.3.1	Number of Observations Required for a Work Sampling Study	102
4.3.2	Planning a Work Sampling Study	103
4.4	Control Charts	105
4.4.1	Introduction	105
4.4.2	Control Chart Construction	105
4.5	Predetermined Motion Time Systems (PMTS)	106
4.5.1	Procedure for Setting a Predetermined Standard	107

4.6	Standard Data	108
4.6.1	Introduction	108
4.6.2	Steps for Developing Standard Data	108
4.7	Estimating	109
4.7.1	Introduction	109
4.7.2	Comparative Estimating (Slotting).	110
4.7.3	Applying Comparative Estimating.	110
4.8	Summary	112
	Exercises.	113
	References.	113
5	Maintenance Material Control.	115
5.1	Introduction	115
5.2	Maintenance Store Components	116
5.2.1	Spare Parts.	116
5.2.2	Normal Maintenance Stock	116
5.2.3	Tools	116
5.3	Maintenance Material Costs	117
5.3.1	Cost of the Item	117
5.3.2	Cost of Inventorying the Item.	117
5.3.3	Cost of the Item at Its Time of Issue.	117
5.4	Maintenance Store Control Procedure	118
5.4.1	Requisition.	119
5.4.2	Inventory Control	119
5.4.3	Items to Be Stocked	119
5.4.4	ABC Analysis	119
5.5	Inventory Systems.	120
5.5.1	Economic Order Quantity (EOQ)	121
5.5.2	The Reorder Level	123
5.5.3	Safety Stock.	124
5.5.4	Effective Ordering Policy.	125
5.6	Ordering Policies for Repairs	125
5.6.1	Demand and Failure Rate Linkage	126
5.6.2	Estimating Units of Spare Needed for Replacing Failures	126
5.7	Spare Part Classification	128
5.7.1	Spare Parts Ordering Strategies Based on Classification.	129
5.7.2	Grouping of Spares According to Criticality and Cost	129
5.8	Summary	129
	Exercises.	130
	References.	130

6	Maintenance Operations and Control	131
6.1	Introduction	131
6.2	Maintenance Control Cycle	132
6.3	Maintenance Work Order System	133
6.3.1	Design of the Work Order	134
6.3.2	Work Order System Flow	135
6.4	Record Keeping	137
6.4.1	Job Card (Report)	137
6.4.2	Equipment History Record	139
6.5	Structure of Maintenance Control	141
6.5.1	Work Order Coordination and Planning	142
6.6	Work Order Processing	144
6.7	Information Feedback and Corrective Action	145
6.7.1	Work Control	145
6.7.2	Cost Control	148
6.7.3	Quality Control	149
6.7.4	Plant Condition Control	149
6.8	Effective Engineered Maintenance Program	150
6.8.1	Planned Maintenance	150
6.8.2	Emergency Maintenance	150
6.8.3	Reliability Improvement	151
6.8.4	Equipment Management Program	151
6.8.5	Cost Reduction	152
6.8.6	Training and Employee Motivation	152
6.9	Role of Information Technology (IT)	153
6.10	Summary	153
	Exercises	154
	References	154
7	Maintenance Planning and Scheduling	155
7.1	Introduction	155
7.2	Planning	157
7.3	Scheduling	159
7.3.1	Elements of Sound Scheduling	160
7.4	Maintenance Job Priority System	161
7.5	Scheduling Techniques	161
7.5.1	Mathematical Programming Approaches for Maintenance Scheduling	164
7.5.2	Critical Path Method	165
7.5.3	Network Diagram Representation	165
7.5.4	Critical Path Calculation	167
7.5.5	Program Evaluation Review Techniques (PERT)	170
7.5.6	Integer and Stochastic Programming Approaches for Maintenance Scheduling	172

7.6	Turnaround Maintenance	177
7.6.1	Turnaround Maintenance Planning	179
7.6.2	Turnaround Schedule.	180
7.6.3	Turnaround Maintenance Reporting.	182
7.7	Summary	182
	Appendix	183
	Exercises.	184
	References.	185
8	Maintenance Quality Control	187
8.1	Introduction	187
8.2	Responsibilities of Quality Control (QC)	188
8.3	Inspection and Check Programs	190
8.4	Statistical Process Control (SPC) in Maintenance	190
8.4.1	Data Collection.	191
8.4.2	Checklist	191
8.4.3	Histogram	192
8.4.4	Cause and Effect (Fishbone) Diagram (CED)	196
8.4.5	Pareto Chart (ABC Analysis)	199
8.4.6	Control Charts	200
8.4.7	Scatter Diagram	201
8.4.8	Failure Mode and Effect Analysis (FMEA)	201
8.5	Maintenance Job Quality Control	202
8.5.1	Factors Related to Procedures and Standards	205
8.5.2	Factors Related to Manpower.	206
8.5.3	Factors Related to Material	206
8.5.4	Factors Related to Tools and Equipment	207
8.6	Quality Circles	207
8.7	Maintenance Link to Quality	208
8.8	Summary	211
	Exercises.	211
	References.	211
9	Maintenance Training.	213
9.1	Introduction	213
9.2	Skill	214
9.2.1	Skill Levels	214
9.3	Maintenance Training Activities	215
9.3.1	Training Policy.	215
9.3.2	Evaluating Current Status.	215
9.3.3	Need Analysis	217
9.3.4	Designing Training Program.	218

9.3.5	Implementation of Training Program	219
9.3.6	Evaluating Effectiveness	220
9.4	Summary	221
	Exercises	221
	References	221
10	Computerized Maintenance Management Systems	223
10.1	Introduction	223
10.2	Overview of CMMS	224
10.3	CMMS Modules	225
10.3.1	Equipment Management Module	225
10.3.2	Work Order Control Module	226
10.3.3	Crafts Management Module	230
10.3.4	Material Supply and Control Modules	230
10.3.5	Performance Reporting Module	235
10.3.6	Maintenance Reporting	235
10.4	Evaluation of Computerized Maintenance Management Systems	237
10.5	Evolution of CMMs for Effective Maintenance	239
10.6	Summary	242
	Exercises	242
	References	243
11	Reliability-Centered Maintenance	245
11.1	Introduction	245
11.2	RCM Goals, Principles, and Benefits	246
11.2.1	RCM Goals and Objectives	247
11.2.2	RCM Principles	247
11.2.3	RCM Benefits	248
11.3	RCM Methodology	249
11.3.1	System Selection and Information Collection	249
11.3.2	System Boundary Definition	250
11.3.3	System Description and Functional Block Diagram	250
11.3.4	System Functions and Functional Failure	253
11.3.5	Failure Modes and Effects Analysis (FMEA)	254
11.3.6	Logic or Decision Tree Analysis (LTA)	255
11.3.7	Task Selection	256
11.4	RCM Standards	257
11.5	RCM Implementation	258
11.5.1	Planning and Organizing for RCM	258
11.5.2	Analysis and Design	259

11.5.3	Execution Stage	259
11.5.4	Assessment and Feedback Stage	259
11.6	Summary	259
	Exercises.	260
	References.	260
12	Total Productive Maintenance.	261
12.1	Introduction	261
12.2	TPM Goals and Key Elements	262
12.3	Autonomous Maintenance	263
12.4	Equipment Management	263
12.5	TPM Implementation.	265
12.5.1	Preparation Stage	265
12.5.2	Preliminary Implementation	266
12.5.3	TPM Implementation.	267
12.5.4	Stabilization	268
12.5.5	Challenges and Success Factors of TPM Implementation.	268
12.6	Summary	269
	Exercises.	269
	References.	270
13	Intelligent Maintenance.	271
13.1	Introduction	271
13.2	Predictive Maintenance	272
13.2.1	P–F Interval	273
13.2.2	Predictive Maintenance Implementation	274
13.3	Elements of Integrated e-maintenance	275
13.4	Implementation of e-maintenance	275
13.4.1	Requirements for Implementation	276
13.4.2	Challenges of Implementation.	276
13.5	Case Studies	277
13.5.1	Roller Bearing Performance Predication.	277
13.5.2	Industrial Network Fault Detection	277
13.5.3	Maintenance Scheduling Using Predictive Information	278
13.6	Summary	279
	Exercises.	279
	References.	279
14	Maintenance System Performance, Productivity, and Continuous Improvement	281
14.1	Introduction	281
14.2	Maintenance Performance Measures	282

14.2.1	Input Measures	282
14.2.2	Output Measures	283
14.2.3	Measures Within the System	287
14.3	Maintenance Indices	288
14.3.1	Maintenance Administration	288
14.3.2	Maintenance Effectiveness	290
14.3.3	Maintenance Costs	291
14.4	Metric Comparisons	292
14.5	Maintenance Auditing	293
14.5.1	Factors in the Audit Scoring Scheme	293
14.5.2	Analytic Hierarchy Process (AHP) for Determining Weights of Factors	297
14.5.3	ABC (Pareto Chart) Analysis	299
14.6	Root Cause Analysis and Possible Corrective Action	300
14.7	A Case Study for Maintenance Productivity Improvement	303
14.8	Benchmarking and World-Class Maintenance	304
14.9	Maintenance Process Re-engineering	306
14.9.1	Process Analysis	307
14.9.2	Activity-Based Costing	308
14.9.3	Competitive Benchmarking	309
14.10	Summary	309
	Exercises	309
	References	310
Appendix A: Statistical Review		311
Appendix B: Reliability and Failure Analysis		337
Appendix C: Optimization Methods		339
References		343
Index		345

Planning and Control of Maintenance Systems

Modelling and Analysis

Duffuaa, S.; Raouf, A.

2015, XXIII, 348 p. 80 illus., 6 illus. in color., Hardcover

ISBN: 978-3-319-19802-6