Table of Contents

CHAPTER 1	**INTRODUCTION**	1
PART 1	**OPTIMISATION OF MAINTENANCE MANAGEMENT**	**3**
CHAPTER 2	**RAILWAY INFRASTRUCTURE DEFINED AS A SYSTEM**	**5**
1.	INTRODUCTION	5
2.	RAILWAY INFRASTRUCTURE SYSTEM	5
2.1.	System Level	5
2.2.	Subsystem Level	6
2.3.	Component Level	6
CHAPTER 3	**INFRASTRUCTURE LIFECYCLE**	13
1.	INTRODUCTION	13
2.	A SYSTEMS ENGINEERING APPROACH TO INFRASTRUCTURE LIFECYCLE	13
3.	PROJECT MANAGEMENT	16
4.	FEASIBILITY AND DESIGN PHASE	16
4.1.	Introduction	16
4.2.	Need Identification and Scope – Owners Requirement Specification	17
4.3.	Feasibility Study	18
4.4.	Project Execution – Detail Design Phase	20
5.	CONSTRUCTION AND COMMISSIONING PHASE	20
5.1.	Construction	20
5.2.	Commissioning	21
6.	OPERATION AND MAINTENANCE PHASE	21
6.1.	Operation and Maintenance	21
6.2.	Track Life Stages	22
7.	RENEWAL PHASE	24
8.	LIFECYCLE COSTS AND COST ANALYSIS	25
8.1.	Introduction	25
8.2.	Cost of Maintenance	26
8.3.	Initial Quality of Construction	28
8.4.	Traffic Characteristics	30
8.5.	Infrastructure Configuration	30
8.6.	The Effect of the Different Maintenance Tactics on Lifecycle Cost	30
8.7.	The Effect of Underinvestment in Maintenance on Lifecycle Cost	32
8.8.	External Uncontrollable Factors	34

CHAPTER 4	**INFRASTRUCTURE DETERIORATION AND FAILURE**	35
1.	INTRODUCTION	35
2.	CONDITION DETERIORATION	35
2.1.	Hypothetical Track Deterioration Curve	35
2.2.	Causes of Condition Deterioration	36
2.3.	Condition Deterioration Rate	36
3.	INFRASTRUCTURE CONDITION MEASURING AND RECORDING	37
4.	MAINTENANCE STANDARDS	37
5.	THRESHOLD FOR MINIMUM ALLOWABLE TRACK CONDITION	39
6.	INITIAL QUALITY	41
7.	FAILURE	41
7.1.	Introduction	41
7.2.	Potential and Functional Failure	42
7.3.	Failure Probability Patterns	44
7.4.	Failure Rates	46
7.5.	Failure Mechanisms or Causes	47
7.6.	Failure Modes	48
7.7.	Failure Detection	49
7.8.	Reliability Analysis	49
7.9.	Failure Analysis Methods	51
CHAPTER 5	**INFRASTRUCTURE MAINTENANCE MANAGEMENT**	53
1.	INTRODUCTION	53
2.	INFRASTRUCTURE MAINTENANCE MANAGEMENT OVERVIEW	53
2.1.	Introduction	53
2.2.	Organisational Mission, Vision and Objectives	54
2.3.	Maintenance Strategy	54
2.4.	Maintenance Tactics	56
2.5.	Maintenance Plan	60
2.6.	Maintenance Execution	62
3.	MAINTENANCE MANAGEMENT PROCESS	62
3.1.	Introduction	62
3.2.	Input in the Maintenance Process	63
3.3.	Resources	68
3.4.	Process	70
3.5.	Output	72
3.6.	Performance Analysis	74
4.	MAINTENANCE DOCUMENTATION	77
4.1.	Introduction	77
4.2.	Manuals	77
4.3.	Policies	77
4.4.	Procedures	78
4.5.	Work Instructions	78
4.6.	Work Order (Job-Card)	78
4.7.	Records	78
5.	MAINTENANCE MANAGEMENT SYSTEMS	79
5.1.	Introduction	79
5.2.	Graphic Display Diagrams	79
5.3.	Computerised Maintenance Management Systems (CMMS)	79

CHAPTER 6	**MAINTENANCE WINDOWS**	81
1.	INTRODUCTION	81
2.	TRAIN SLOTS VS MAINTENANCE SLOTS	82
2.1.	Train Slots	82
2.2.	Maintenance Slots	82
3.	THE INFLUENCE OF TRAIN OPERATIONS ON MAINTENANCE	83
4.	ON-TRACK MAINTENANCE OPPORTUNITIES	85
4.1.	In-Between Train Working	85
4.2.	Track Occupation (Possession) on Single Lines	86
4.3.	Working in the "Shadow" of a Maintenance Window (Single Lines)	87
4.4.	Working in Default Maintenance Window (Single Lines)	88
4.5.	Track Occupation (Possession) on Multiple Lines	88
4.6.	Permit	89
4.7.	Maintenance Shutdown	89
4.8.	Working at Night	90
5.	PRIORITY CRITERIA FOR THE LOCATION OF MAINTENANCE WINDOWS	90
6.	COSTS ASSOCIATED WITH MAINTENANCE WINDOWS	91
6.1.	Direct Costs Associated with Maintenance Windows	91
6.2.	Indirect Costs Associated with Maintenance Windows	91
6.3.	Hypothetical Example	93
PART 2	**INFRASTRUCTURE MAINTENANCE ACTIVITIES**	97
CHAPTER 7	**INFRASTRUCTURE MAINTENANCE ACTIVITIES**	99
1.	INTRODUCTION	99
2.	MATERIAL TRAINS	99
3.	INFRASTRUCTURE INSPECTION, MEASURING AND RECORDING	101
3.1.	Introduction	101
3.2.	Track and OHE Geometry and Rail and Ballast Profile Measurements	101
3.3.	Rail Flaw Detection	102
3.4.	Management Trolley Inspections and Visual Inspections	102
3.5.	Ground Penetrating Radar	102
4.	RAIL	103
4.1.	Introduction	103
4.2.	Rail Transportation, Offloading and Loading	103
4.3.	Rail Replacement (Installation)	103
4.4.	Rail Profiling	104
4.5.	Rail Destressing	105
5.	RAIL FASTENINGS AND INSULATORS	106
6.	RAIL PADS	107
7.	SLEEPERS	107
7.1.	Introduction	107
7.2.	Sleeper Transportation	107
7.3.	Sleeper Replacement	107
8.	BALLAST	108
8.1.	Introduction	108
8.2.	Ballast Cleaning	108
8.3.	Ballast Tamping	108
8.4.	Ballast Regulating	109
8.5.	Ballast Transportation and Offloading	109

9.	FORMATION	110
10.	TURNOUTS, SLIPS AND CROSSINGS (S&C)	110
10.1.	Transportation of S&C	110
10.2.	Set Replacement	111
10.3.	Set Component Replacement	111
10.4.	Set Grinding	111
11.	OVERHEAD EQUIPMENT	112
11.1.	Introduction	112
11.2.	Phase Break and Section Insulator Balancing and Replacement	112
11.3.	Substation and Booster Transformer Maintenance	112
11.4.	Electrification Structure Inspection, Adjustments and Replacement	112
11.5.	Contact Wire Replacement	113
11.6.	Setting Contact Wire Stagger	113
11.7.	Tensioning Device Maintenance	114
11.8.	Insulator Cleaning and Replacement	114
11.9.	Mast Pole Replacement	114
11.10.	Electric Third Rail	114
12.	SIGNALLING INFRASTRUCTURE	114
13.	BRIDGES, CULVERTS AND TUNNELS	115
14.	CUTTINGS AND EMBANKMENTS	116
15.	COLLECTOR DRAINAGE SYSTEMS CLEANING	116
15.1.	Surface Drains	117
15.2.	Subsurface Drains	117
16.	OTHER WAYSIDE (LINESIDE) MAINTENANCE	118
16.1.	Vegetation Control	118
16.2.	Level Crossings	119

PART 3	**SELECTION CRITERIA OF MECHANISED INFRASTRUCTURE MAINTENANCE MACHINES**	121

CHAPTER 8	**INFRASTRUCTURE CRITERIA**	123
1.	INTRODUCTION	123
2.	INFRASTRUCTURE MATERIAL	123
2.1.	Introduction	123
2.2.	Rails	123
2.3.	Fastenings	124
2.4.	Rail Pads	124
2.5.	Sleepers	124
2.6.	Ballast	125
2.7.	Turnouts, Slips and Crossing (S&C)	125
2.8.	Formation	126
3.	INFRASTRUCTURE DESIGN	126
3.1.	General Design Features	126
3.2.	Vehicle Structure Gauge	126
3.3.	Gauge	127
3.4.	Dual Gauge	127
3.5.	Single vs Multiple Lines	127
3.6.	Branch Lines	128

4.	NETWORK FEATURES	128
4.1.	Track Length	128
4.2.	Topography	131
4.3.	Turnouts, Slips and Crossings (S&C)	132
4.4.	Passing Loops and Stations	134
4.5.	Off-Tracking Spurs for Maintenance Machinery and Material Trains	134
4.6.	Level Crossings	135
4.7.	Service Roads	135
5.	INFRASTRUCTURE CONDITION	135
5.1.	Track Deterioration	135
5.2.	Measuring Infrastructure Condition	135
5.3.	Effect of the Value of the Intervention Level on Machine Selection	136
5.4.	Effect of the Track Condition on Machine Selection	136
CHAPTER 9	**OPERATING CRITERIA**	139
1.	INTRODUCTION	139
2.	SIGNALLING SYSTEMS	139
2.1.	Mechanical (Semaphore) Signal	139
2.2.	Colour Light Signal	140
3.	TRAIN OPERATING METHODS	141
3.1.	Timetable Operation	141
3.2.	Block Operation	142
4.	TRAIN DETECTION SYSTEMS	144
4.1.	Track Circuits	144
4.2.	Axle Counters	144
5.	TRANSPORT SERVICE TYPE	144
5.1.	Structured Service	144
5.2.	Ad-Hoc Service	146
6.	TRAIN OPERATING ON DOUBLE AND SINGLE LINES	146
7.	TRACK UNAVAILABILITY	147
8.	SPEED OF TRAINS	147
9.	TRAFFIC ENTERING AND EXITING THE TRACK SECTION	148
10.	DELAY OF TRAINS	148
11.	TIME BETWEEN TRAINS (HEADWAY)	149
CHAPTER 10	**THROUGHPUT CRITERIA**	151
1.	INTRODUCTION	151
2.	CONSTRUCTION OF ADDITIONAL LINES	151
3.	SHORTER HEADWAY BETWEEN TRAINS	152
3.1.	Introduction	152
3.2.	Effect on Infrastructure Requirements	152
3.3.	Effect on Track Deterioration and Maintenance Machinery Selection	152
4.	INCREASING TRAIN LENGTHS	153
4.1.	Introduction	153
4.2.	Effect of Long Trains on Curve Deterioration	153
4.3.	Effect of Distributed Power Technology on Track Deterioration	153
4.4.	Effect of Long Trains on Track Maintenance Machinery Selection	154
5.	INCREASING AXLE LOADING	154
5.1.	Introduction	154
5.2.	Effect of Increasing Axle Loads on Operating Costs	154
5.3.	Effect of Increasing Axle Loads on Track Deterioration	155
5.4.	Economic Effect of Increasing Axle Loads	158
5.5.	Effect of Increasing Axle Loads on Track Maintenance Machinery Selection	158
6.	SPEED OF TRAINS	162

CHAPTER 11 ENVIRONMENTAL CRITERIA 163
1. INTRODUCTION 163
2. ENVIRONMENT AND SUSTAINABLE DEVELOPMENT 163
3. WASTE PRODUCTS AND SOURCES 164
4. REDUCE, REPAIR, RECYCLE 165
4.1. Prevent 165
4.2. Containment and Clean-Up 165
4.3. Reduce 166
4.4. Repair 166
4.5. Recycle and Reuse 166
4.6. Dispose 167
5. VISUAL POLLUTION 167
6. SOIL POLLUTION 168
7. WATER POLLUTION 168
8. AIR POLLUTION 168
8.1. Exhaust Gasses 168
8.2. Dust from Open Wagons 169
8.3. Dust from Maintenance Activities 169
8.4. Working in Tunnels 169
9. NOISE AND VIBRATION 170
10. CLIMATOLOGICAL CONDITIONS 171
10.1. Lightning Density 171
10.2. Arid Areas 171
10.3. High Rainfall and Coastal Areas 172
10.4. Extreme Temperatures 172
11. EFFECT OF ENVIRONMENTAL STANDARDS ON CONTRACTORS 172

CHAPTER 12 SAFETY CRITERIA 173
1. INTRODUCTION 173
2. RISK MANAGEMENT 173
2.1. Introduction 173
2.2. Identifying Hazards 174
2.3. Risk Evaluation 174
2.4. Controlling Safety Risks 174
2.5. Monitoring 179
3. RESPONSIBILITY FOR SAFETY 179
4. OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM 180
4.1. Health and Safety Policies, Procedures and Standards 181
4.2. Legal, Site Specific and Railway Specific Requirements 181
4.3. Hazard Identification, Risk Assessment and Risk Control 182
4.4. Accidents and Incidents Emergency Response 182
4.5. Health and Safety Communication and Consultative Processes 182
4.6. Health and Safety Training and Competency 182
4.7. Health and Safety Related Appointments 183
4.8. Health and Safety Performance Measurements and Reporting 184
4.9. Safety Related Meetings 185
4.10. Medical Fitness 185
4.11. Debilitating Substances Use 185
4.12. Safety Equipment 186
4.13. Health and Safety Auditing 186
5. MACHINE SAFETY FEATURES 186
6. EN STANDARDS FOR MECHANISED INFRASTRUCTURE MAINTENANCE RELATING TO SAFETY 187

CHAPTER 13	**MACHINE OWNERSHIP**		191
1.	INTRODUCTION		191
2.	TYPE OF MACHINE OWNERSHIP		191
	2.1.	Machines owned, operated and maintained by the railways:	191
	2.2.	Machines owned operated and maintained by the contractor:	192
	2.3.	The machine is owned and operated by the railway but maintained and supported by the original equipment manufacturer (OEM) or a contractor:	194
	2.4.	The machine is owned by the railway but operated and maintained by two different contractors:	194
	2.5.	The machine is owned by the OEM but contracted to the railway by a civil engineering contractor:	194
3.	CONSIDERATIONS FOR MACHINE OWNERSHIP		195
	3.1.	Availability of a Competitive Outsourcing Market	195
	3.2.	Location of the OEM	195
	3.3.	OEM Reputation for Quality and Support	195
	3.4.	Range of Machines Offered by the OEM	195
	3.5.	Availability of Suitably Qualified Machine Staff	195
	3.6.	Training	196
	3.7.	Spare Parts Holding	196
	3.8.	Machine Maintenance	197
	3.9.	Technical Support	198
	3.10.	Standards	198
	3.11.	Conventions	198
4.	COSTS OF MACHINE OWNERSHIP		199
CHAPTER 14	**INFLUENCE OF THE MAINTENANCE ORGANISATIONAL STRUCTURE**		201
1.	INTRODUCTION		201
2.	CONSIDERATIONS FOR ORGANISATIONAL STRUCTURE		201
	2.1.	Asset Ownership, Maintenance and Operations	201
	2.2.	Asset Life Phases	201
	2.3.	Engineering Disciplines	203
	2.4.	Size and Characteristics of the Railway Infrastructure	204
	2.5.	Geographic Layout	205
	2.6.	Maintenance Planning and Execution Functions	206
	2.7.	Centralised or Decentralised Decision Making	207
	2.8.	In-House or Outsourced Maintenance	209
CHAPTER 15	**MACHINE FEATURES**		211
1.	INTRODUCTION		211
2.	INFRASTRUCTURE CONDITION MEASURING AND RECORDING		211
	2.1.	Measuring Systems	212
	2.2.	Supporting Systems	212
	2.3.	Positioning of Measured Data	213
	2.4.	Measurements	213
	2.5.	Reports	215
3.	RAIL FLAW DETECTION EQUIPMENT AND MACHINES		219
	3.1.	Rail Flaw Detection Technologies	219
	3.2.	Rail Flaw Detection Vehicles and Equipment	220
4.	SLEEPER EXCHANGING MACHINES		221
	4.1.	Single Sleeper Exchanging without Track Dismantling	221
	4.2.	Single Sleeper Continuous Laying Requiring Removal of the Rails	222
5.	TAMPING MACHINES		222
	5.1.	Production	222
	5.2.	Application	223

6.	DYNAMIC TRACK STABILISING MACHINES	225
6.1.	Self-Propelled Machines	227
6.2.	Integrated Machines	227
7.	BALLAST OFFLOADING	227
8.	BALLAST REGULATING AND DISTRIBUTION MACHINES	228
8.1.	Ballast Regulating Machines	228
8.2.	Ballast Regulating and Distribution Machines	228
9.	BALLAST CLEANING MACHINES	229
9.1.	Production	230
9.2.	Specialised Features	230
10.	SPOIL AND MATERIAL CONVEYING WAGONS	231
11.	RAIL PROFILING MACHINES	232
11.1.	Rail Grinding	232
11.2.	Rail Planing	234
11.3.	Rail Milling	234
12.	FLASH-BUTT WELDING MACHINES	235
12.1.	K355 Welding Head	235
12.2.	APT 1500 Welding Head	235
12.3.	Platform on which the Welding Head is Fitted	236
13.	TURNOUT TRANSPORTATION AND INSTALLATION MACHINES	237
14.	RAIL HANDLING EQUIPMENT	237
14.1.	Transportation of Short Rail Lengths	238
14.2.	Transportation of Long Welded Rails	238
14.3.	Rail Threader	238
15.	TRACK RENEWAL MACHINES	238
15.1.	Semi-Mechanised Methods	239
15.2.	Fully Mechanised Methods	239
16.	FORMATION REHABILITATION MACHINES	239
16.1.	Conventional Methods using Off-Track Earthmoving Machinery and Labour	240
16.2.	Semi-Mechanised Methods Using a Variety of On-Track Machinery	240
16.3.	Fully Mechanised Formation Rehabilitation Methods	241
17.	OVERHEAD ELECTRIFICATION EQUIPMENT MAINTENANCE MACHINES	241
17.1.	OHE Maintenance Machines Equipment and Features	241
17.2.	Rail-Bound OHE Maintenance Machines	243
17.3.	Road/Rail OHE Maintenance Machines	243
18.	OVERHEAD ELECTRIFICATION RENEWAL MACHINES	243
19.	OTHER MACHINES	244
CHAPTER 16	**DECISION MAKING MODEL**	245
1.	INTRODUCTION	245
2.	MACHINE SELECTION MODEL	245
2.1.	Factors that are fixed	245
2.2.	Factors that were predetermined or existing but can be changed if required	246
3.	CONCLUSION	259
TABLE OF FIGURES		261
REFERENCES		265