## Contents

Dunt			
Pref		2.2.3.1 Dynamic gertical lebiel food 5th	XX
		gements	XXII
Aut		2.2.3.3 Onsign vertical winter load 34	XX
Sym	bols an	nd Abbreviations	XXVI
The	railway	y as a transport system	
1.1	Defini	ition 1	
1.2		ituents 1	
1.2		Railway infrastructure 1	
		Rolling stock 5	
	1.2.3	Railway operation 8	
1.3		tilway system technique 9	
2.0	1.3.1	Description of the system 9	
	1.3.2	Fundamental functional principles 11	
		1.3.2.1 Running on a straight path 13	
		1.3.2.2 Running in curves 14	
	1.3.3	Distinctive features of railway systems	
		compared to road means of transport 14	
1.4	Classi	fication of railway systems 15	
	1.4.1	Speed in railway engineering: Design	
		and operational considerations 15	
	1.4.2	Classification of railway systems based on functionality 17	
	1.4.3	Classification of railway systems based on track gauge 27	
	1.4.4	Classification of railway systems based on traffic 28	
1.5	The ca	apabilities of the railway system 29	
	1.5.1	Advantages and disadvantages of the railway 29	
	1.5.2	Comparison of the characteristics of railway systems 33	
	1.5.3	Comparison of the capabilities of different	
		transportation systems 33	
		1.5.3.1 Comparison of air and high-speed train transport 37	
		1.5.3.2 Comparison of urban systems 37	
1.6	Histor	rical overview of the railway and future perspectives 37	
Refe	rences 3		

2	Load	ls on tra	nck		4
	2.1	Classifi	cation of loads 41		
	2.2		l loads on track 42		
		2.2.1	Static vertical loads 46		
			2.2.1.1 Axle load 46		
			2.2.1.2 Wheel weight 47		
			2.2.1.3 Daily traffic load 47		
		2.2.2	Quasi-static vertical loads 48		
			2.2.2.1 Vertical wheel load due to crosswinds 48		
			2.2.2.2 Vertical wheel load due to residual centrifug	al force	49
		2.2.3	Dynamic vertical loads 50		
			2.2.3.1 Dynamic vertical wheel load 50		
			2.2.3.2 Total vertical wheel load 51		
			2.2.3.3 Design vertical wheel load 52		
			2.2.3.4 Design loads of bridges 52		
	2.3	Transve	ersal loads on track 54		
		2.3.1	Gravitational forces 55		
		2.3.2	Creep forces 57		
			2.3.2.1 Running on straight path 57		
			2.3.2.2 Running in curves 59		
		2.3.3	Crosswind forces 60		
		2.3.4	Residual centrifugal force 61		
		2.3.5	Guidance forces 63		
		2.3.6	Forces due to vehicle oscillations 64		
		2.3.7	Total transversal force 64		
	2.4	Longita	udinal forces 65		
		2.4.1	Temperature forces 65		
		2.4.2	Rail creep forces 67		
		2.4.3	Braking forces: Acceleration forces 68		
		2.4.4	Traction forces: Adhesion forces 69		
		2.4.5	Fishplate forces 72		
	Refer	ences 7.	3		
3	Beha	viour o	f rolling stock on track		7
	3.1		our of a single railway wheelset 77		
		3.1.1	Movement on straight path 77 Movement in curves 77		
	2.2	3.1.2			
	3.2		our of a whole vehicle 78		
		3.2.1	Operational and technical characteristics of bogies 78		
			3.2.1.1 Object and purposes of bogies 78 3.2.1.2 Conventional bogies 79		
			8	21	
			. , ,	14	
			3.2.1.5 Bogies with creep-controlled wheelsets 85	,	
			3.2.1.6 Bogies with wheels with mixed behaviour 8	0	

	3.2.2	Wheel rolling conditions and bogies inscription behaviour in cur	rves 86
	3.2.3	Lateral behaviour of a whole vehicle 89	
		3.2.3.1 Vehicles with conventional bogies 90	
		3.2.3.2 Vehicles with bogies with self-steering wheelsets 92	
		3.2.3.3 Vehicles with independently rotating wheels 93	
		3.2.3.4 Comparative assessment 94	
	3.2.4	Selection of bogie design characteristics based	
		on operational aspects of networks 94	
		3.2.4.1 High-speed networks 94	
		3.2.4.2 Conventional speed networks 95	
		3.2.4.3 Mountainous networks 95	
		3.2.4.4 Metro networks 95	
		3.2.4.5 Tramway networks 96	
3.3	Derail	nent of railway vehicles 96	
	3.3.1	Definition 96	
	3.3.2	Derailment through displacement of track 98	
	3.3.3	Derailment as a result of vehicle overturning 98	
	3.3.4		
		3.3.4.1 Description of the phenomenon 99	
		3.3.4.2 Derailment criteria 99	
		3.3.4.3 Factors affecting derailment 100	
Refer	rences 1		
Tran	nway		103
4.1	Definit	ion and description of the system 103	
4.2		ication of tramway systems 103	
	4.2.1	Physical characteristics of the corridor 103	
	4.2.2	Functional/operational criteria 107	
	4.2.3	Floor height of the vehicles 109	
		4.2.3.1 Low floor 109	
		4.2.3.2 Very low floor 110	
		4.2.3.3 Moderately high floor 110	
		4.2.3.4 High floor 111	
	4.2.4	Power supply system 111	
	4.2.5		
12	7.2.3	Other classifications 111	
4.3		Other classifications 111 uctional and operational characteristics of the system 112	
4.3		Other classifications 111 uctional and operational characteristics of the system 112 Data related to track alignment and track superstructure 112	
4.3	Constr	uctional and operational characteristics of the system 112  Data related to track alignment and track superstructure 112	
4.3	Constr 4.3.1	uctional and operational characteristics of the system 112 Data related to track alignment and track superstructure 112 Rolling stock data 115	
4.3	Constr 4.3.1 4.3.2	uctional and operational characteristics of the system 112  Data related to track alignment and track superstructure 112	
4.3	Constr 4.3.1 4.3.2 4.3.3	Data related to track alignment and track superstructure 112 Rolling stock data 115 Tramway signalling system and traffic control 115	
4.3	Constr 4.3.1 4.3.2 4.3.3 4.3.4	Data related to track alignment and track superstructure 112 Rolling stock data 115 Tramway signalling system and traffic control 115 Transport capacity of the system 116 Travel time and commercial speeds 116	
4.4	Constr 4.3.1 4.3.2 4.3.3 4.3.4 4.3.5 4.3.6	Data related to track alignment and track superstructure 112 Rolling stock data 115 Tramway signalling system and traffic control 115 Transport capacity of the system 116	
	Constr 4.3.1 4.3.2 4.3.3 4.3.4 4.3.5 4.3.6	Data related to track alignment and track superstructure 112 Rolling stock data 115 Tramway signalling system and traffic control 115 Transport capacity of the system 116 Travel time and commercial speeds 116 Cost of implementing a tramway 118	
	Constr 4.3.1 4.3.2 4.3.3 4.3.4 4.3.5 4.3.6 Integra	Data related to track alignment and track superstructure 112 Rolling stock data 115 Tramway signalling system and traffic control 115 Transport capacity of the system 116 Travel time and commercial speeds 116 Cost of implementing a tramway 118 tion of tramway corridors across the road arteries 119	

		4.4.1.2	Double track on one side of the road 120
		4.4.1.3	Central alignment 120
	4.4.2		ric features of the integration of tramway corridors 122
			Technical and total tramway infrastructure right-of-way 122
		4.4.2.2	Geometric integration of tramway corridors at
			curved sections of roads in the horizontal alignment 124
4.5	Integra	ation of ste	
	4.5.1		stops integration 125
	4.5.2		ric and operational features of tramway stop integration 131
		4.5.2.1	Geometric criteria 131
		4.5.2.2	Operational criteria 133
4.6	Tramu		facilities 133
	4.6.1		description and operational activities 133
		4.6.1.1	Parking area/yard 134
			Maintenance hall/workshop 134
			Vehicle cleaning/washing area 135
	4.6.2		ation of tramway depots 135
	4.6.3		sign principles and selection of a ground plan area 135
4.7			r implementing the system 138
4.8			ification of alternative alignments 140
7.0	4.8.1		ion of track alignment and geometric integration 141
	4.8.2	The Carl I have a present to	ion of impact on other transport modes 145
	7.0.2	4.8.2.1	Roadside land uses 145
			Pedestrians 145
		4.8.2.3	
	102	4.8.2.4	Road traffic 146
	4.8.3		ion of environmental impacts 147
		4.8.3.1	Noise pollution 147
		4.8.3.2	Visual annoyance 148
		4.8.3.3	Impact on the urban space 148
		4.8.3.4	Impact on safety 149
		4.8.3.5	Impact during construction 149
	4.8.4		pility verification of operational efficiency 149
			Verification of commercial speed 149
			Verification of passenger transport volume 151
		4.8.4.3	Verification of operating cost $(K_{op})$ 153
	4.8.5	Applicat	pility verification of a tramway depot 153
	4.8.6	Verificat	ion of implementation cost 155
4.9	Histor	ical overvi	iew and present situation 155
	4.9.1	Historica	al overview 155
		4.9.1.1	The first horse-drawn tram 155
		4.9.1.2	The transition period from the horse-
			drawn tram to electrification 156
		4.9.1.3	The development of electric trams 156
		4.9.1.4	The period of dismantling of tram networks 156
		4.9.1.5	Restoration and reintegration of tramway systems 156

Met	ro 16
5.1	Definition and description of the system 161
5.2	Classification of metro systems 161
	5.2.1 Transport capacity 161
	5.2.2 Grade of automation of their operation 162
	5.2.3 Guidance system 164
	5.2.4 Other classification categories 165
5.3	Constructional and operational characteristics of a metro system 165
	5.3.1 Track layout 166
	5.3.2 Track superstructure 166
	5.3.3 Tunnels 171
	5.3.4 Rolling stock 173
	5.3.5 Operation 173
	5.3.5.1 Commercial speeds, service frequency
	and service reliability 174
	5.3.5.2 Fare collection and ticket supply 175
	5.3.5.3 Revenues for the system operator 176
	5.3.6 Implementation cost 176
5.4	Metro stations 177
	5.4.1 Location selection for metro stations 178
	5.4.2 Construction depth of metro stations 179
	5.4.3 Construction methods 180
	5.4.3.1 Construction of the station's shell 180
	5.4.3.2 Surface construction 181
	5.4.3.3 Number of station levels 182
	5.4.3.4 Station architecture 183
	5.4.4 Platforms 184
	5.4.4.1 Layout of platforms 184
	5.4.4.2 Platform dimensions 185
5.5	Depot facilities 187
5.6	Requirements for implementing the system 190
5.7	Historical overview and present situation 191
3.7	5.7.1 Historical overview 191
	5.7.2 Present situation 191
Dafa	
Reje	rences 194
195	2.5.1.1 Constructional Agencia of the Authors information of
Mor	norail 19'
6.1	Definition and description of the system 197
6.2	Classification of the monorails and techniques of the system 197
	6.2.1 Train placement on the guidebeam 197
	6.2.2 Transport capacity 198
	6.2.3 System techniques 200

4.9.2 Present situation 157

	6.3	Constructional and operational characteristics of the system 200	
		6.3.1 Permanent way 200	
		6.3.2 Rolling stock 202	
		6.3.3 Operation 203	
	6.4	Advantages and disadvantages of monorail systems 204	
		6.4.1 Advantages 204	
		6.4.2 Disadvantages 204	
	6.5	Requirements for implementing the system 204	
	6.6	Historical overview and present situation 205	
		6.6.1 Historical overview 205	
		6.6.2 Present situation 205	
	Refer	ences 207	
		Talk Trade loves to the State of the State o	
7	Auto	matic passenger transport railway systems of low- and medium-	
		port capacity	209
			-07
	7.1	Definition 209	
	7.2	Cable-propelled railway systems 209	
		7.2.1 General description and classification 209	
		7.2.2 Constructional and operational features of the systems 211	
		7.2.2.1 System 'principles' and superstructure configurations	211
		7.2.2.2 Guideway 215	
		7.2.3 Advantages and disadvantages 215	
		7.2.4 Requirements for implementing the system 217	
	7.3	Self-propelled electric systems 218	
		7.3.1 General description and classification 218	
		7.3.2 Battery-powered systems 221	
		7.3.3 Outside power feeding systems 223	
	Refer	ences 225	
3	Subu	rban railway	227
	8.1	Definition and classification of suburban railway systems 227	
	8.2	Definition and classification of suburban railway systems 227	
	8.3	Constructional and operational characteristics of the system 227	
	0.5	Advantages and disadvantages of the suburban railway 230	
		8.3.1 Advantages 230	
	0.1	8.3.2 Disadvantages 230	
	8.4	Requirements for implementing the system 230	
	8.5	Applicability verification of the system 231	
		8.5.1 Operation of suburban trains on existing infrastructure 232	222
		8.5.1.1 Constructional features of the railway infrastructure	232
		8.5.1.2 Passenger transport volume 233	
		8.5.1.3 System operability 233	
		8.5.1.4 The station service level 234	
		8.5.1.5 Availability of the depot facilities 235	
		8.5.1.6 Environmental impacts 235	
		8.5.1.7 Implementation cost 235	

		8.5.2 Operation of suburban trains on new infrastructure 235	
		8.5.2.1 Constructional features of the railway infrastructure 235	
		8.5.2.2 Passenger transport volume 236	
		8.5.2.3 Location, construction and operation	
		of the depot facilities 236	
		8.5.2.4 Environmental impacts 236	
		8.5.2.5 Implementation cost 236	
	Refer	ences 236	
	Rejer		
9	Rack	railway and the state of the st	237
	9.1	Definition and description of the system 237	
	9.2	Classification of rack railway systems 237	
		9.2.1 Type of cog rail 237	
		9.2.2 Type of adhesion along the line 242	
	9.3	Evolution of the system and application examples 243	
	9.4	Constructional and operational features of rack railway systems 243	
	7.7	9.4.1 Track alignment 243	
		9.4.2 Track superstructure 244	
		9.4.3 Rolling stock 246	
	0.5	9.4.4 Operation 247	
	9.5	Advantages and disadvantages of rack railway systems 248	
	9.6	Requirements for implementing the system 249	
	Refer	rences 250	
10	Cabl	e railway systems for steep gradients	251
	10.1	Definition and description of the system 251	
	10.2	The funicular 252	
	10.2	10.2.1 Evolution of funiculars and application examples 252	
		10.2.2 Constructional and operational features of funiculars 253	
		10.2.2.1 Infrastructure 253	
		10.2.2.2 Rolling stock 258	
		10.2.2.3 Operation 259	
	10.2	The inclined elevator 259	
			261
		Advantages and disadvantages of cable railway systems for steep gradients	201
		Requirements for implementing the system 261	
	Kejer	rences 262	
11	Orga	nisation and management of passenger interurban railway transport	263
	11.1	Services and basic design principles 263	
	11.2		
		transport: Quality parameters 264	
	11.3	Scheduling of passenger train services 265	
		Selection and purchase of rolling stock 266	
	16.1	11.4.1 Step 1: Assessment of the existing situation 267	
		11.4.2 Step 2: Determination of the target year 267	

12

13

13.2 Tilting techniques and systems 312 13.2.1 Passive tilting 312 13.2.2 Active tilting 312

	11.4.4	Step 4: D	etermination of the transport volume target 271	
	11.4.5	Step 5: D	etermination of the service frequency target 273	
	11.4.6	Step 6: N	lew train timetable scheme 273	
	11.4.7	Step 7: C	hecks on corridor track	
			and transport volume 274	
	11.4.8		theory: Required rolling stock for	
			rmance of scheduled services 274	
	11.49		ractically required rolling stock 275	
			Required rolling stock 277	
Refer	ences 2		Required forming stock 277	
Rejer	ences 2			
High	-speed	trains		27
12.1	Disting	tion hetwo	een high speeds and conventional speeds 279	
			issues 280	
			d technical solutions for the achievement of high speed	ds 284
12.5	12.3.1		ometry alignment characteristics 284	201
	12.5.1	12.3.1.1		
			Distance between track centres 285	
			Longitudinal slopes 287	
	1232		perstructure components 287	
	12.3.3		ineering structures 287	
	12.5.5		Tunnel traffic 287	
			Passage under bridges 289	
			Track fencing 291	
			Noise barriers 291	
		12.3.3.3	Handling aerodynamic effects in an	
	1221	T 1	'open' track and on platforms 293	
		Track sys		
	12.3.5	Rolling s		
			Aerodynamic design of vehicles 293	
		12.3.5.2	Design of bogies 294	
		12.3.5.3		
		12.3.5.4		
		12.3.5.5		
12.4			and current situation of high-speed networks	
		ins 295		
		perability i	ssues 301	
Refer	rences 3	07		
Tilti	ng trair	ıs		30
13.1	Definit	ion and fu	enction principle of tilting technology 309	

11.4.3 Step 3: Assessment of the situation in the target year 269

13.3	Main constructional and operational characteristics of tilting trains 314
	13.3.1 Performances in terms of speed 314
	13.3.2 Tilting angle 316
	13.3.3 Track gauge 316
	13.3.4 Axle load 316
	13.3.5 Track superstructure 316
	13.3.6 Bogies technology 316
	13.3.7 Train formation 316
	13.3.8 Signalling 316
	13.3.9 Traction 316
	13.3.10 Cost of rolling stock supply 317
13.4	Requirements for implementing the system 317
	13.4.1 Existing conventional-speed infrastructure 317
	13.4.2 New conventional-speed infrastructure 319
	13.4.3 New high-speed infrastructure 319
13.5	Historic overview and present situation 319
Refer	rences 322
Metr	ric track gauge interurban railway networks 323
14.1	Definition and description of the system 323
	General overview of metric gauge interurban railway networks 324
	Main constructional characteristics of interurban metric track gauge lines 326
	14.3.1 Track alignment: Differences between
	tracks of metric and normal gauge 326
	14.3.2 Track superstructure 328
14.4	에 있는 10kg 보다 10kg 10kg 10kg 10kg 10kg 10kg 10kg 10kg
14.5	Requirements for implementing the system 330
	rences 332
Orga	nnisation and management of freight railway transport 335
15.1	Services and cargo movement 335
15.2	Services and cargo movement 333 Service level of freight railway transport: Quality parameters 336
15.3	Scheduling of freight train services 337
15.4	
15.5	Mass transport 341
15.6	
13.0	15.6.1 Differentiation from the rest of freight transport services 344
	15.6.2 Creation of safe transport conditions 344
	15.6.3 Special measures to protect the environment 345
Refer	ences 345
10,01	19.5.1 Special features of each 95 level back an advantage 457, Sec. 37, 5.6.1
Heav	y haul rail transport 347
	Compact the thin research to Astronomic Security Tomas (being a great to the terms)
16.1	Definition and general description of the system 347
16.2	The international market in heavy haul rail transport 347

16.3 Differences between conventional and heavy haul freight railway networks 348

14

15

16

	16.5	Impacts of heavy haul rail operations and main design principles 348  16.4.1 Selection of track infrastructure components 351  16.4.1.1 Selection of the track's alignment geometric characteristics 351  16.4.1.2 Selection of rails 351  16.4.1.3 Selection of the type of sleepers and the distances between them 352  16.4.1.4 Selection and dimensioning of track bed layer features 352  16.4.1.5 Construction principles of the formation layer 353  16.4.1.6 Dimensioning of bridges 354  16.4.1.7 Dimensioning of the signalling system 354  16.4.2 Effects on the rolling stock 354  16.4.3 Effects on the operation 354  Economic efficiency of heavy haul rail transport 355  sences 359
17	Imna	act of traffic composition on the economic profitability of a railway
1/	syste	그리는 사람들이 보내는 그는 사람들이 모든 사람들이 되었다면 하는 것이 없는 것이 없다.
	17.4	Traffic composition and classification of railway networks/corridors 361  Economic profitability and classification of railway networks/corridors 362  The problem of mixed traffic operation 365  Investigation of the impact of traffic composition on the economic profitability of a railway system 368  17.4.1 Data published by the railway networks 368  17.4.2 Mathematical simulation 369  17.4.2.1 Selection of the operational framework for a new railway corridor 369  17.4.2.2 Selection of the operating framework for an existing railway corridor 372  sences 374
18	Raily	way safety 377
	18.1	Types of railway incidents and definition of railway safety 377 18.1.1 Types of railway incidents 377 18.1.2 Definition of railway safety 377 18.1.2.1 Risk level 377 18.1.2.2 Incident 'indicators' 379
	18.2	Significance of safety in railway systems and differences in road safety 380 18.2.1 Significance of safety in railway systems 380 18.2.2 Distinctions between railway and road safety 380
	18.3 18.4 18.5	Classification of railway incidents 381 Causes of railway incidents 381

	18.5.3 Safety in railway tunnels 387
	18.5.4 Safety at road overpasses 387
	18.5.5 Safety on embankments 389
	18.5.6 Safety in cuttings 390
18.6	Safety at railway stations 390
18.7	Safety on the 'open' track 391
	18.7.1 Potential risks 391
	18.7.2 Safety measures 391
18.8	Safety at RLCs 393
18.9	Correlation between the cost of interventions
	and the safety level improvement 397
	18.9.1 General approach 397
	18.9.2 The change in the value of accident indicators 398
	18.9.3 The change in the risk level 400
	18.9.3.1 Characterisation of the frequency
	of a particular incident 401
	18.9.3.2 Characterisation of the severity of a particular incident 402
Refer	ences 404
	7.24 ASSECTIONS ADDRESS ASSESSED AND ASSESSED AS
Raily	vay and the natural environment 407
19.1	
19.2	Energy consumption 408
	19.2.1 Definition: Units expressing energy consumption 408
	19.2.2 Energy-consuming railway activities 408
	19.2.3 Special features of each railway system category 409
	19.2.4 Measures for energy consumption reduction 410
19.3	Air pollution 411
	19.3.1 Definition: Expression units of air pollution 411
	19.3.2 Railway activities causing air pollution 411
	19.3.3 Special features of each railway system category 412
	19.3.4 Measures for air pollution reduction 413
19.4	Soil and water pollution 414
	19.4.1 Definition: Measurement methods of soil and water pollution 414
	19.4.2 Railway activities causing soil pollution 415
	19.4.3 Special features of each railway system category 415
	19.4.4 Countermeasures against the pollution of soil
	due to the presence of the railway 415
19.5	Visual annoyance 416
	19.5.1 Definition: Measurement methods of visual annoyance 416
	19.5.2 Railway activities causing visual annoyance 416
	19.5.3 Special features of each railway system category 417
	19.5.4 Countermeasures against visual annoyance
	caused by the presence of the railway 417
19.6	Integration of the track into the landscape 418
	19.6.1 Definition: Measurement indices of integration 418

19

		19.6.2	Railway activities causing a change of landscape 418	
		19.6.3	Special features of each railway system category 419	
		19.6.4	Measures for smooth integration of the railway into the landscape	419
	19.7		tem disturbance 420	
		19.7.1	Definition: Indices of expression of ecosystem disturbance 420	
		19.7.2	Railway activities causing ecosystem disturbance 420	
		19.7.3	Special features of each railway system category 420	
		19.7.4	Reduction measures of ecosystem disturbance 420	
	19.8		pance of local resident activities: Access	
			ion and disruption of urban space 422	
		19.8.1	Definition: Measurement indices of	
			disturbance on local resident activities 422	
		19.8.2	Railway activities causing disturbance on local resident activities	422
		19.8.3	Special features of each railway system category 422	
		19.8.4		
			residential activities due to the presence of railway infrastructure	423
	19.9	Acousti	ic annoyance 424	
			Definition: Units of expression of acoustic annoyance 424	
		19.9.2	Railway activities causing acoustic annoyance 425	
		19.9.3	Special features of each category of railway systems 425	
		19.9.4		
			19.9.4.1 The path of noise transmission 427	
			19.9.4.2 The source of noise 428	
	19.10	Ground	d-borne noise and vibrations 429	
			Definition: Measurement units of ground	
			borne noise and vibrations 429	
		19.10.2	Railway activities causing and affecting	
			ground-borne noise and vibrations 432	
		19.10.3	Special features of each category of railway systems 434	
			Countermeasures against vibrations and ground-borne noise 434	
	19.11		s on land use 436	
			rative assessment of the impacts of various	
			of transport to the natural environment 436	
			Methodology approach 436	
			Long distances: Comparison between the	
		17.112.2	aeroplane and the high-speed train 436	
		19 12 3	Urban transport: Comparing the metro,	
		17.112.0	tram, urban bus and private car 438	
		19.12.4	High-speed transport modes: Comparisons of the aeroplane,	
		17.112.1	the high-speed train and the magnetic levitation train 439	
		19 12 5	Freight transport: Comparison of freight trains and road trucks 44	10
	Refer	ences 44		ru
	110/01	0.1005 11		
20	Cutti	ng-edge	e technologies in railways	443
	20.1	Definiti	on and classification of cutting-edge technologies 443	
	20.2		vindows 443	

20.3 Carbon and glass fibr	res 446
----------------------------	---------

20.4 Laser railhead cleaner system 447

20.5 Catenary-free power supply of tramway systems 447

20.5.1 Ground power supply systems 449

20.5.1.1 The APS system 449

20.5.1.2 The TramWave system 453

20.5.1.3 The PRIMOVE system 454

20.5.2 Power supply systems with energy storage devices 456

20.5.2.1 Supercapacitor charging/ESS

(supercapacitors or ultracapacitors) 457

20.5.2.2 Charging/ESS with batteries 459

References 460

Index

463