Contents

1 Background and Motivation 1
1.1 Development of Urban Mobility 1
1.2 Advantages of Automated Rail Transport Systems 5
References. 9

2 System Components and Surrounding Systems of Automatic Train Control Systems 11
2.1 System Components of Automatic Train Control Systems 11
2.1.1 Trackside Equipment (ATP wayside). 13
2.1.2 On-board Equipment (ATP Onboard and ATO Onboard) 16
2.1.3 Data Communication System. 18
2.1.4 Automatic Train Supervision (ATS) 23
2.2 Surrounding Systems Automatic Train Control Systems. 27
References. 34

3 Grades of Automation of Automatic Train Control Systems 37
3.1 Grade of Automation 0: Train Operations on Sight (TOS) 37
3.2 Grade of Automation 1: Non-Automated Train Operations (NTO) 39
3.3 Grade of Automation 2: Semi-Automatic Train Operations (STO). 40
3.4 Grade of Automation 3: Driverless Train Operations (DTO) 40
3.5 Grade of Automation 4: Unattended Train Operations (UTO) 41
References. 41

4 Operating Modes and Operating Mode Transitions in Automated Operations 43
4.1 Operating Modes of Automatic Train Conrol Systems 43
4.1.1 Operating Modes for Regular Train Operations 44
4.1.2 Operating Modes for Fallback Level Operations. 45
4.1.3 Operating Modes for Deactivation Conditions 48
4.1.4 Operating Modes for Trains Supervised by Other Train Control Systems. 49

4.2 Operating Mode Transitions in Semi-Automatic Train Operations 50
4.2.1 Transition between Restricted Manual Mode and Supervised Manual Mode 50
4.2.2 Transition between Supervised Manual Mode and Automatic Mode 52
4.2.3 Transition between Automatic Mode and Full Automatic Mode for Turnback Operations 52
4.2.4 Transition from Automatic Mode to Full Automatic Mode in the Depot 54
4.2.5 Transition between Automatic Mode and Restricted Mode in Case of Malfunctions. 55
4.3 Operating Mode Transitions in Unattended Train Operations. 57
4.3.1 Transition between Switch-off States and Unattended Train Operations. 57
4.3.2 Transition between Dangerous and Fault States and Unattended Train Operations 58
References. 59

5 Main Functions of Automatic Train Control Systems 61
5.1 Main Function: Ensuring the Safe Movement of the Train 61
5.1.1 Core Function: Route Protection 61
5.1.2 Core Function: Safe Train Separation 63
5.1.3 Core Function: Ensure Safe Speed. 64
5.2 Main Function: Driving the Vehicle. 73
5.2.1 Core Function: Determination of the Driving Profile 73
5.2.2 Core Function: Control of the Trains Depending on the Driving Profile 77
5.3 Main Function: Monitoring the Clearance Gauge 81
5.3.1 Core Function: Preventing Collisions with Objects. 82
5.3.2 Core Function: Preventing Collision with Persons on the Track 82
5.4 Main Function: Monitoring Passenger Exchange 85
5.4.1 Core Function: Control and Monitor Door Release. 86
5.4.2 Core Function: Preventing Injury to Persons between Vehicles 86
5.4.3 Core Function: Securing the Platform Edge 87
5.4.4 Core Function: Ensuring Safe Starting Conditions of the Train 94
5.5 Main Function: Automatic Train Operation. 96
5.5.1 Core Function: Putting into Service and Taking Out of Service of Vehicles. 97
5.5.2 Core Function: Running a Vehicle between Operational Stops. 99
5.5.3 Core Function: Monitoring the Vehicle Condition. 100

5.6 Main Function: Detection and Handling of Incidents 102
5.6.1 Core Function: Passenger Alarm Messages 102
5.6.2 Core Function: Fire Detection 105
5.6.3 Core Function: Evacuation. 107
5.6.4 Core Function: Obstacle Detection 110
5.6.5 Core Function: Derailment Detection 110
References 112

6 Dependability of Automatic Train Control Systems 113
6.1 Safety and Security 113
6.1.1 Functional Safety 114
6.1.2 Security 119
6.2 Availability 120
6.2.1 Optimization of Maintainability in Order to Increase Availability 120
6.2.2 Increasing Reliability to Increase the Availability 122
6.2.3 Fault-Tolerant Systems to Increase Availability. 123
References 125

7 Balancing Costs and Benefits of Automatic Train Control Systems 127
7.1 Determination of the Costs in the Course of the Life Cycle 127
7.1.1 Elements of Life Cycle Costs. 128
7.1.2 Calculation of Life Cycle Costs 129
7.1.3 Results of the Analysis of Life Cycle Costs. 130
7.2 Determination of the Benefits with Operational Simulations and Transport Models 131
7.2.1 Simulative Investigation of the Performance of Signaling Equipment Variants 131
7.2.2 Use of the Higher Capacity for Improvements to Public Transport Services 135
7.2.3 Evaluation of the Overall Benefits of Adjustments to the Public Transport Service 136
References 137

8 Migration, Testing and Commissioning of Automatic Train Control Systems 139
8.1 Definition of the Migration Strategy 140
8.2 Application-Specific Configuration of Automatic Train Control Systems 141
8.2.1 Categories of Track-Specific Configuration Data 142
8.2.2 Categories of Vehicle-Specific Configuration Data 142
8.2.3 Quality Characteristics of Configuration Data. 143
8.2.4 Quality Assurance Processes for Configuration Data 143
8.2.5 Capture of Track-Specific Configuration Data. 144

8.3 Retrofitting of Vehicles with CBTC Onboard- Units 145
8.3.1 Definition of Operational Use Cases 145
8.3.2 Mechanical Integration of the CBTC Onboard Unit 145
8.3.3 Electrical Integration of the CBTC Onboard Unit 147
8.4 Retrofitting the Track with CBTC Trackside Equipment 148
8.5 Definition of Test Strategy and Test Execution 150
8.5.1 Environmental Testing 150
8.5.2 Tests in the Factory 151
8.5.3 Vehicle Tests. 152
8.5.4 Test Track in the Depot 153
8.5.5 Test During Commissioning of the Wayside System Components 153
8.6 Adjustment of Operational Rules and Regulations for Automated Train Operations 156
8.6.1 Principles for the Adjustment of Rules and Regulations in Renewal Projects 156
8.6.2 Process of Creating Operating Rules and Regulations in a Renewal Project. 159
8.6.3 Roles and Responsibilities for the Creation of Operating Rules and Regulations. 160
8.7 Training of Operating Staff 161
8.7.1 Training of Train Drivers 162
8.7.2 Training of Operations Control Center Staff 163
8.7.3 Training of Maintenance Staff 164
References 164

9 Perspectives and Future Challenges 167
9.1 Development of the Installed Base 167
9.2 Standardization of System Solutions 168
9.3 Integration of Road Traffic Technology in Light Rail Systems 169
9.4 Alternative Allocation of Functions between Wayside Equipment and Onboard Equipment 170
9.4.1 Centralization of Safety-Relevant Applications in Data Centers 171
9.4.2 Vehicle-Centered Allocation of Functions 171
References 173

Index 175