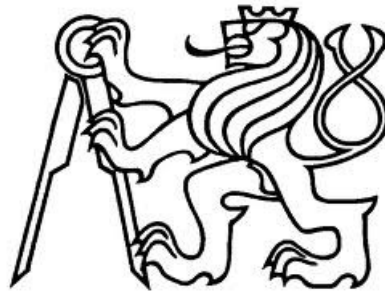


Czech Technical University in Prague

Faculty of Transportation Sciences



Lukáš Petřík

Functional specification for a Driver's Cab Simulator
with ETCS

Master's thesis

2016



CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Transportation Sciences

Dean's office

Konviktská 20, 110 00 Prague 1, Czech Republic

K620.....Department of Transport Telematics

MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

Bc. Lukáš Petřík

Code of study programme code and study field of the student:

N 3710 – IS – Intelligent Transport Systems

Theme title (in Czech): **Specifikace požadavků na simulátor stanoviště strojvedoucího s ETCS**

Theme title (in English): **Functional Specification for a Driver's Cab Simulator with ETCS**

Guides for elaboration

During the elaboration of the master's thesis follow the outline below:

- Analysis of conditions for driver's cab simulation
- Analysis of relevant requests for on-board and stationary part of ETCS for usage in Traffic Laboratory of Faculty of Transportation Sciences
- Proposal of architecture and functional requirements for driver's cab with ETCS for usage in Traffic Laboratory of Faculty of Transportation Sciences

Graphical work range: according to supervisor's recommendations.

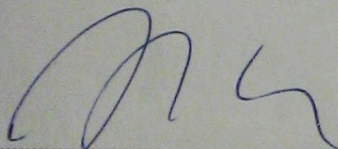
Accompanying report length: min. 55 pages including figures, graphs and tables.

Bibliography: EU regulations and directives for convention railway system (2008/57/EU, TSI 2012/88/EU, TSI 2012/757/EU, TSI 1302/2014/EU)
Subset 026
ERA 015560
UIC Leaflet 612

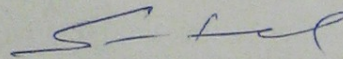
Master's thesis supervisor: **Doc. Ing. Martin Leso PhD.**

Date of master's thesis assignment: **July 31, 2015**
(date of the first assignment of this work, that has be minimum of 10 months before the deadline of the theses submission based on the standard duration of the study)

Date of master's thesis submission: **November 30, 2016**
a) date of first anticipated submission of the thesis based on the standard study duration and the recommended study time schedule
b) in case of postponing the submission of the thesis, next submission date results from the recommended time schedule

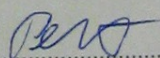


doc. Ing. Pavel Hrubeš, Ph.D.
head of the Department
of Transport Telematics



prof. Dr. Ing. Miroslav Svítek, dr. h. c.
dean of the faculty

I confirm assumption of master's thesis assignment.


Bc. Lukáš Petřík
Student's name and signature

Prague June 1, 2016

Declaration

I hereby submit for the evaluation and defence the master's thesis elaborated at the CTU in Prague, Faculty of Transportation Sciences.

I have no relevant reason against using this schoolwork in the sense of § 60 of Act No. 121/2000 Coll. on Copyright and Rights Related to Copyright and on Amendment to Certain Acts (the Copyright Act)

I declare I have accomplished my final thesis by myself and I have named all the sources used in accordance with the Guideline on ethical preparation of university final theses.

In Prague, 29. 11. 2016



.....

Bc. Lukáš Petřík

Specifikace požadavků na simulátor stanoviště strojvedoucího s ETCS

Vedoucí práce: doc. Ing. Martin Leso, PhD.

České vysoké učení technické v Praze, Fakulta dopravní

2016

Klíčová slova

Simulátor železničního vozidla, Evropský vlakový zabezpečovací systém, Dopravní laboratoř, stanoviště strojvedoucího

Abstrakt

Tato práce poskytuje stručný náhled do problematiky železničních simulátorů a shrnuje jejich nasazení ve světě. Dále popisuje požadavky na simulátor stanoviště strojvedoucího s ETCS. Je navržena architektura simulátoru a návod pro jeho implementaci. Specifikace ETCS jsou analyzovány a převedeny do přehlednější podoby.

Bc. Lukáš Petřík

Functional specification for a driver's cab simulator with ETCS

Supervisor: doc. Ing. Martin Leso, PhD.

Czech Technical University in Prague, Faculty of Transportation Sciences

2016

Keywords

Rail vehicle simulator, European Train Control System, Transportation Laboratory, locomotive cab

Abstract

This thesis provides a brief introduction into the rail simulator issues and summarizes their deployment in the world. It describes the requirements for a locomotive cab simulator equipped with ETCS. The architecture of the simulator and a guideline for the implementation is proposed. The specifications of ETCS are examined and transformed into more transparent form.

Table of contents

1 Introduction.....	17
1.1 Purpose.....	17
1.2 Types of locomotive simulators.....	18
1.2.1 Desktop.....	18
1.2.2 Mobile desk.....	18
1.2.3 Fixed desk.....	18
1.2.4 Full cab.....	18
1.3 Simulators in use.....	19
1.3.1 Czech Republic.....	19
1.3.2 Germany.....	21
1.3.3 Switzerland.....	22
1.3.4 Austria.....	22
1.3.5 Belgium.....	23
1.3.6 France.....	23
1.3.7 Luxembourg.....	23
1.3.8 Ireland.....	24
1.3.9 Canada.....	24
1.3.10 India.....	24
1.3.11 Australia.....	24
1.3.12 United States of America.....	24
1.3.13 Turkey.....	24
1.4 Transportation Laboratory.....	25
2 Simulation.....	26
2.1 Time and weather.....	26
2.1.1 Time.....	26
2.1.2 Season.....	26
2.1.3 Visibility.....	26
2.1.4 Wind.....	27
2.2 Infrastructure.....	27
2.2.1 Track.....	27
2.2.2 Mileage.....	28
2.2.3 Points and buffer stops.....	29
2.2.4 Signals.....	30
2.2.5 Catenary.....	30
2.2.6 Outside world.....	30
2.3 Interlocking.....	31
2.4 Radio.....	31
2.4.1 Simplex system.....	31
2.4.2 TRS system.....	32
2.4.3 GSM-R.....	32
2.4.4 Public GSM.....	34
3 Vehicle dynamics.....	35
3.1.1 Input variables.....	35
3.1.2 Track induced variables.....	35
3.1.3 Driver induced variables.....	35
3.1.4 Simulated variables.....	35
3.1.5 Movement equation.....	35
3.1.6 Tractive effort.....	37

3.1.7 Dynamic brake.....	38
3.1.8 Automatic brake.....	38
4 Locomotive simulation.....	41
4.1 Cab construction.....	41
4.1.1 Cab mode.....	43
4.1.2 Elements description.....	44
4.1.3 Element activity.....	53
4.1.4 Geometric forms.....	54
4.1.5 Displays.....	55
5 ETCS Subsystem.....	57
5.1 ETCS Levels.....	57
5.1.1 Level 0.....	57
5.1.2 Level STM.....	57
5.1.3 Level 1.....	58
5.1.4 Level 2.....	59
5.1.5 Level 3.....	59
5.2 Stationary part.....	60
5.2.1 Level 0.....	60
5.2.2 Level STM.....	60
5.2.3 Level 1.....	60
5.2.4 Level 2.....	61
5.2.5 Level 3.....	61
5.2.6 Level transitions.....	61
5.3 Subset 026 Chapter 4.....	61
5.3.1 Modes.....	61
5.3.2 Mode Profile.....	64
5.3.3 Functions and transitions.....	64
5.4 Subset 026 Chapter 5.....	66
5.5 ETCS DMI.....	66
6 Scenarios.....	67
6.1.1 Training.....	67
6.1.2 Ride with a timetable.....	67
6.1.3 Ride with a timetable and dangers.....	67
6.1.4 Ride with a degraded situation.....	69
6.1.5 ETCS scenarios.....	69
6.1.6 Other.....	71
7 Conclusion.....	72
8 Literature.....	73
9 List of appendixes.....	76

Vocabulary

As the foreign railway terminology is based on the language of the country and also the national specifics of the railway operation, it is rather difficult to translate the terms used in the Czech Republic directly to English. I used English terms presented in the Dictionary of Signalling and Security Systems for Railways, published by the company AŽD Praha [1]. Terms, which are not mentioned in this book, are usually taken from articles on the English Wikipedia. If the correct translation is not clear or standardized or if it is needed to describe an element used only in the Czech Republic, I use my own terms, which are clarified if necessary. Here I present a list of the terms, which may cause confusion, and their explanation.

automatic brake is an air brake used on trains which engages automatically if the pressure in the main air pipe decreases

brake percentage gives a ratio between the brake weight and the train weight

brake weight is a technical quantity that describes the performance of a brake on a certain railway vehicle

brake valve is a device, placed on a leading vehicle of a train, which controls the air brake and may be operated by the driver or by an automatic system

braking position is a mode of operation of the automatic brake, affecting the reaction time of the brake

cant of a track is the difference between the heights of the two rails at a certain crosssection of the track

continuous automatic train protection is a system placed on board of the train that provides safety in case of a driver error, using continuously transmitted information from the track

direct brake is a brake used used on a locomotive or other vehicle with a driver cab, providing direct control of brakes of this vehicle without affecting the train brake

distant signal is a signal that provides information about the state of another signal placed at certain distance behind it, providing sufficient time for the driver to react

facing point is a point that is passed by the train in a direction in which the position of the point affects the direction of the train

flip switch is an electrical switch controlled by a lever

force opening of a point is a situation when a train enters the point in the trailing direction and the point is not properly set

integration lever is a lever with discrete positions that affect the rate of change of a certain variable, e. g. three positions for increasing, decreasing and keeping the value

intermittent automatic train protection is a system placed on board of the train that provides safety in case of a driver error, using information from the track which is transmitted in certain spots

loading gauge defines the maximal width and height of vehicles on a certain track

locked position is a position of a control element in which the element stays when not operated by the user

main circuit breaker is a device on an electric locomotive which switches the electric supply from the power collecting device

marker light is a light on a railway vehicle which serves to alert other subjects about the state and position of the vehicle

mileage is a coordinate system on railway, describing a distance relative to a certain point

overcharge is a state of the automatic brake in which the main pipe pressure is higher than the normal working pressure

proportional lever is a lever with an operation area in which the position of the lever can be set continuously

route locking is a process that blocks the elements of a train route so their position can not be changed until the train has passed them

subsidiary aspect is an aspect of a main signal that enables the train to pass this signal set at Danger in case that the signal can not be properly set due to a technical fault or other reason

super-elevation ramp defines the change of cant in a certain section of a track, e. g. in transition from straight line to a curve

trailing point is a point that the train passes in a direction in which the branches of the point converge into a single track

transition spiral defines the gradual change of radius of a curve on a track between a curve and a straight line or two curves of different radius

tread brake is a rail brake that uses blocks of iron or other material pressing against the running surface of the vehicle's wheels

triple valve is a device on a rail vehicle that is connected between the main brake pipe, the brake cylinder and an auxiliary air reservoir, controlling the pressure in the brake cylinder by evaluating the change of pressure in the main pipe

turnout direction of a point is the branch in which the track is not straight

Abbreviations

ARR.....	automatic speed regulation
ATO.....	automatic train operation
ATP.....	automatic train protection
AVV.....	automatic train guidance
CTU.....	Czech Technical University
ČD.....	České Dráhy (Czech rail operator)
EOA.....	end of authority
ETCS.....	European Train Control System
GSM.....	Global System for Mobile Communications
JRU.....	jurisdictional recording unit
MA.....	movement authority
OBU.....	on-board unit (of ETCS)
RBC.....	Radio Block Centre
STM.....	Specific Transmission Module
VBC.....	Virtual Balise Cover

Preface

After many years of decline, the rail transport has started to prosper again. The reason is its balanced mixture of efficiency, capacity, comfort and speed when compared to road or air transport. This becomes important in the recent years as the natural and human resources are more and more scarce.

To perform education of the staff and research new possibilities for enhancing the abilities of the rail transport, it is necessary to introduce a technology that combines safe operation with affordable cost: simulation. The new technologies of the recent years enable the simulation to be very realistic.

I would like to express my thanks to all people who have helped me with the creation of this thesis, mainly the personnel of the Transportation Laboratory lead by doc. Ing. Martin Leso, PhD.

1 Introduction

1.1 Purpose

Simulation is used in all fields of science, technology and industry to obtain results whose acquisition would be complicated in the real world. The reasons why a simulation may be performed are:

- **Safety.** The risk of an accident resulting in personnel fatality or financial loss, caused by human or technical fault, is usually reduced to zero when compared to a real device.
- **Finance.** The simulation is far less expensive than a real life experiment in many cases. This is important mainly in case that multiple simulations are performed using a single simulation equipment, as the costs of obtaining the equipment are dissolved. Also the physical processes, which would require obtaining a new physical equipment, can be simulated by changing the parameters of the simulation on computer, requiring much less finance and time.
- **Convenience.** The parameters of the simulation can be changed easily and quickly. Situations that happen only rarely in real life can be simulated as often as needed. This is very important, as the goal of simulators involving humans is often to prepare them for non-standard situations.

It is possible to simulate either a process which does not involve human interaction during the simulation, such as in traffic or electric circuit modelling. On the other hand, simulations directly incorporating a human operator are made, mainly to investigate human-machine interaction or to perform education of the person. Simulators involving human operators are used in all fields of industry and transportation, both civil and military.

Simulation is well known in aviation industry and operation. The reason may be that both the risk and the cost of performing real life experiments is very high. Simulators of aircraft cockpits are extensively used in pilot education. They are also used for training of Air Traffic Control dispatchers. These simulators use a cab similar to a control room in an ATC tower, providing a 360° visualisation simulating a view of the whole airport from the tower. Simulation is naturally used also in space industry.

Road simulators have been regularly used in driving schools for education of new drivers since many decades ago. They are also used for scientific experiments which are not possible in real traffic, such as studies of alcohol or tiredness effects on driver performance. The CTU Faculty of Transportation is equipped with simulators of passenger cars and a dynamic simulator of a truck.

Rail vehicle simulators are a well-known issue in rail operation. They have been used for decades both for driver and train dispatcher education. The train dispatchers are usually trained using a model railway, which is operated in the same way as a real railway. Also the model railway on the Transportation Laboratory of CTU Faculty of Transportation belongs to this type of simulators. [2]

However, the state of technology did not enable a realistic simulation of a cab of a running locomotive in the past and only the function of the technical subsystems or a very simplified version of a train movement was simulated. On the other hand the present

technologies offer a base for a very realistic simulation of the complete train operation. This is why the train cab simulators are currently introduced into operation all over the world. Introduction of this type of simulators in the Czech Republic is necessary to keep with the pace of the technology and to exploit the benefits of simulation, which were mentioned above.

1.2 Types of locomotive simulators

The construction of a locomotive simulator is dependent on the purpose of its use and the financial abilities of its owner. Taking into account the simulators currently available on market, the physical outline of a simulator can match one of the following categories.

1.2.1 Desktop

This type of simulator is basically a standard computer with a display. It can be controlled either by classic computer peripherals (a keyboard and a mouse) or by a specially made control desk, which simulates the original desk of a real vehicle to some degree, but is generally smaller and simpler than the original and only the basic control elements are present. This type of simulator is portable and can be set on a standard office table. The level of sense of reality is low, but that is not necessarily a problem, for example if the purpose of the simulator is just to teach correct reactions to signals.

1.2.2 Mobile desk

Mobile desk simulator is constructed on a specially made desk base, which contains a desk derived from the original locomotive, a display and a computer. It is portable, but the desk has to be transported as a single part. The properties of this type are similar to the desktop type, but the desk is more realistic.

1.2.3 Fixed desk

This type usually uses a complete desk from the real locomotive. It is not portable, so a projection system may be used instead of the display. The projection system may provide a 3D visualisation. As a result, the simulation is much more realistic than with the previous types and the similarity with the real locomotive is higher.

1.2.4 Full cab

This is the most advanced class of simulator. It uses a complete cab, which may be the same as on the real locomotive, so the impression of a real locomotive is almost perfect. Projection system is usually implemented, although usage of displays is also possible. The whole cab may be placed on an actuator system, simulating the movements of the vehicle. In that case, the simulator is called dynamic.

The non-moving simulators are referenced to as static. A drawback of a static simulator is that the brain of the driver does not have a sensorical feedback of the movements that the driver sees on the visualisation. This often results in the so-called simulator sickness, which includes nausea and dizziness. This is a well-known phenomenon on aviation simulators, but is also present on car and rail simulators. [3] Also the driver can not develop a feel for the train's dynamics, which is necessary for safe and efficient train operation.

The dynamic simulator moves the whole cab assembly, together with the projection system. Acceleration on small trajectories (centimetres) is provided usually by a hydraulic system and imitates the shakes from a rough track, points etc. The source of acceleration over long trajectories is the gravity and the hydraulic system serves to change the tilt of the cab, which changes the direction of the vector of gravity acceleration relative to the cab's axes. This simulates the acceleration caused by traction and brake forces. The dynamic simulator provides sense of acceleration to the driver, so the driver can develop a feel for accelerating and braking. Of course, it is necessary that the simulation is corresponding to reality, otherwise the results on the driver skills may be even negative. Other advantage of the dynamic simulator is that the simulator dizziness is suppressed. The disadvantage of this type is high complexity, which results in high price. The issue is not only the movement of the cab and its control, but also the projection system, as the visualisation shall stay motionless to the driver during the cab's movements. This is usually provided by mounting the whole projection assembly to the cab, so it is moving together with it. This type of simulator also requires lot of space and it is quite heavy. The floor on which the simulator is placed has to be sufficiently strong. This might be an issue when the simulator shall be placed in an ordinary office building.

1.3 Simulators in use

A locomotive cab simulator is a device that is not uncommon to see. The following simulators are currently working in the Czech Republic and other countries of the whole world.

1.3.1 Czech Republic

1.3.1.1 Prague, Království železnic

Království železnic (Railway Kingdom) is a company running an amusement center in a shopping park in Prague. The center's theme is railways and it is focused mainly on children. The center is equipped with a large model railway and several other attractions, one of them the locomotive simulator. [4]

This simulator is based on a locomotive of ČD Class 141. These passenger electric locomotives were manufactured at the end of the 1950s and they are very outdated today. As the purpose of the simulator is not to provide education for professionals, but fun for children, the simulation is very crude. The cab is taken from a real locomotive with all the control elements. The windows of the cab are converted to monitors. The core of the simulator is a commercial computer game. The movement of the locomotive is controlled with the original traction and brake controller. Interlocking and signalling is not simulated, as the children would not understand it anyway.

1.3.1.2 Česká Třebová

The locomotive depot in Česká Třebová is equipped with an electric locomotive simulator. It is based on a ČD Class 181, which is a freight electric locomotive built by Škoda Plzeň from 1961. The age of the simulator is similar.

This simulator is different from what we usually understand as a simulator today. It is basically a setting of internal components of the real locomotive, placed inside a building, so they can be easily accessed. The components are functional and they are controlled by an original desk, only the high voltage circuits are not powered because of safety. No

simulation of movement of the locomotive, nor any visualisation is provided.

The purpose of this simulator is to show the drivers the components of the locomotive, explain how they work and teach the drivers how to manage problems and failures. However, this simulator is very outdated, as the Class 181 was built at the beginning of 1960s. Recent locomotives are based on a completely different technology.



Locomotive simulator in Česká Třebová [www.malevlaky.cz]

1.3.1.3 Ostrava

A group of railway enthusiasts from Ostrava has developed several simulators based on a real locomotive cab, for example an electric multiple unit Class 452 or a diesel locomotive Class 742. The simulators are based on a commercial computer game and the cab works simply as an extended keyboard, similarly to the simulator in Království železnic. Thus, the possibilities of the simulators are limited and they may serve mainly as entertainment.

1.3.1.4 Contract announced by České dráhy

Czech railway operator, České dráhy (ČD, Czech Railways), tendered a bid for two locomotive simulators in summer 2016. [5] The simulators will be placed in Prague and Česká Třebová. The period for delivering the simulators from making the contract is 12 months. The contractor is requested to have delivered at least three simulators for at least two customers in the past.

The contract includes a training course for the staff operating the simulators (eight instructors and two editors). The simulator shall be a static full cab based on a contemporary electric vehicle corresponding to UIC 612. The visualisation shall be provided by a high definition display with at least 170 cm diagonal, placed at least 1 m

from the eye of the driver. Also the sounds of the vehicle shall be simulated. The cab shall be equipped with a camera and the videos from both the camera and the visualisation shall be recorded. Storage of at least 600 hours of video and a search based on date, time and the driver's name shall be possible. The software shall run on Windows 7.

The touch displays on the desk shall have at least 17“ diagonal (that is significantly more than the requirements in UIC 612). The radio shall simulate simplex, TRS and GSM-R. The displays shall be prepared for installation of electronic timetable.

The simulator shall be supplied with 250 km of tracks with variable properties such as one or more track lines, presence of radio, type of interlocking system, presence of ETCS. Also a track editor shall be supplied. The signalling and interlocking shall be compliant with SŽDC D1 [6] and shall include outdated types of signalling, such as mechanical aspects. Interestingly, the contract documentation includes a large part which is basically a copy of SŽDC D1, but the ETCS simulation is not described any further.

Other trains on the track shall be also visualised. The landscape shall be simulated too, together with buildings, road vehicles, people and animals.

The vehicle shall be equipped with ARR and AVV. The simulated situations shall include a departure and arrival of a train into a station, running on a track, shunting between stations and between a station and a locomotive depot. Simulation of shunting in a station is not requested.

The simulator shall check the driver's reactions and record any violations of the rules, such as exceeding the maximal speed or forgetting to sound a horn in places where it is requested. Fire on other trains or objects near the tracks shall be also simulated. Collisions with other trains or objects on level crossing shall result in stopping the simulation. Weather and season of the year shall be also simulated. Failures on the track and the vehicle can be induced, including speed meter failure or activation of emergency brake by a passenger in the train. The simulator shall automatically generate a report from the simulation.

1.3.2 Germany

1.3.2.1 DB AG

DB AG have developed a series of simulators which is in correspondence with the contemporary needs of the driver education. The simulators are dynamic and the cab may be compliant with UIC 612 [7] or can be based on a specific vehicle. The simulators are located in 12 places across the country, for example in Karlsruhe and Hamburg. The simulators are used to train drivers and serve to teach them energy-efficient train operation and prepare them for non-standard and dangerous situations, which do not happen often enough in normal operation to become familiar to the drivers, such as a fire on a train running on the neighbouring track. The tracks are fictional, so it is not possible that the driver knows them from before. [8] The simulator in Karlsruhe can serve 2000 drivers per year and cost 1,4 million €. [9]

1.3.2.2 Raildox GmbH

Apart from DB AG, a private company Raildox GmbH developed a train cab simulator, which is placed in Erfurt. [10] The simulator is commercially offered for training of drivers and also as a public entertainment enterprise. The cab is based on DB Class 185, which

basically corresponds to [7]. The control elements are original. The scenarios are based on selection from more than 100 train compositions. The ride is based on timetable. Automatic train control is also possible. The company says that the train dynamics are „absolutely realistic“.

The infrastructure is based on modules of tracks, which can be composed together. The tracks vary from branch lines to high-speed lines. The necessary track documentation is also provided. The ride can be either regular or complicated with irregularities.

1.3.3 Switzerland

1.3.3.1 LOCSIM

This Swiss company offers locomotive simulators for schools and railway operators across the whole world. [11] The company also uses their software for calculations of train movement, which can be used to evaluate energy consumption, train dynamics, investigate accidents etc. The results can be used in timetable construction and also vehicle or infrastructure design.

One of the simulators is placed in Kreuzlingen and is operated by railway company Thurbo AG. It is based on a cab of one of the company's electric multiple units and it is not compliant with UIC 612. The simulation is based on a video footage of a real track, whose speed is changed according to the current speed of the simulated train. Variable signals are modified in the video, so their aspect can be controlled. The disadvantage of this approach is that non-static objects in the video, such as pedestrians, also change the speed of their movement with relation to the speed of the train. The signals and train and track parameters are controlled by the supervisor. [12]

1.3.3.2 Verkehrshaus Luzern

The transport museum in Luzern is equipped with three locomotive simulators, which are available to the visitors, and are targeted also on children. The simulation involves a timetable and signalling. Each simulator is based on a different vehicle, but all of them are contemporary electric multiple units. [13] One of the simulators is quite crude, providing only a simplified cab desk and a projector, but other one is very realistic, using a complete cab and all the operating elements. [14]

1.3.3.3 Kaeserberg

Kaeserberg is a large model railway, built as a tourist sightpoint. A locomotive simulator is present on the site. It is based on a complete cab taken from an old locomotive, so the cab is relatively outdated. The visualisation is presented on a standard computer display. The visitor is met by a retired train driver and the first ride is made on a virtual network. The visitor can then choose from two simulations based on a real track. The simulation takes three hours and costs CHF 485. [15]

1.3.4 Austria

1.3.4.1 Wiener Linien

This U-bahn operator introduced a U-bahn cab simulator in 2015. The simulator is used to prepare the drivers for unusual situations, such as fires, obstacles on the track or snow. [16]

The simulator is equipped with 3D visualisation, radio and control elements identical with the original.

1.3.5 Belgium

1.3.5.1 SNCB

The railway operator SNCB has introduced two cab simulators for driver training. The simulators were constructed by SNCB themselves. The simulators are based on Class 13, which is a universal locomotive with maximal speed of 200 km/h, built around the year 2000. The simulators use a complete cab from this class. They are dynamic. 1200 drivers use the simulator each year. They get prepared for unusual situations, for example a defective signal. [17]

1.3.5.2 Infrabel

The Belgium's railway infrastructure managing company Infrabel uses a simulator of a track maintenance machine. The simulator uses a simplified cab with original control elements and a computer screen. [18]

1.3.6 France

1.3.6.1 SNCF

The railway operator SNCF uses multiple simulators for staff training, mainly to prepare them for unusual situations. One of them simulates the high-speed trainset TGV. The simulator is dynamic and uses a realistic cab. Other is static and uses just a desk with original control elements. [19]

1.3.6.2 Corys

A French company Corys supplies railway freight and passenger main line and high-speed service simulators. The simulators are equipped with GSM-R and ERTMS and can serve for route learning, train dynamics understanding or economical operation learning. A range of simulators is provided, from desktop simulators, mobile desk simulators, fixed desk simulators to dynamic cab simulators. The company has supplied simulators for dozens of railway operators across the whole world, including Eurotunnel, Swiss SBB or Hungarian MÁV. [20]

1.3.7 Luxembourg

In 2002, the railway operator CFL introduced a simulator of a cab of its new locomotive Class 3000, which is the same as the Class 13 of SNCB. The simulator served to prepare the drivers for unusual and dangerous situations. The contractor was a German company Krauss-Maffei-Wegmann. The simulator was relatively innovative, taking into account the year when it was built. It was a dynamic simulator and the cab was identical to the cab of the real locomotive. The visualisation was computer generated and provided two 50 km long tracks, each of them fictional. It cost 2,5 million €. [21]

1.3.8 Ireland

A simulator facility is operated by Irish Rail in Dublin. The facility consists of seven different simulators. They are of cab desk type. The simulators are equipped with radio, signalling, changeable conditions and failures. Complete model of the whole train is provided and the failures can be induced in it. It is used to teach new drivers before they get to a real vehicle and also prepare them for dangers. [22]

1.3.9 Canada

A subway operator in Montréal, STM, has introduced a subway cab simulator in 2014. The purpose of the simulator was to teach drivers how to operate new trainsets before the trains were actually delivered. The simulator was delivered by Oktal Toulouse and Tru Training Simulation +. A new driver is said to be trained in 26 days. The simulator is an exact copy of the real cab and is dynamic. The visualisation is 3D. The simulated tracks are taken from the real network. [23]

1.3.10 India

The Indian Railways have introduced railway simulators for driver education in 2015. The simulators were supplied by an Australian company Sydac, which is a subsidiary of German company Knorr-Bremse. They are placed in 12 cities and the whole project cost \$ 30 million. The contract included 12 complete cab simulators, 60 desk simulators and 72 small simulators. Several diesel and electric locomotives and 2100 km of tracks are modelled. [24]

1.3.11 Australia

The Sydac company has also delivered an electric multiple unit simulator for the Australian government. The simulator serves to introduce the drivers to a new type of vehicle before it is delivered. Also faults and incidents are simulated. Replication of a real incident is also possible to determine the causes of the incident. [25]

1.3.12 United States of America

The American rail operator Amtrak uses simulators to train its drivers. One of the older types of simulators uses a cab desk identical to the original locomotive and a computer-generated visualisation. Multiple simulators were built, each for a particular type of locomotive. [26]

The author of the article, which was published in 2001 and describes the simulator as new, also mentions the fact that he got dizzy while the simulation was running.

Amtrak also used a simulator to investigate an accident in 2015. The simulator uses a cab desk and a computer display. [27]

1.3.13 Turkey

Turkish company Simsoft offers simulators of many types of machines, including armoured vehicles for Bangladesh Army, and also railway simulators. The railway simulator is designed as based on the specifications from the customer. Two types of simulators are offered: a full dynamic cab and a desk simulator. [28]

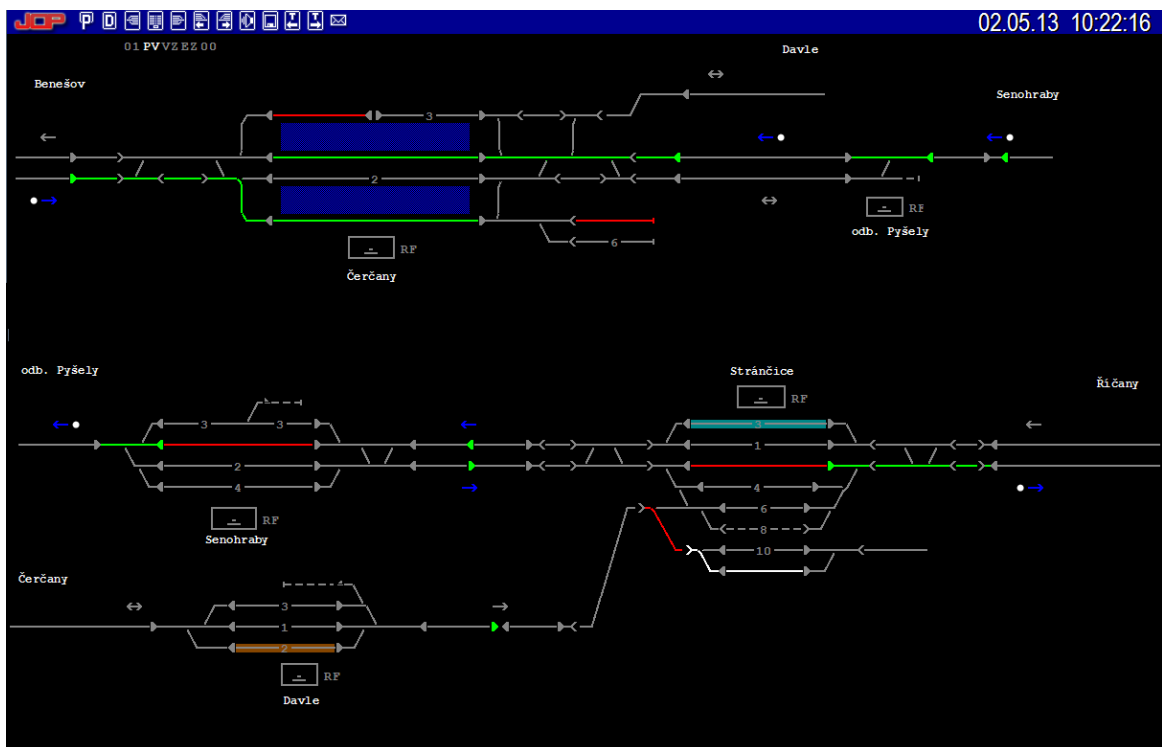
The simulator is also offered on an e-shop, only the specifications have to be sent to the manufacturer and the final price is evaluated from them. [29]

1.4 Transportation Laboratory

The Transportation Laboratory is a facility of the CTU Faculty of Transportation. The Laboratory contains a large model railway, which is equipped with interlocking systems identical to types used real Czech railway infrastructure. The vehicles are operated by an ATO system, similar to the Czech system AVV used on real vehicles.

Currently, the staff of the Laboratory is working on introduction of the ETCS system. Also the infrastructure description system, RailML, is currently under examination.

The simulator proposed in this thesis might use similar systems as the model railway of the Laboratory.



Electronic interlocking system [dsfd.fd.cvut.cz]

2 Simulation

Based on the facts mentioned in the previous chapter, the layouts made by all the companies were evaluated. Here I present the possible conditions of the simulation, which would be necessary to make the simulation beneficial for the driver's education.

2.1 Time and weather

The simulation shall contain all the types of weather possible in the Czech Republic. In case that any other land is about to be simulated in the future, other types of weather, which are possible in that place, shall be easily incorporated.

2.1.1 Time

It shall be possible to continuously change the time between two values:

- Day
- Night

The value shall be presented as a percentage variable of „day“. If the value is 100 %, the visualisation should correspond to a day at noon, 0 % to midnight. Simulating the dusk and dawn is thus possible. Depending on the direction and time, the visualisation shall show the sun above the horizon, dazzling the driver. The transition from day to night may be automatic, running in natural time.

2.1.2 Season

The season of the year shall be set before the simulation is started. It shall have these possibilities:

- Summer
- Autumn
- Winter

Autumn introduces leaves falling from the trees. The track may become slippery in places where the trees are close to the track. That is simulated by reducing the adhesion coefficient in these sections.

During the Winter, the vegetation shall have fallen leaves and a snow cover shall be visualised. Again the adhesion may be reduced and problems with the vehicle or the catenary, such as frost affecting the collection of current, may be introduced.

2.1.3 Visibility

The simulation shall visualise the following visibility problems, again on scale from 0 to 100 %:

- Clouds (0 % - no clouds, 100 % - overcast sky)
- Fog (0 % - no fog, 100 % - nothing visible)
- Rain (0 % - no rain, 100 % - downpour)

- Snow (0 % - no snow, 100 % - snowstorm)

Lightning shall be also incorporated in the simulation. It may serve as a cause of technical failures requiring the driver to perform certain actions.

The values of the variables shall be set manually before starting the simulation or they may be changed manually or randomly during the simulation. The Rain and Snow may be simulated only when the Clouds variable is non zero.

Rain and Snow shall have impact on transparency of the windscreen, which will force the driver to use wipers. The rain shall induce blurred circles randomly appearing on the head projection with a rate corresponding to the intensity of the rain. The snow shall work in the same way, only the circles shall be white and opaque.

The simulator contract announced by České dráhy requires the wipers to be automatic. This function does not have to be incorporated in case of the proposed simulator.

2.1.4 Wind

The simulation shall incorporate the effects of wind. The wind shall move the trees and catenary in the visualisation. The force shall be controlled at scale from 0 to 100 %.

The driver may be required to contact the train dispatcher or do other measures, specified by the operating rules such as SŽDC D1, if they observe a strong wind.

2.2 Infrastructure

The simulation shall have incorporated multiple track models. The models shall simulate a track, which exists in real world, or a track which was artificially created.

2.2.1 Track

The track shall be modelled by means of a three-dimensional array. Position of each element of the visualisation shall be described by its coordinates in the array. The model may be based on RailML modelling language which is currently under research in the Transportation Laboratory.

The infrastructure model may be created by first describing each track as a curve in the three-dimensional space, taking into account also the super-elevation ramps and transition spirals. Also the cant of the track is defined. The maximal permitted speed on the track is defined separately for a certain class of rail vehicles. The classes currently used in the Czech Republic are:

- Class 3: Valid mainly for heavy six-axle freight locomotives
- Class N: Valid for locomotives and cars of normal construction
- Class N₁₃₀: Valid for vehicles, which are able to use cant deficiency of 130 mm; mainly express locomotives and cars
- Class NS: Valid for tilting vehicles

As the maximal speed is related to the curve radius and cant and the maximal possible value of the cant is defined, it may be possible to calculate the maximal speed of the track automatically for each class. The driver is then responsible for keeping the speed under the limit valid for the class of their train.

Other properties of the track, affecting suitability of the track for the train, shall be also incorporated. This includes:

- loading gauge
- traction system
- axle load category

As the driver is not responsible for checking whether the track is suitable of the train, as this shall be done by the dispatchers before the train is actually routed to the track, these elements of the simulation may look purposeless. These elements have a value for the simulation of the ETCS subsystem, which incorporates processes checking the track suitability. Moreover, the driver may be tested whether they do not forget to stop the train before entering unsuitable track, e. g. with incompatible traction system.

The adhesion coefficient of the track shall be variable, as mentioned in the Weather chapter. This may require the driver to deploy sanding or it may even result in stalling the train, requiring the driver to perform certain measures, such as requesting help from the train dispatcher.

2.2.2 Mileage

The track would be first divided into sections of a certain length, for example 10 meters, and the maximal speed would be calculated for the beginning or end of each of the sections. Then, these sections would be aggregated into larger sections of the same maximal speed. In each of these long sections, the maximal speed would be determined from the lowest maximal speed present in the group of short sections. The goal would be to make as little speed changes as possible while not restricting the speed too much in parts of the track where the theoretical maximal speed is higher than the permitted speed.

The system of defining the position of the train or the stationary elements, for example the signals, on certain track is called mileage. The mileage shall be defined not for each track separately, but for a reference starting point, similarly to the system used on real railway. Also the direction of the track is defined, the direction going from the starting point is „odd“ and the other is „even“.

The result is that each track has a defined starting point and the mileage running from the starting point. The mileage on the rest of the track is based on the length of the track. If a track separates from another track and then joins back and the lengths of these two tracks are not the same, one of them shall be defined as the „main“. Each of the tracks has its own mileage. When the main track joins the other track, the following track shall use the mileage taken from the main track. Thus discontinuities may happen in the mileage. This is common also on real railway. Also the ETCS system takes into account the possibility of discontinuities.

Loops and circles are managed in the same way. The loop or circle must have its beginning defined. After the loop or circle is passed and the beginning point is reached, the mileage is reset to the starting value.

The track serves as a reference for the position of other elements of the railway. For example, the position of signals may be defined by its track, mileage, direction and side relative to the track.

2.2.3 Points and buffer stops

The track can end either with a point or with a buffer stop. The buffer stops shall have defined an amount of energy they can absorb without damage in case that they are hit by a train. If the train hits the buffer stop and its kinetic energy is lower or equal to the maximal energy the buffer stop can absorb, the train shall be stopped. However, this energy limit may be equal to zero. If the maximal energy is exceeded, the simulation shall end, either by displaying an error message, or by visualising the accident. In any case, the collision with a buffer stop shall be considered as an accident, as the personnel is not allowed to use buffer stops for stopping the vehicles.

Points are described by their turnout radiuses and cant. The turnout radius is selected from several possible radiuses used in reality. The length of the point is dependent on the turnout radius and it is defined as based on the length of a real point of the actual radius. The maximal permitted speed in the turnout direction depends on the turnout radius. For example, the types of points used in the Czech Republic are: [30]

- 1:7,5 – 40 km/h
- 1:9 – 50 km/h
- 1:12 – 60 km/h
- 1:14 – 80 km/h
- 1:18,5 – 100 km/h
- 1:26,5 – 120 km/h

Other types of points with higher speed in the turnout direction are likely to be introduced in the Czech Republic in the future.

Due to the complexity of creating a track layout with the geometry of real points and tracks, including the cant, transition spiral and other issues, the simulation may be simplified by using a unified geometry of the points, neglecting the geometry of the connection of the point to the tracks. However, if a dynamic simulator is supposed to be developed in the future, based on the static simulator, the geometry of the points shall correspond to reality. Only then the movement of the cab can be realistic without needing a separate definition of the geometry.

The point blades shall be visualised as well. Their position shall be according to the position in which the point is set. This enables the driver to visually evaluate the position of the point. Although this is not necessary during standard operation, it may be useful in some cases, for example when moving on a subsidiary aspect or during shunting.

When running against a facing point, depending on the position of the point, the train moves onto another part of the track and a new track description is used. When running against a trailing point, the movement of the train is not related to the position of the point, but if the point is force-opened, its state is recorded by the interlocking subsystem and this shall be recorded as an accident. This is not the case if a self-returning point is used. This type of point is designed to be force-opened regularly.

2.2.4 Signals

The signals are described by their type, state (in case if the signal is variable) and position. The position is relative to the track and the signals shall be inherently in standard position in relation to the track, but an alternation shall be possible, so a signal can be placed into a non-standard position, for example on the other side of the track or on a ramp above the track. This is used when there is not enough space for the signal or if the signal would not be visible well enough in the standard position.

Variable signals are controlled by the interlocking subsystem. The simulator shall use not only the contemporary signalling systems, but also old types of signalling systems, as the procedures and rules for such systems differ from the contemporary systems and the driver may be required to get familiar with them.

The signalling system shall correspond to the country whose railway is simulated. The Czech signalling system is described in [6]. If a different signalling system is to be simulated, for example a newly proposed alternative, it shall be first described in a fashion similar to [6] and then the simulation may be made, based on the document.

The visibility of the signals shall be correspondent to the time and weather conditions. Fixed signals and non-variable parts of variable signals shall behave as if they were made of retroreflective material.

2.2.5 Catenary

Catenary may be defined as present or non-present on the actual track. If the catenary is present, it is visualised and it is possible for an electric locomotive to collect current from it. All the signals valid for electric traction issues shall be present and they shall correspond to the model of the catenary.

Multiple traction systems may be incorporated into the simulation. In that case, the driver has to change the setting of the current system correctly on the point of the track where the traction systems change, if they are driving a multisystem locomotive, or stop if the new system is not compliant with the locomotive. If the driver tries to connect the locomotive to a non-compliant system, the simulation shall end and the situation shall be reported. This situation would cause damage to the locomotive and infrastructure.

Section breaks shall be also modelled and they shall behave as parts of catenary with no current present. The actions of the driver shall correspond to the signals related to electric traction. For example, the driver may be obliged to lower the pantograph when passing a section break. Any error of the driver to do so shall be reported.

The section breaks will be also incorporated into the ETCS subsystem, which may control the main switch and pantograph either directly or by advising the driver to operate them.

2.2.6 Outside world

Objects of the outside world not directly related to the railway, such as the terrain, trees, roads, buildings etc. shall be also modelled. Their appearance shall correspond to the Season. Out of these elements, the roads are not completely unrelated to the railway, as the level crossings shall be also modelled. For this reason, the road traffic shall be also visualised to make it possible to show a crossing occupied by a road vehicle. The intersections may be either equipped with a safeguarding device or not. The safeguarding devices shall be controlled by the interlocking subsystem.

2.3 Interlocking

The interlocking system may be based on the electronic interlocking system currently used in the Railway Laboratory of the Czech Technical University, Faculty of Transportation. It is a computer-controlled system similar to the ESA systems developed by the company AŽD Praha. It is equipped with a graphic technology overlay, which incorporates a transmission of train numbers into the operator's interface. Development of automatic setting of the train routes is currently in progress in the Railway Laboratory. This may be particularly useful in the simulator.

The interlocking shall be based on the track description, mentioned in the previous chapter. Based on the position and the length of the train, taken from the train data, the tracks shall be shown as occupied in the interlocking system. The system may be operated either manually by a train dispatcher or automatically in case that the automatic route setting is incorporated. The output of the interlocking shall affect the point positions, variable signals and other variable elements in the simulation, and also the ETCS system – variable balises in Level 1 and RBC in Level 2.

If any other trains are present in the simulation, they shall be incorporated into the interlocking system in the same way.

In some cases, the railway operation is controlled not only by means of the interlocking system, but also directly by the railway employees, who communicate with the train driver either directly or via radio, for example during shunting. In that case, the role of the employees is played by the dispatcher. Despite the fact that the driver always calls the same person, they should behave as if every role was played by a different person.

In some cases, it is not important to have the interlocking system simulated, for example for getting the driver familiar with the simulator or for presentation purposes. In that case, the track does not have to be equipped with signals and the train route is fixed. This may use a special simplified track model.

2.4 Radio

The radio is presented to the driver by a Train Radio Display and a handset in the cab. The driver may use the radio to contact the dispatcher or other person the driver needs, but the other employees are also played by the dispatcher. Despite that, the driver shall be always required to use the correct radio or telephone communication channel, distinct for each situation. Because of this reason, the dispatcher shall be provided with information about the channel the driver used.

The radio system shall be composed of four separate subsystems, based on the current situation in the Czech Republic. All of these subsystems are incorporated into a single device, the Train Radio Display.

2.4.1 Simplex system

The so-called simplex system operates as a semi-duplex radio (the communication is bidirectional, but only one direction is possible at a certain moment). There are several channels, each dedicated to a particular usage. Each railway station has a dedicated set of channels which shall be used there. The list of channels is in the track documentation. The driver selects a channel and if they want to talk, they push a PTT (Push To Talk) button. The driver can hear the response only if the PTT button is released. In reality, this system works in a fashion that „everyone hears everyone“ in reach of the transmitting

station. This system is used mainly for shunting purposes in the Czech Republic. On the other hand, the same system is used in Slovakia as the only radio system available on majority of Slovakian network.

2.4.2 TRS system

The TRS (Traťový rádiový systém, Track radio system) is a Czech standard for railway radio. It is a duplex system, where the communication can be heard only by the station that is called. The driver has to enter the train number and the so-called „ribbon“ number into the locomotive's radio station. The track is divided into sections and each has its distinct ribbon number, so the driver has to change this number when entering a new section of the track and perform a procedure that tests the connection.

This system is equipped with a remote stop feature. The train dispatcher can either stop a train of a certain number or all the trains in reach of their radio station. As this feature is an open-loop system, it is not inherently fail-safe, so it can happen that the command will not be received by the train, for example in case that the train is in a place where the radio signal is weak.

The TRS system shall be incorporated into the simulation in a way that corresponds to reality. Each track shall have a dedicated channel, which is indicated by special signals in the places where the channels change (§1232 [6]), which show the number of the „ribbon“. If the driver does not have set a number which corresponds with the ribbon number of the track where the train is at that moment, the communication shall not be possible.

Also the remote stop shall be incorporated, enabling the driver to learn a correct reaction if their train gets stopped remotely.

2.4.3 GSM-R

The GSM-R is the latest system in use on the European railways and it is currently in construction on the Czech network. It is also used to continually transceive data for the ETCS level 2 and 3. The core and fashion of operation of the system is similar to public GSM. The GSM-R standard is defined by [31].

The connection is bidirectional, the handover of the moving train between the base stations is automatic. A priority control over the connections is established. The station calling numbers are not always fixed, but in case of the train, they are dependent on the train number, so the dispatcher can easily figure out the number they have to call to contact a certain person on a certain train. However, this feature is useless in case of the simulator.

The serviced area is divided into groups. This property enables a considerable simplification of the operation. If a driver needs to call a dispatcher responsible for the track where the driver's train currently is, they do not have to know the dispatcher's number. The system establishes the connection with the responsible dispatcher automatically. The location of the train is estimated from its position in the GSM-R cell system, but may be enhanced with train location systems or track balises.

The GSM-R is not equipped with a remote stop feature, although discussions about the possibility of incorporating it in Czech environment are currently running. [32]

The implementation of this system into the simulator shall be simplified. The driver shall be required to enter a correct number or select an operation which does not require entering any number. The connection with the dispatcher shall be always established, but

the dispatcher shall check whether the driver has used a correct number.

The GSM-R system offers the following functions to the driver:

2.4.3.1 Call controller

A connection with a dispatcher relevant to the train's position is made. The driver's functional number is passed to the network.

2.4.3.2 Call other drivers in the area

A high priority group call with other drivers in the relevant area is established. The driver's functional number is passed to the network.

2.4.3.3 Emergency call

The dispatcher receives the emergency call from a driver. The calling train's position is shown to the dispatcher.

2.4.3.4 Communicate with other drivers on the same train

This feature serves to communicate between the drivers of multiple active vehicles of a single train. The driver of the leading vehicle establishes the connection.

2.4.3.5 Call train staff

To call a certain person from the staff of a train of certain number, only the train number and the rank of the person has to be known.

2.4.3.6 Call other authorised users

This feature behaves as an ordinary GSM phone. The driver enters a phone number and a connection is established.

2.4.3.7 Receive short text messages

SMS service is also incorporated in GSM-R. The driver can send and receive text messages in the same fashion as if establishing a voice connection.

2.4.3.8 Shunting mode

This mode serves to connect a group of personnel involved in shunting. The connection is established as a group call. An acoustic signal is provided to ensure the involved personnel that the connection is working. It is a 820 Hz tone beep followed by 5 to 10 s of silence.

2.4.3.9 Direct mode

This is a special feature of GSM-R which is not present in public GSM and enables communication in case that the radio infrastructure has failed or is not installed. The users can communicate with each other in reach of their devices. The direct mode operates similarly to the simplex connection with a Push To Talk button. Five channels are provided, the first channel is used defaultly as a channel where the users can arrange a connection on a different channel.

2.4.4 Public GSM

The public GSM system is currently also used on Czech railway network, mainly if no other system is available. The employees use standard GSM cell phones, the system is not incorporated into the Train Radio Display. The driver has to have a list of numbers of the personnel they need to contact.

As this communication system usage is rather a temporary issue of the Czech network, mainly on old vehicles, which are not equipped with a radio station, it may not be incorporated into the simulation.



GSM-R terminal [siemens.co.uk]

3 Vehicle dynamics

The physical properties of the model of the train shall correspond to reality as much as possible. The dynamics are based on the sum of forces applying to the train. The forces are dependent on the following variables, which affect them either directly or through some technical means, such as in the case of train brake pipe pressure that induces a braking effect.

3.1.1 Input variables

- Train weight M [t]
- Braking weight M_B [t]
- Maximal traction power P_{MAX} [kW]
- Maximal tractive effort N_{MAX} [kN]
- Maximal dynamic brake power P_{BMAX} [kW]
- Maximal dynamic brake tractive effort N_{BMAX} [kN]
- Continuous speed V_C [km/h]
- Minimal speed for dynamic brake V_{BM} [km/h]
- Coefficient of friction C [%]

3.1.2 Track induced variables

- Gradient s [‰]
- Cant c [mm]
- Radius r [m]

3.1.3 Driver induced variables

- Traction/brake T [binary]
- Relative tractive or dynamic brake effort R [%]
- Brake pipe pressure p [bar]

3.1.4 Simulated variables

- Speed V [km/h]
- Power P [kW]

3.1.5 Movement equation

According to [33], the force acting on the train running on a flat track can be expressed by the following equation:

$$F_s = m_v \cdot (1 + \rho_d) \cdot a + O_v + O_t$$

where

- F_s traction force [N]
- m_v train weight [kg]
- ρ_d coefficient of rotating mass [1]
- a acceleration [$m*s^{-2}$]
- O_v vehicle resistance [N]
- O_t track resistance [N]

Rewriting the equation, we obtain the following expression, which shows us the acceleration resulting from the traction force set by the driver and applied by the locomotive:

$$a = \frac{F_s - O_v - O_t}{m_v * (1 + \rho_d)}$$

If the train is composed of more than one vehicle, the values O_v , m_v and ρ_d are sums from all the vehicles.

If we add the possibility that the track is at gradient, the problem starts to be more complex as the gradient of the track section lying under the train may not be constant throughout the whole train. This can be solved by calculating the gravitational force for each vehicle of the train, using its centre of mass and the gradient of the track lying under it. This will result in a force acting on the vehicle in the direction of the longitudinal axis of the vehicle, with respect to the orientation of the gradient. By summing all these forces coming from all the vehicles of the train, we obtain the final force that will set the acceleration of the whole train caused by the gradient.

The accelerating force acting on a mass on a gradient is expressed as

$$F_g = \frac{g * m * \frac{s}{1000}}{\sqrt{\frac{s^2}{1 * 10^6} + 1}}$$

where F_g is the accelerating force [kN], g is gravitational constant [$m*s^{-2}$], m is the mass [t] and s is the gradient [‰].

The overall acceleration of the whole train expressed as a sum of the final forces acting on each vehicle in a certain section of the track can be written as

$$a = \sum_i \frac{F_{si} + F_{gi} - O_{vi} - O_{ti}}{m_i * (1 + \rho_{di})}$$

Vehicle resistance is dependent on the speed of the train and has a constant, linear and quadratic component. The coefficients of each of the components are different for each vehicle, but we can generalise and differentiate only the groups of vehicles, which, when taking the values from [33], will look as following:

Passenger 4-axle cars of normal construction.....	$O_v = 1,35 + 0,0008 \cdot V + 0,00033 \cdot V^2$
Passenger 4-axle cars of light construction.....	$O_v = 1,8 + 0,01 \cdot V + 0,000476 \cdot V^2$
Passenger 2-axle cars of light construction.....	$O_v = 1,5 + 0,00089 \cdot V^2$
Empty 2-axle freight cars.....	$O_v = 2,0 + 0,00125 \cdot V^2$
Empty 4-axle freight cars.....	$O_v = 2,0 + 0,0008 \cdot V^2$
Full 2-axle freight cars.....	$O_v = 1,7 + 0,0033 \cdot V + 0,00018 \cdot V^2$
Full 4-axle freight cars.....	$O_v = 1,3 + 0,00033 \cdot V^2$

There is also a value for all cars in general, which could be used for a train with unspecified composition: $O_v = 1,9 + 0,000465 \cdot V^2$

The coefficient of rotating mass has the following values: [33]

Passenger cars.....	$\rho_d = 0,06$
Empty freight cars.....	$\rho_d = 0,1$
Full freight cars.....	$\rho_d = 0,04$
Locomotives.....	$\rho_d = 0,2$
Motor cars and multiple units.....	$\rho_d = 0,15$

The weight of the vehicle is much dependent on the particular type. We can use the examples of classic vehicles for obtaining a general value. The values come from the website [34]. For passenger cars, there is only one value, as the difference between the weights of an empty and full car is quite small. I took the value of an empty car. Also the differences between the weights of passenger cars of the same construction type, but different class, are small. For example, difference between air-conditioned class Aee¹⁴⁵ from year 2003 and class Ba from 1958 is less than 1,5 t.

Passenger 4-axle normal car class Bee.....	41 t
Passenger 4-axle light car class Bmx.....	32 t
Passenger 2-axle light car class Btax.....	15 t
Empty 2-axle freight car class Es.....	12,8 t
Empty 4-axle freight car class Eas-u.....	22,7 t
Full 2-axle freight car class Es.....	38,8 t
Full 4-axle freight car class Eas-u.....	79,7 t

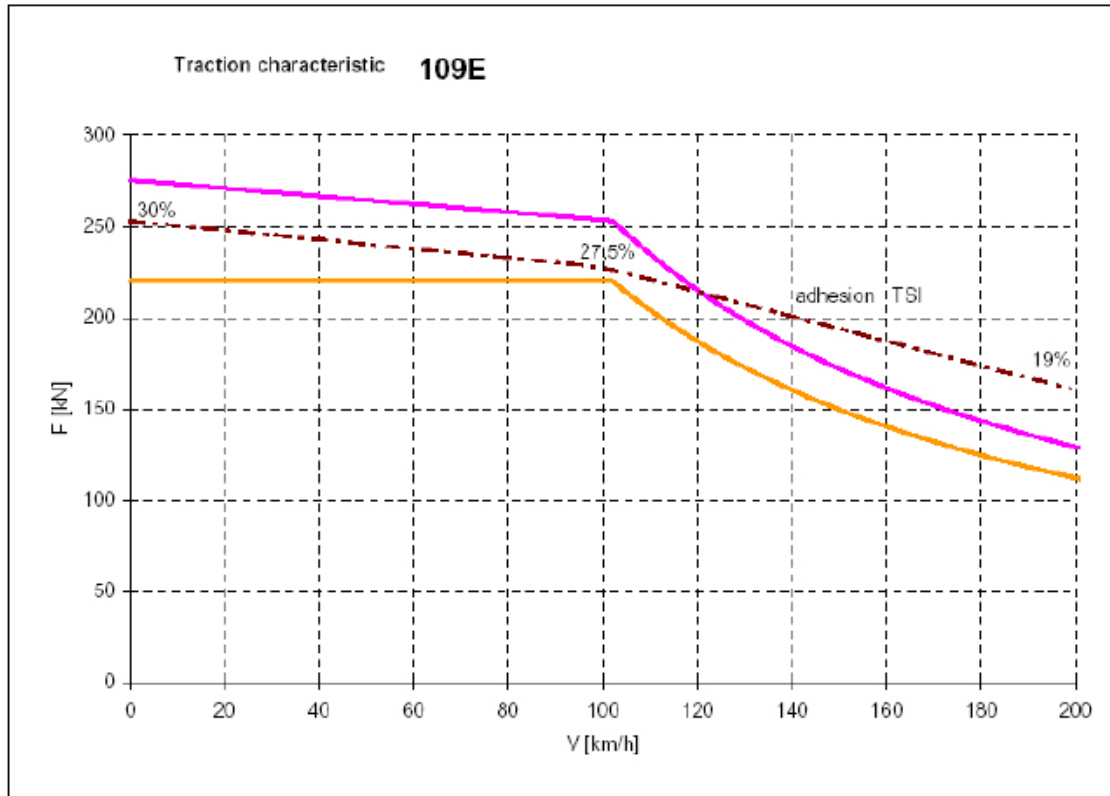
These classes of cars shall be inherently incorporated into the simulation. If any other class will be added in the future, it will use the same weight as in reality.

3.1.6 Tractive effort

The tractive effort is controlled in a form of percentage of the maximal tractive effort for the current speed. The limitation of the tractive effort is the adhesion, traction power and

maximal tractive effort. At speed interval between zero and the continuous speed V_C , the tractive effort limit is nearly constant. At speeds higher than the continuous speed, the tractive effort starts to fall as the maximal power output is reached. These characteristics are called the traction characteristics.

The traction characteristics depend on the type of the locomotive. For example, the traction and adhesion characteristics of type Škoda 109E are:



Traction characteristics of type 109E [50]

We can see that the traction effort is dependent not only on the power of the locomotive, but also on the adhesion. The value of the adhesion presented in the figure applies for normal conditions. The adhesion may be reduced to zero in bad conditions, which will affect not only the tractive effort, but also the brake effort.

3.1.7 Dynamic brake

When using only the dynamic brake, the whole process is the same as with applying traction force, only the direction of the force is opposite, resulting in negative acceleration. Dynamic brake can not work at low speeds, so under certain speed, the braking force shall be gradually reduced to zero. Actual value depends on the type of vehicle (ČD Class 150: 45 km/h, the speed is much lower on modern vehicles). Depending on the type of the simulated vehicle, it shall be automatically replaced by automatic brake or not.

3.1.8 Automatic brake

The effect of the automatic brake depends on pressure in the main pipe. This pressure is described by a real variable and it can obtain vales between 0 and 5,5 bar. [35]

If using the integration type of electric brake valve controller, it should take approx. 8 seconds to induce full braking effect from running position. This does not mean that the brakes will react in this time – just the pressure in the main pipe is lowered.

The reaction time of the brake depends on the construction of the brake valve, the volume of the main pipe (which is proportional to the length of the train), the triple valve on each of the cars and the filling mode which is set on the triple valve. The main pipe has inner diameter 1,25“ (32 mm). [36]

The speed of the propagation of the pressure difference is approximately the same as the speed of sound in air, between 250 and 280 m/s. [37] This means that each 100 m of the length of the train induce a delay of the braking effect of about 0,3 s.

Lowering of the pressure propagates very quickly, but setting the pressure higher takes some time, which can be very long when a long train and a weak locomotive compressor combine. This is caused by the fact that air brake reservoirs on the cars must be filled. The compressor can deliver about 250 m³/h on modern locomotives. [36] The pressure in the main air reservoir is higher than the nominal pressure of the main pipe (usually about 9 bar). This means that the reservoir can supply some amount of the air without a need for switching on the compressor. The main reservoir has a volume in hundreds of litres. For example, a freight locomotive class 181 has a reservoir with volume of 1330 litres and an universal locomotive class 363 has 900 litres. [38]

If we apply Boyle's law, we easily find out the amount of air available for the main pipe from the main air reservoir for constant temperature, if we assume that the temperature is not changed. Then the volume of air for the main pipe will be:

$$V_{MP} = \frac{P_{MAR} * V_{MAR}}{P_{MP}}$$

where

V_{MP}volume available for the main pipe from the main reservoir [m³]

P_{MAR}pressure in the main reservoir [bar]

V_{MAR}volume of the main reservoir [m³]

P_{MP}nominal pressure of the main pipe [bar]

In fact, the volume available will be somewhat lower, because the air will get colder by the expansion. After this reserve is consumed, the filling time is dependent only on the power of the compressor. The compressor switches on automatically after the pressure in the main reservoir falls under a certain limit.

The car air brake reservoir volume depends on the particular class of the car and ranges from tens to hundreds of litres. For example, freight cars have the volume as following: [39]

- 2-axle freight cars.....57 l
- 4-axle freight cars of older type (bogies 26-2.8).....75 l
- 4-axle freight cars of newer type (bogies Y 25 Cs).....100 l

Volumes on passenger cars are similar. Cars with antislip regulator have the volume higher as the air consumption is higher when the antislip is engaged.

In case that the air reserve is lower than the volume of the car reservoirs, the time for filling the air brake system of the train can be obtained from the following expression:

$$t = \frac{(\sum V_{CAR} - V_{MP}) * 3600}{P_C}$$

where

t.....filling time [s]

V_{CAR}.....car air reservoir volume [m³]

V_{MP}.....volume available from the main reservoir [m³]

P_C.....flow from the compressor [m³/h]

If the value of the time is lower than zero, the time should be considered zero.

The filling mode means the way the triple valve of the car reacts to changes of the main pipe pressure. The filling mode is set on each car of the train individually. It mainly influences the delay between sensing the change of the pressure and filling or unfilling the brake cylinder. There are three main categories:

Name	Filling time [s]	Unfilling time [s]
G (Goods train)	18 to 30	45 to 60
P (Personal train)	6 to 10	15 to 20
R (Fast train)	3 to 5	15 to 20

The values in the table show the delay to filling the cylinder to 95 % of the maximal pressure. The maximal pressure depends on the particular type of the vehicle.

These three categories can be differentiated into more subcategories. For example, it is common on modern passenger cars to have modes P, R and R+Mg. The last mode applies also the magnetic brakes during emergency braking and so enhances the braking effect, but the reaction times are the same.

The deceleration depends on the type of brake (tread or disc brake). For tread brake, it shall be approximately 1 m*s⁻² at 100 braking % and full service brake applied at speeds 40 km/h or higher. At lower speeds, the deceleration grows up quadratically to approx. double (2 m*s⁻²) at speeds near zero. For disc brakes, the deceleration remains approximately constant for all speeds. The dependency of deceleration on brake cylinder pressure is linear for constant speed.

These conclusions are based on consultation with Ing. Jindřich Sadil, PhD., which took place in July 2016.

The brake behaviour is largely unpredictable even on real railway. It is dependent on the temperature, humidity, type of the vehicles in the train and so on. It will be necessary to evaluate the brake behaviour with professional train drivers and tune the brake behaviour to make it as close to reality as possible.

4 Locomotive simulation

The simulator shall be of static type and use a full cab. However, the simulator shall be made in a way that would enable its modification to a dynamic type, e. g. the construction of the cab shall be strong enough to withstand the movements of the dynamic platform.

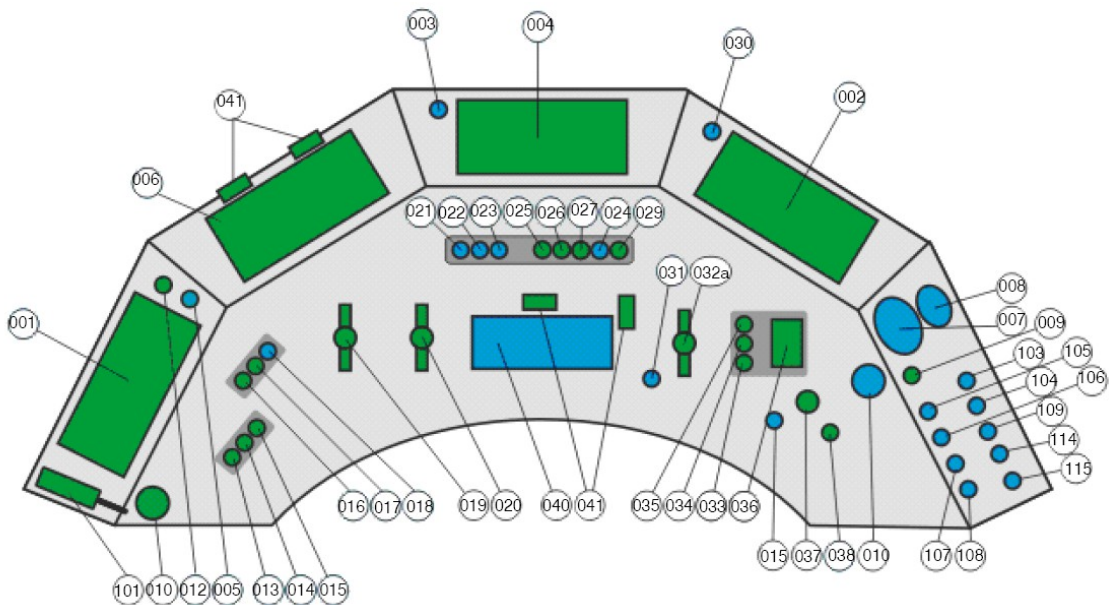
The driver controls the simulation by using the cab's control elements. Most of the elements control only a virtual model, which does not have any directly visible or audible outputs to the driver. For example, the traction controller will affect only the simulated traction effort, which is not visible to the driver, except for the values on the TDD. The effect of the traction effort, the acceleration, is an indirect consequence of the driver's input.

However, other elements have a direct impact on the visualisation or sound of the simulation, for example the train horn or wipers. Activation of these elements can be immediately perceived by the driver.

The locomotive that is simulated shall be based on a contemporary European electric locomotive.

4.1 Cab construction

The construction of the cab shall be based on [7] specification. The cab consists of a dashboard and a frame with a windscreen. The dashboard as specified by UIC 612 shall look as following.



UIC 612-0 dashboard specification

The dashboard contains the following elements with numbers corresponding to the figure above. Elements serving as outputs have yellow numbers, input elements have red numbers, mixed function elements are grey. The letters in brackets indicate the physical form, which will be further described in the next paragraph.

No	Name	Function	Physical description
001	Train Radio Display (TRD)	DMI for the radio and GSM-R	Display with keys
002	Technical and Diagnostical Display (TDD)	DMI for the locomotive systems	Display with keys
003	(not used)		
004	ETCS DMI	DMI for ETCS	Display with keys
005	(not used)		
006	Electronic Timetable Display	DMI for the Electronic Timetable	Display with keys
007	Brake pipe and Main reservoir gauge	Displays the pressures in brake pipe and main air reservoir	Manometer
008	Brake cylinder gauge	Displays the pressure in the brake cylinder	Manometer
009	Brake pipe pressure adjuster	Controls the brake pipe pressure during overcharge	Push button [Q]
010	Emergency stop	Applies emergency stop	Push button
012	Radio emergency call	Starts emergency communication	Illuminated push button [R]
013	ETCS override	Enables the Override EOA function	Red push button [Q]
014	ETCS release	Releases the brake intervention	Flip switch [B]
015	ETCS acknowledgment	Confirmation of a request from ETCS	Flip switch [K]
016	Pantograph	Sets the pantograph position	Flip switch [Z]
017	Main Circuit Breaker	Turns off the main circuit breaker	Push button
018	Train Power Supply	Controls the electrical heating supply	Rotary switch [H]
019	Automatic Speed Control	Controls the ASC system	Proportional lever with a lock in OFF position
020	Combined traction and brake controller	Controls the traction and brake Two different types of the lever are interchangeable	Bidirectional proportional lever with a lock in central position or Integration lever (not specified in UIC 612)

021	Door control Left	Releases the doors on the left side	Illuminated yellow push button [Q]
022	Door control Close	Closes all the doors and locks them	Red push button
023	Door control Right	Releases the doors on the right side	Illuminated yellow push button [Q]
024	(not used)		
025	Sanding	Turns the sanding on	Flip switch [K]
026	Release brake	Releases the pneumatic locomotive brakes activated by the automatic brake	Flip switch [B]
027	External front light	Controls the front lights (five positions)	Flip switch [B]
029	Task and Cab lighting	Controls the task and cab lights	Flip switch [B]
030	(not used)		
031	Driver Activity Control	Confirms the driver vigilance	Push button [XX]
032 a	Automatic Brake Controller	Controls the air brake	Proportional lever with three locked positions
033	Travel direction Forward	Controls the direction	Illuminated push button
034	No travel direction	Sets the direction to neutral	Push button
035	Travel direction Reverse	Controls the direction	Illuminated push button
036	ID card reader	Activates the cab	RFID reader
037	Direct brake controller	Controls the direct brake	Five-position lever
038	Train horn	Controls the high- and low-tone train horn	Flip switch [M]
040	(not used)		
041	Document holder		
101	Radio handset		

4.1.1 Cab mode

The functions of the control elements depend on the mode of the cab and also differentiate for the selected direction. The possibilities are as following:

- **F** – active, forward direction
- **N** – active, no direction

- **R** – active, reverse direction
- **0** – inactive

4.1.2 Elements description

The function of the levers and rotary switches is shown in a form of a table. An arrow indicates that the lever or switch returns in the shown direction to the neighboring position, a dot indicates a locked position. A line indicates a linear change detecting area. The leftmost position in the table is the closest to the driver.

4.1.2.1 001 – Train Radio Display

This display is described in UIC Leaflet 612-04. As this document is not publicly available, the display shall be constructed only once the document is acquired.

The display shall have incorporated all the radio systems mentioned in the Simulation – Radio chapter, except for public GSM.

4.1.2.2 002 – Technical and Diagnostical Display

This display shows the state of the vehicle – mainly the speed, traction effort, catenary voltage, traction current etc. It also enables the driver to control components that do not have their dedicated control element on the desk or elsewhere.

This display is described in UIC Leaflet 612-03. As this document is not publicly available, the display shall be constructed only once the document is acquired.

4.1.2.3 004 – ETCS DMI

This display is described in a separate paragraph in the ETCS chapter.

4.1.2.4 006 – Electronic Timetable Display

The electronic timetable display is described in UIC Leaflet 612-05. As this document is not publicly available, the display shall be constructed only once the document is acquired.

Before the specification is obtained and the display is constructed, a paper timetable may be used. Some form of paper „notebook timetable“ used by Czech Railways may be applied.

4.1.2.5 007 – Brake pipe and Main reservoir gauge

The gauge indicates the main pipe pressure (yellow pointer) and the main reservoir pressure (red pointer). The pointers shall be vertical for a pressure of 5 bar. The diameter shall be 100 mm and the background shall be black. The range shall be 10 bar. The device is always active.

This device shall be controlled by real variables **007p** (for the pipe) and **007r** (for the reservoir). The value shall correspond to the shown value in bar with precision to two digits.

Mechanical construction may use a standard railway gauge, modified to be electrically controlled. Using an air compressor and a pressure valve would be impractical. For example, type DRChg 100-1 manufactured by MANOTHERM GmbH could be used. This

gauge is certified for railway use and is equipped with backlight. The actual way of modification depends on the actual construction, which is to be examined on the real device. Using components from common car dashboard meters could be possible.

Using a non-railway gauge is also possible. These gauges are also available with two pointers and are much cheaper than the certified railway ones, but are not equipped with backlight and the colors are not compliant with UIC 612. Therefore a more thorough modification would be required.

The simplest way of implementing the pressure gauges would be to use a digital display showing the gauges. This is also proposed in UIC 612. Small LCD displays are broadly available.

4.1.2.6 008 – Brake cylinder gauge

This gauge indicates the pressure in the brake cylinder. It shall have diameter of 80 mm and the background shall be black. The range shall be 6 bar. The device is always active.

The gauge shall be controlled by real variable **008**. The value shall correspond to the shown value in bar with precision to two digits.

This device may use the same technology as the device 007. Using type RChg 80-1 from MANOTHERM may be possible.

4.1.2.7 009 – Brake pipe pressure adjuster

This button serves to temporarily increase the pressure in the brake pipe in order to terminate the effects of overcharging the brakes.

Pushing the button for less or equal to 1 s shall increase the brake pipe pressure to 5,4 bar at rate of 0,05 bar/s. After 20 s, the pressure is reduced to the original value 5 bar at rate of 0,0022 bar/s. [36]

Continuous pushing shall increase the pressure continuously at the same rate as in the previous case, but only to the maximal permitted value, which shall be no more than 6 bar. After releasing the button, the release rate is the same as in the previous case.

The device is active at modes F, N and R.

The button shall control a boolean variable **009** (pushed – 1, not pushed – 0).

The geometric form of the button shall be type Q. The button shall have a white label with a pictogram presented in [7].

4.1.2.8 010 – Emergency stop

This button shall induce an emergency stop. The button shall stay in pushed position once activated. It is always active. The activation shall result in:

- venting the brake pipe
- activating the electropneumatic brake
- interlocking the traction circuit

These functions shall be inactivated by pulling the button to normal position.

The buttons used on real vehicles are equipped with air brake vent, providing a safe way to release the brake pipe pressure without any need for electrical connections. This is not

useful in the simulator, as this type of button would be expensive to obtain.

The button shall control a boolean variable **010** (pushed – 1, not pushed – 0).

Type XA1E manufactured by IDEC may be suitable.

4.1.2.9 **012 – Radio emergency call**

Pushing this button shall activate an emergency call via the train radio. When the emergency call is activated, the button is illuminated. The button is always active.

The button controls a boolean variable **012b** (pushed – 1, not pushed – 0). The light is controlled by a variable **012l** (1 – illuminated, 0 – not illuminated).

The button is a geometric form R.

4.1.2.10 **013 – ETCS Override**

This button activates the ETCS Override function. It controls a boolean variable **013** (pushed – 1, not pushed – 0). It is active in mode F.

The button is a geometric form Q and the color is red.

4.1.2.11 **014 – ETCS Release**

This lever releases the brake intervention caused by ETCS. It is active only in mode F.

It is a three-position lever. The central position is default, there is one unlocked position in each direction. Both active positions are functionally equal, but because a different use of each of them is possible in the future, each of them has its own variable.

The position closer to the driver controls a boolean variable **014d**, the other active position activates a boolean variable **014u** (active – 1, non-active – 0).

The lever is a geometric form B and the color is black.

4.1.2.12 **015 – ETCS Acknowledgement**

This lever confirms the request from the ETCS OBU. It is active in modes F and R.

The physical description is the same as with the device 014, only the lever shall have a yellow ball at its end. The variables are **015d** and **015u**.

4.1.2.13 **016 – Pantograph**

This flip switch controls the pantograph and the main switch of the locomotive. Its function is different from the requests of UIC 612 and is the same as on the EMU class 640 ČD [40]. It is active in modes F, N and R.



It is a lever with four positions, two locked and two unlocked. Each of them has its own boolean variable (active – 1, non-active – 0). They are arranged in the following order:

- turn on the main circuit breaker and lift the pantograph (unlocked, returns to normal position), variable **016a**
- running position (locked), variable **016b**

- turn off the current consumption (unlocked, returns to running position), variable **016c**
- turn off the current consumption and lower the pantograph (locked), variable **016d**

4.1.2.14 **017 – Main circuit breaker**

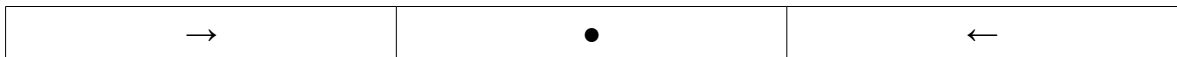
This element has a different function than in the [7] and is again copied from the cab of the EMU class 640. The reason is that this solution is more common in the Czech environment as most Czech electric locomotives have a separate push button for turning off the main circuit breaker, which is also used for emergency situations. It is a button which is physically the same as the button 010, but it is yellow. It is always active.

Pressing the button shall turn off the main circuit breaker and lower the pantograph. No conditions shall be controlled.

The button controls a boolean variable **017** (active – 1, non-active – 0).

4.1.2.15 **018 – Train power supply**

This switch controls the high voltage train power supply. It is a three-position rotary switch with locked central position. Turning the switch right sets the train heating on (boolean variable **018r**), turning it left switches it off (boolean variable **018l**). The variables are set to 1 when the position is active and 0 when inactive. Turning on is possible only in modes F, N and R.



The switch is a geometric form H.

4.1.2.16 **019 – Automatic Speed Control**

This lever serves to set the desired speed in the Automatic Speed Control system. When pulled in the direction to the driver, it is set in a locked position, in which the system is turned off. This position shall set a boolean variable **019a** (1 – in OFF position, 0 – elsewhere). When in the active area, the lever shall be coupled to a potentiometer or any other suitable position detecting component. The position shall influence an integer value **019b** with 8-bit resolution. The lever shall set the speed from 0 to the maximum permitted for the locomotive. The maximal speed corresponds to the uppermost position of the lever. The speed is set in 5 km/h steps for speed ≤ 160 km/h and in 10 km/h steps above 160 km/h. For reverse direction, the maximal speed shall be 50 km/h.



The speed set by the lever shall be immediately indicated on the TTD, but it shall have a delay of 0,5 s before taking effect.

This element is active only in F and R modes.

A lever of this type is not available on free market. Its acquisition may be consulted with suppliers of locomotive components.

4.1.2.17 020 – Combined traction and brake controller

This lever controls the traction and the dynamic brake. It is specified as a proportional lever in [7], but as integration levers are common on Czech railways, it shall be possible to make the lever replaceable with an integration one. Both levers shall be made as a removable component containing also the electronics needed to connect them to the digital bus of the simulator.

The lever is active in modes F and R.

The proportional lever has a locked central position and two variable-position areas. The central position sets the traction and the dynamic brake effort to zero fluently in a time of 1 s. It shall activate a boolean variable **020a**.



Each of the variable-position areas shall provide a 8-bit resolution output of its position. Depending on the type of the lever acquired, there might be either a single integer variable for both areas and a boolean variable defining the actual area, or a separate integer variable for each area. Depending on this, the variables are to be defined once the lever is acquired.

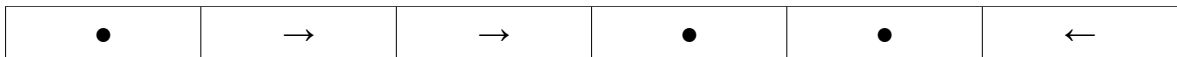
The variable-position areas shall control the traction or brake effort in 0 to 100 %. The change of the traction effort shall have a speed of 20 %/s up and 30 %/s down, or 50 kN/s up and 75 kN/s down for a single locomotive and 22 kN/s up and 37,5 kN/s down for multiple electrically coupled locomotives. The lower rate from these two values applies.

The dynamic brake effort shall increase at rate of 30 kN/s, independently on the position of the automatic brake controller except for the emergency brake, and decrease at 20 kN/s when the automatic brake is not applied. For the other cases when the automatic brake is applied, the rates for each filling mode are as following:

G.....	5 kN/s
P.....	10 kN/s
R.....	20 kN/s

The integration lever is based on EMU class 640. It has six positions, three of them are locked. The positions are as following:

- S: unlocked, increases the tractive effort. The full tractive effort shall be obtained 6 s after the tractive force starts to apply.
- J: locked, tractive effort stays unaffected, brake effort decreases to zero (25 %/s), automatic brake disengages
- V: locked, tractive effort decreases to zero (25 %/s), brake unaffected
- BE: unlocked, dynamic brake effort increases (16,6 %/s), automatic brake does not apply; if the tractive effort was positive before this position was applied, then its percentage is used for the brake effort and further increases
- BP: the same as the previous position, only the automatic air brake starts to apply after 100 % of dynamic brake effort is obtained.
- R: locked, emergency brake applied



Each position shall affect a boolean variable (**020s, 020j, 020v, 020be, 020bp, 020r**) with values 1 for active position and 0 for inactive.

These levers are not commercially sold. Their purchase will have to be consulted with locomotive component suppliers.

4.1.2.18 021 – Door control Left

This illuminated button serves to control the door on the left side of the train. Pushing the button releases the door on the left side if the train is in standstill. If the train is moving, then the release shall take effect once the train stops. Pushing it again cancels the release and closes the door after 3 s. The button is active in modes F, N and R.

The light has the following meanings:

- Not lit: All doors closed and not released
- Lit at standstill: Doors released
- Lit while moving: The doors will be released when the train stops
- Flashing at 1 Hz: Some of the doors are not locked while not released

The button shall control a boolean variable **021b** (pushed – 1, not pushed – 0). The light shall be controlled by a boolean variable **021l** (1 – lit, 0 – not lit).

The button is yellow and the geometric form is Q.

4.1.2.19 022 – Door control Close

This button cancels any release and closes any open door when pushed. It is active in modes F, N and R. It controls a boolean variable **022** (pushed – 1, not pushed – 0).

The button shall be red and of geometric form Q.

4.1.2.20 023 – Door control Right

This button has the same properties as the button 021, but operates the door on the right side. Its variable is **023**.

4.1.2.21 025 – Sanding

Sanding is controlled by a three-position flip switch locked in central position. The sanding is activated by moving the lever from central position (both active positions have the same effect). It controls a boolean variable **025** (active – 1, not active – 0). It is active in modes F and R.

When the sanding is activated, it shall increase the adhesion to the same value as in normal conditions. Although the sanding is not always this effective in reality, it should be simplified on the simulator.

The flip switch has geometric form K.

4.1.2.22 026 – Release brake

When the automatic brake is applied, this flip switch is used to release the automatic brake of the locomotive. When the switch is released, the brake is again activated according to the current brake pipe pressure. The effect of the brake release shall be inhibited if emergency brake is applied or the brake pipe pressure is below 3,4 bar.

The flip switch is three-position with the central position locked. Both active positions are equal. The switch controls a boolean variable **026** (active – 1, not active – 0). It is active in modes F, N and R.

The geometric form is B.

4.1.2.23 027 – External front light

The external lights are controlled by this flip switch. It has five locked positions. Each position controls a boolean variable (1 – active, 0 – non active). The first position is the closest to the driver.

- No light (**027a**)
- Dimmed marker light (**027b**)
- Full marker light (**027c**)
- Full marker light and dimmed head light (**027d**)
- Full marker light and full head light (**027e**)

If a train-wide communication is available and the train configuration is set, the tail lights shall engage automatically. If it is not available, the setting of the tail lights shall be made via the TDD. Also the cases not mentioned in the list above (single white marker light, single red marker light) shall be set via the TDD.

The switch is active in modes F, N and R. The geometric form is B.

4.1.2.24 029 – Task and Cab lighting

The lighting is controlled with a flip switch with three locked positions. Each active position controls a boolean variable (1 – active, 0 – non active). The first position is the closest to the driver.

- Driver cab lighting on (**029a**)
- No light
- Task light on (**029b**)

This element is always active. The geometric form is B.

4.1.2.25 031 – Driver Activity Control button

This button confirms the driver activity. It is a touch button with geometric form XX. It shall control a boolean variable **031** (1 – active, 0 – non active). The button is active in modes F and R.

4.1.2.26 032a – Automatic Brake Controller

This lever controls the automatic brake. It is a locked lever with 10 positions and each of them controls a boolean variable (1 – active, 0 – non active). Except for the emergency position, which is always available, the positions are active only in modes F, N and R and if the main reservoir pressure is higher than 5,5 bar. Each position is locked except for the charging stroke position. The first position is the closest to the driver:

- Emergency brake (**032a**). The brake pipe shall be emptied.
- Full service brake (**032b**). The brake pipe pressure shall be set to 3,5 bar.
- 6 steps of partial decrease of the brake pipe pressure (**032c, d, e, f, g, h**). These positions are linearly dividing the pressure scale between 5 and 3,5 bar.
- Running position (**032i**). The brake pipe pressure shall be set to 5 bar.
- Charging stroke (**032j**). This position shall cause the brake pipe and reservoirs connected to it, with total volume of 400 l, to be filled from 3,5 bar to 4,9 bar in 5 s.



Decrease of pressure in the brake shall automatically engage the dynamic brake with an effort of 0 % at 5 bar and linearly increasing to 100 % at 3,5 bar or less, with the same gradient as in case of using the dynamic brake alone (control element 020).

This lever is useful only in combination with the proportional combined controller (020), but it shall be active also in combination with alternative integration controller.

The lever is not normally available on market. Its obtaining may be consulted with railway component suppliers.

4.1.2.27 033 – Travel direction Forward

This illuminated button sets the Forward mode if the driver's ID card is inserted and the traction/brake controller is in normal position. If these conditions are not met, then the command is ignored. The mode shall be changed only at standstill. If an attempt to change the mode is made when running, then traction effort shall be inhibited. The button controls a boolean variable **033b** (1 – pressed, 0 – not pressed).

If the Forward mode is active, then the button shall be illuminated. The illumination is controlled by a boolean variable **033i** (lit – 1, not lit – 0).

4.1.2.28 034 – No travel direction

If the driver's card is inserted, the vehicle is not moving and the traction controller is in normal position, this illuminated button sets the mode to Neutral. If it is not inserted while the other conditions are met, then it sets the mode to 0 (deactivates the cab). If pressed when moving, the traction effort shall be inhibited. The button controls a boolean variable **034b** (1 – pressed, 0 – not pressed).

If the Neutral mode is active, then the button shall be illuminated. The illumination is controlled by a boolean variable **034i** (lit – 1, not lit – 0).

4.1.2.29 **035 – Travel direction Reverse**

The function is the same as with the button 033, but for the Reverse mode. The button controls a boolean variable **035b** (1 – pressed, 0 – not pressed).

If the Reverse mode is active, then the button shall be illuminated. The illumination is controlled by a boolean variable **035I** (lit – 1, not lit – 0).

4.1.2.30 **036 – ID card reader**

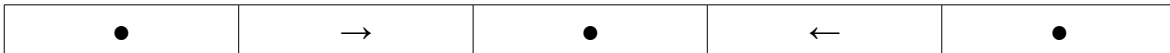
The reader serves to identify the driver, based on their card. The card shall be held in the reader in a way that an accidental removal is improbable.

The reader shall provide a boolean variable **036** (valid card inserted – 1, invalid or missing card – 0). Other data may be provided, depending on the requests of other systems.

4.1.2.31 **037 – Direct brake controller**

This integration lever controls the direct air brake of the locomotive and has five positions. Each position controls a boolean variable (active – 1, not active – 0). The lever is fully active in modes F, N and R and only the brake application positions are available in mode 0. The maximal brake effort shall be 30 kN per axle. The positions are as following, proceeding from the position closest to the driver:

- Direct brake fully applied (**037a**). The brake of the locomotive is fully applied, independently on the automatic brake. Locked position.
- Brake effort increases (**037b**). Unlocked position, returns to the middle position.
- Brake effort unchanged (**037c**). Locked position
- Brake effort decreases (**037d**). Unlocked position, returns to the middle position.
- Brake fully disengaged, running position (**037e**). Locked position.



The higher pressure in the brake cylinder applies from the two pressures commanded by the automatic and the direct brake.

The lever is not available on free market, its acquisition may be consulted with locomotive component suppliers.

4.1.2.32 **038 – Train horn**

The lever of the train horn shall be a three-position device locked in the middle position. It controls two boolean variables (position active – 1, inactive – 0). Pulling the lever in the direction to the driver shall activate low-tone horn (variable **038a**) and pushing it forward shall activate the high-tone horn (variable **038b**). If the horns are activated, a sound shall be played from the loudspeakers of the simulator. The switch has a geometric form M. The device is always active.

4.1.2.33 **114 – Washing and Wipers**

This switch controls the simulation of the wipers and washing. It is a pushable rotary switch with six revolving positions and one push position. The positions control boolean

variables (1 – active, 0 – inactive). The push position is not mentioned in the function table.

•	•	•	•	•	•
---	---	---	---	---	---

- Pushed: washing + automatic wiping for 5 s (**114a**)
- Slow interval wiping – 1/60 s (**114b**)
- Medium interval wiping – 1/30 s (**114c**)
- Fast interval wiping – 1/15 s (**114d**)
- Off
- Slow wiping – 1 wipe/s (**114e**)
- Fast wiping – 2 wipes/s (**114f**)

The switch is active in modes F, N and R.

As there is not any real windscreen, the wipers will be simulated in the central projection area. If the rain or snow is simulated, the vision shall gradually become blurred. Activation of the wipers shall result in a wiper moving across the area, wiping out the rain drops or snow flakes.

4.1.2.34 ETCS isolation and power

These two switches for controlling the ETCS system shall be mounted in the cab, preferably behind the driver's seat. A locked flip switch or rotary switch shall be used. The switches are always active.

4.1.3 Element activity

To sum up, the activity of each element for each mode is presented in the following table. P indicates that the element is only partially active, X indicates that it is fully active:

No	Name	Mode 0	Mode F	Mode N	Mode R
001	Train Radio Display				
002	Technical and Diagnostical Display				
004	ETCS DMI				
006	Electronic Timetable Display				
007	Brake pipe and Main reservoir gauge	X	X	X	X
008	Brake cylinder gauge	X	X	X	X
009	Brake pipe pressure adjuster		X	X	X
010	Emergency stop	X	X	X	X
012	Radio emergency call	X	X	X	X
013	ETCS Override		X		
014	ETCS Release		X		
015	ETCS Acknowledgement		X		X

016	Pantograph		X	X	X
017	Main circuit breaker	X	X	X	X
018	Train power supply		X	X	X
019	Automatic speed control		X		X
020	Combined traction and brake controller		X		X
021	Door control Left		X	X	X
022	Door control Close		X	X	X
023	Door control Right		X	X	X
025	Sanding		X		X
026	Release brake		X	X	X
027	External front light		X	X	X
029	Task and Cab lighting	X	X	X	X
031	Driver Activity Control button		X		X
032 a	Automatic brake controller	P	X	X	X
033	Travel direction Forward		sets		
034	No travel direction	sets (no ID)		sets (ID)	
035	Travel direction Reverse				sets
037	Direct brake controller	P	X	X	X
038	Train horn	X	X	X	X
114	Washer and wipers		X	X	X
	ETCS Isolation	X	X	X	X
	ETCS Power	X	X	X	X

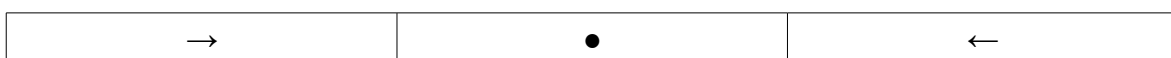
4.1.4 Geometric forms

Due to the fact that certain control elements, mainly the special levers used for the controllers, are not freely available on market, the acquisition of the elements will have to be consulted with a railway components supplier. Due to this fact, the other, less special elements may be also acquired from this supplier. Thus the possibilities of obtaining them on public market will not be analysed.

4.1.4.1 B

Used for elements 014, 015, 026, 027, 029. It is a black flip switch with rectangular top.

Levers 014, 015 (with yellow ball), 026:



Lever 027:



Lever 029:



4.1.4.2 H

Used for element 018. It is a black rotary switch with white dot or arrow.



4.1.4.3 K

Used for element 025. It is a black lever with a ball on top.



4.1.4.4 M

Used for element 038. Black lever with round crosssection and hemispherical top.



4.1.4.5 Q

Used for buttons 009, 013, 021, 022, 023. Buttons 021 and 023 shall be illuminated, the other buttons are not illuminated and shall have red color. Button 009 will have a label, so the color is irrelevant.

The button shall be of square shape and the side shall have dimension between 22 and 32 mm.

4.1.4.6 R

Used for element 012. It is an illuminated button with round shape with diameter between 22 and 32 mm.

4.1.4.7 XX

Used for element 031. It is a round knob with diameter of 50 mm, sticking out of the dashboard.

4.1.5 Displays

All the displays use a color screen, which may be equipped either with push buttons (soft keys) on its edges or with a touch sensitive layer. The displays shall have an audio output. The minimal resolution of the DMI display is 640x480 and the minimal area is 180x135 mm, which corresponds to 8,9“ diagonal. [41]. All the displays may use the same technology. Because of simplicity of acquisition, a touch display may be used instead of a display with push buttons.

These displays are also offered as a stand-alone unit containing a PC-compatible computer and all the peripherals. The computer runs an ordinary PC operating system, such as Windows or Linux. Communication is provided mainly through Ethernet. Multiple companies offer a convenient display, although the price of a display dedicated to real railway use would be relatively high.

4.1.5.1 AP9xxx/APAxxx/APUxx

A Czech company AMIT Transportation offers a 10,4" TFT touch panel computer dedicated to railway use. Intel ATOM 1,6 GHz processor, 1 GB RAM, 4 GB Flash. Preinstalled Windows XP Embedded or Linux. Audio output, optional output for an external buzzer. The type APUxx is UIC-612 compatible and may be used also for the ETCS DMI. The display is equipped with soft keys, which behave to the system as certain keys on standard PC keyboard. [42]

4.1.5.2 Cheap chinese panel computer

Many panel computers can be found on chinese E-shops, all similar to each other. For example, a computer with 10,1" touch panel, Intel Atom 1,8 GHz, 2 GB RAM and 16 GB SSD can be bought for \$342 with preinstalled Windows 7. Audio output is present, but no loudspeaker. [43]

These computers are not dedicated to railway use. The reason of using them would be their much lower price when compared to the special railway displays.

4.1.5.3 Touch display

Other option is to use standard touch displays, which are not containing a computer. The displays would be connected to a single computer with multiple display outputs. These displays are available on Ebay. They usually come from old cash registers and are refurbished. The main advantage of this approach would be much lower price than in the previous cases.



Technical and diagnostical display [AMiT Transportation]

5 ETCS Subsystem

The thing that makes this simulator project special is the fact that it will be equipped with ETCS. Although the basic principles of ETCS are relatively simple, the implementation of the system might be relatively complicated. The reason is the presence of lots of degraded situations, which shall always ensure the safety of the train. Also the communication between the stationary part, the on-board part and the driver is not trivial.

5.1 ETCS Levels

The function of the ETCS is based on five levels. Each level has a different principle of operation, which results in different technical layout and different demands on the staff.

5.1.1 Level 0

This level is used for operation of ETCS equipped trains on tracks where ETCS infrastructure is not present or is not operational. Only the speed is shown and controlled, where the lower value from the maximal train speed and maximal permitted speed in Level 0 applies. The balises are used only to command level transitions.

The driver shall enter the train data in order to perform the maximal train speed supervision and also to prepare the system for entering a higher level, in which the data would have to be entered anyway.

5.1.2 Level STM

The STM (Specific Transmission Module) level is used to enable operation of ETCS equipped vehicle on infrastructure where a national ATP system is installed. This is done through a STM module, which serves as an interface between the ETCS OBU and the national ATP system. The STM manages the information from the national system in a way that it is interpretable by the ETCS OBU. Balises serve only to command level changes.

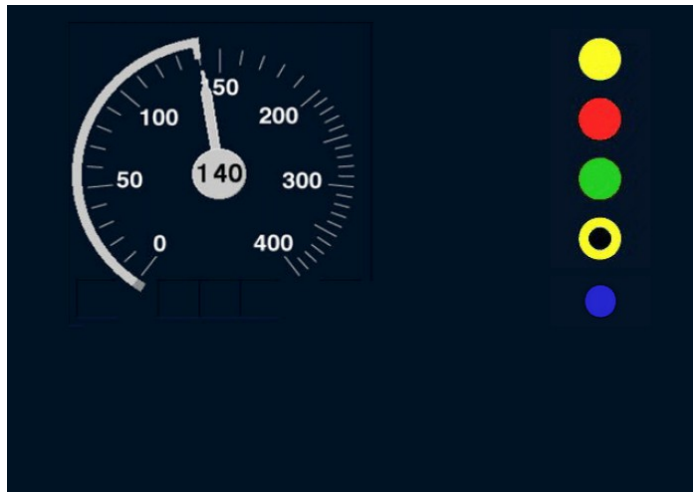
In case of the Czech Republic, the national ATP system is LS06, which is a continuous semi-automatic train protection system. Also a Slovak system Mirel is used in some cases, which is an extension of the LS06 system, equipped with a simplified brake curve control.

The LS06 is a final evolution step of the LS system, which dates back to 1950s. It transmits information about signal aspect to the locomotive cab, where it is displayed on a signal repeater. The transmission is made through coding of track circuit current. If the train approaches a limiting signal or if the coding is not present, the driver is obliged to press an activity control button in certain intervals, otherwise the system will apply emergency brake. No additional speed or distance control is implemented, due to the fact that the length of the track blocks is not fixed, no additional information about the block length is known to the system and the resolution of the transceived signals is limited (a signal obliging a speed decrease is transmitted, but the actual speed is not). The further evolution of the LS system was ceased due to the fact that the ETCS was selected as the main ATP system to be used in the future.

The STM for LS06 is made by AŽD Praha and called STMLS. It can use the ETCS DMI instead of the traditional cab signal repeater of the LS system, although this solution is currently not implemented on any vehicle and a separate cab repeater is used instead. [44]

The reason why the DMI is not used for STMLS is that the displayed signal repeater must be fail-safe, which can be easily implemented on a traditional construction with light bulbs, but is complicated in the case of a digital display.

The Mirel system is not implemented as STM on Czech or Slovak locomotives equipped with ETCS. It is used only as a separate system on some Slovak locomotives used for domestic operation and is applied in a case that the ETCS level 1 is not available. A simple interface is used for this reason and it only transfers the information about the state of the ETCS OBU to Mirel. [45] Other information, such as train data, which are necessary for each of the two systems, have to be entered separately into each system.



STMLS on DMI [44]

5.1.3 Level 1

The level 1 works as an intermittent automatic train protection system. The position of the train is evaluated and a restricting speed profile is calculated. The communication is arranged only from the trackside to the train and is provided by variable balises. No radio communication is established in the basic operation of this level.

This means that the communication is possible only if the train is in reach of the balise. The balises are usually placed at the level of the signals. The result is that the train can not receive any information about a change on a signal until it passes it. This means that:

- a certain non-zero speed must be permitted to pass a signal whose state is not known to the system, only to the driver,
- this speed shall not be high to keep safety for a case that the signal is at danger,
- lineside signals must be present

The request to keep the proceeding speed low results in reduced infrastructure capacity.

The problem with the uncertainty of the change may be solved by so-called infill. The infill means that the information can be transmitted to the train before it passes the signal balise. The infill is possible via the following means:

- balise group
- magnetic loop (Euroloop)
- radio

If the infill is continuous enough, it is theoretically possible to leave out the lineside signals. Experiments with the actual system have shown that the problem is that the Euroloop installation is technically problematic (lots of copper cable lying in the tracks, free for everyone to steal it) and the semi-continuous radio communication is not fast enough to have any significant impact on the track capacity – the train usually reaches the signal before a safe radio communication is established. This is the reason why Level 1 with infill has not been implemented almost anywhere.

Due to these facts, the infill will not be further analysed in this thesis, neither it will be incorporated in the simulation.

The benefit of the Level 1, compared to the other two levels, is relative simplicity – no continuous data connection is needed, the ETCS relies on an existing interlocking system and only the outputs of this system (usually the signal lamp current) are interpreted by the ETCS. The trackside system is not technically demanding and is quite cheap.

5.1.4 Level 2

Level 2 works as a mixed intermittent and continuous automatic train protection system. The balises are still present, but a continuous bidirectional safe radio communication between the train and the trackside is established. The system again relies on an existing interlocking system. The outputs of the interlocking system are connected to a RBC (Radio Block Centre). A movement authority is generated by the RBC and transmitted to the OBU by the radio. The OBU calculates the speed profile from track and train properties. The position of the train is evaluated from static balises and an odometer and the position of the train relative to the balises is sent to the RBC, which calculates the train's position. The lineside signals are not necessary, although they may be useful in case when vehicles not equipped with ETCS operate on the track.

Level 2 is more technically demanding than Level 1, as a continuous radio communication for each train must be provided on every spot of the track. Also the transition between the RBCs has to be managed. The benefit is higher infrastructure capacity, as the position of the train relative to the track is always known and thus the safety of the train is less dependent on the driver's responsibility, which enables less prudent speed profiles.

5.1.5 Level 3

This level takes a whole new approach to the railway operation. While the current interlocking systems are based on a division of the infrastructure into fixed blocks, Level 3 is based on a moving block. There is not any underlying interlocking system, nor any track occupancy detection. The position of the train is evaluated continuously from fixed balises and an odometer, similarly to Level 2. Moreover, train integrity is evaluated on board. Routes are set, locked and released by ETCS trackside, based on the position and integrity information received from the train.

Level 3 brings technical simplicity to the infrastructure (no signals and occupancy detectors) and enhances infrastructure capacity thanks to the moving block, which enables the trains to move at a certain fixed distance from each other, which is lower than in the case that the trains move in a fixed block system. However, there are major challenges to be solved before the system is put into operation on conventional railway, mainly the train integrity detection and a problem with incorporating shunting and other operations with separate vehicles into an infrastructure without occupancy detection. The Level 3 is currently feasible only on tracks where only multiple units operate, which means mainly

high-speed rail systems. Operation of vehicles not equipped with ETCS is impossible.

As the purpose of the simulator is to model mainly conventional railway and the Level 3 is currently not applied on any real railway track, according to [46], and some issues of the Level 3 are still not solved and defined in the ETCS specifications, this level will not be incorporated into the simulator.

On the other hand, the functionality of on-board in Level 3 is very similar to Level 2, except for the train integrity detection. Implementation of Level 3 should be quite simple due to this fact, when regarding the simulation of the vehicle.

5.2 Stationary part

The stationary subsystem is different for each level. The problems of introducing the ETCS system into the Transportation Laboratory and also the ETCS language were analysed by Tomáš Konopáč in his diploma thesis. [47] Although the scope of the thesis is a bit different, as it focuses rather on the infrastructure part of the ETCS than the on-board, the ETCS subsystem of the simulator shall use the same solutions if possible. The reason to have the systems similar is to ease the deployment and maintenance of both systems.

The implementation of trackside ETCS systems is currently further analysed by other personnel of the Transportation Laboratory with focus on the Level 2.

It shall be possible to model multiple levels in a single scenario, so the level transitions may be simulated.

5.2.1 Level 0

The Level 0 does not require any stationary equipment and no information is sent to the train.

5.2.2 Level STM

This level demands a national ATP system to be installed. This system is the LS06 in case of the simulator. LS06 uses track circuit current coding for the transmission of the information to the vehicle. This shall be simulated by assigning the code information to the track. The information is derived from the aspect of the next variable signal. It is also possible that no code is provided for the track. Also a possibility to simulate a dubious code shall be provided, for example by changing the code quickly.

5.2.3 Level 1

In case of Level 1, only the balises present the trackside system. They may be either fixed or variable. The variable balises are connected to the signalling subsystem. A „proceed“ aspect on a main signal will change the telegram of the balise, so the balise gives a Movement Authority. The balises are defined by their position on the track and the telegrams they send. If the train passes the balise, the telegram is read and processed by the on-board subsystem, unless a VBC (Virtual Balise Cover) is present on-board. In that case, the balise is ignored.

5.2.4 Level 2

As mentioned above, Level 2 uses static balises and RBCs. Differently from the proposal of implementation the ETCS into the Laboratory, which shall use only one RBC, more RBCs shall be present in the simulation, so the transition between RBCs can be performed. The RBCs may be modelled separately from each other.

The RBCs are connected to the interlocking subsystem and give MAs as based on the information received from the interlocking system. The communication between the RBC and the on-board unit may be performed separately from the GSM-R model, but the driver shall be always obliged to set the communication correctly as if the GSM-R was used.

5.2.5 Level 3

Level 3 shall not be modelled in the simulator.

5.2.6 Level transitions

A balise group requesting a level transition shall be placed on the border between the levels.

5.3 Subset 026 Chapter 4

This chapter describes the modes of ETCS and the transitions between them.

5.3.1 Modes

The modes define the behaviour of the ETCS system. Some of the modes will probably never be used on the simulator, but despite that, they shall be incorporated because of a possibility of using the subsystems of the Simulator for other projects in the future (the Sleeping, Non Leading and Passive Shunting mode).

5.3.1.1 Isolation (IS)

The ETCS OBU is physically isolated from the vehicle and the driver. This mode shall be indicated to the driver. The mode is activated by a switch.

It is used in all levels.

5.3.1.2 No Power (NP)

The ETCS system is in this mode when it is not powered. The emergency brake shall be activated. The mode is activated by a switch.

It is used in all levels.

5.3.1.3 System Failure (SF)

This mode shall be entered if a fault affecting safety occurs. The emergency brake shall be activated. This mode may be applied by the supervisor to simulate a failure.

It is used in all levels.

5.3.1.4 Sleeping (SL)

This mode is used when the vehicle is in slave mode. It is detected automatically from the communication with the leading locomotive and the driver's desk must be inactive. No supervision is performed unless any of the triggering conditions disappear.

It is used in all levels.

5.3.1.5 Stand by (SB)

This mode is defaultly entered when the ETCS OBU is activated. It supervises that the train is in standstill.

It is relevant for all levels.

5.3.1.6 Shunting (SH)

In this mode, the OBU supervises the shunting speed limit, the enabled balise list, if sent, and „stop if in shunting mode“ sent from balises. It can be activated by the driver when the train is in standstill, or by trackside if confirmed by the driver. In levels 2 and 3, the OBU must always receive permission from the trackside.

It is used in all levels.

5.3.1.7 Full Supervision (FS)

If all conditions are fulfilled, the OBU automatically enters the Full Supervision mode. Then it supervises the movement of the train under the dynamic speed profile. Train speed, permitted speed, target distance and target speed are displayed. When this mode is entered, the driver is responsible for checking the speed limit applying to the rest of the train if the speed profile and gradient are available only for the front end, but not the rest.

This mode is used in levels 1, 2 and 3.

5.3.1.8 Unfitted (UN)

This mode is used when the train operates in areas unfitted with working ETCS or compatible STM system. It only supervises that the top speed of the train, the top speed for Unfitted mode and temporary speed restrictions are not passed. The speed is displayed.

It is used in level 0.

5.3.1.9 Staff responsible (SR)

This mode is used to move the train under driver's responsibility – to pass an end of authority, in case of trackside failure and when the OBU is turned on. The system supervises the speed limit, direction, permitted distance, a list of expected balises and „stop if in SR“ balises.

The permitted distance is taken from the default value or transmitted by RBC or Euroloop.

This mode is used in levels 1, 2 and 3.

5.3.1.10 On Sight (OS)

This mode is used to enter a track that may be occupied by another train or obstacle. The driver is requested to confirm that the track is free.

Used in levels 1, 2 and 3.

5.3.1.11 Trip (TR)

This mode is activated when the safety of the train is compromised, for example when the train passes the EOA. The emergency brake is applied and the reason shall be displayed to the driver. Acknowledgement from the driver is requested when the train stops to enable exiting this mode.

It is used in all levels.

5.3.1.12 Post Trip (PT)

It is entered when the driver acknowledges the trip. The emergency brake is released. Movement backwards for a nationally defined value may be permitted. In level 1, the ongoing forward movement demanded by the driver is Staff Responsible, in levels 2 and 3 a new MA is requested.

Used in levels 1, 2 and 3.

5.3.1.13 Non Leading (NL)

This mode is used on a locomotive that is active, but not leading the train, nor electrically connected to the leading locomotive. No supervision is made, only the locomotive location is evaluated and the speed is displayed.

Used in all levels.

5.3.1.14 STM National mode (SN)

This mode enables the STM to use the elements of the ETCS OBU: DMI, JRU, odometer, train and brake interface. No supervision is made, the responsibility comes to the STM.

Used in level STM.

5.3.1.15 Reversing (RV)

This mode enables the driver to move the train backwards while staying at the same cab. It is possible only in areas permitted by trackside. It is used to move the train from a dangerous position. Top speed and maximum distance are supervised. Current speed and the rest of the distance allowed are displayed. Moving forward is not allowed.

Used in levels 1, 2 and 3.

5.3.1.16 Limited supervision (LS)

This mode is applied when not all the informations necessary for full supervision are available. Regarding the informations, which are present, the OBU shall take responsibility for the safety of the train to a certain degree.

It is used in levels 1, 2 and 3.

5.3.1.17 **Passive shunting (PS)**

The Passive Shunting mode is used when the locomotive is mechanically coupled to another engine and shunting is performed. It is also used when the driver changes the cab on a locomotive with two cabs. The cab must be inactive. No supervision is made, only the location of the engine is evaluated. This mode may be activated only if preceded by the Shunting mode.

Used in all levels.

5.3.2 *Mode Profile*

Trackside can send a Mode Profile to the OBU. The Mode Profile may request OS, LS or SH. It defines the length and entry of LS and OS area and the length of SH area.

5.3.3 *Functions and transitions*

This part of Chapter 4 defines:

- onboard functions active in each mode (4.5.2)
- transitions between modes (4.6)
- DMI interactions (4.7)
- acceptance of received information (4.8)
- management of stored information during level change (4.9)
- management of stored information during mode change (4.10)
- Effect of exiting NP mode on stored information (4.11)

5.3.3.1 **Active functions (4.5.2)**

One of the most important parts of the specification are the functions which run in each mode. They range from very simple to intricate processes such as the speed and distance monitoring.

The functions active in each mode are defined mainly by Chapter 3. The definitions are presented mainly in form of text. To ease the work when constructing the system, I transformed this text into flow charts.

I used software called yEd for their creation. It is a freeware program written in Java. [48] I used the version 3.15.0.2. The names of files created by this program have extension *graphml*. The flow charts that I created use common rules and elements. The only exception is a rectangle box without black border, which I use for notes and explanations. Also the conditions do not have their branches labeled. The branch going downwards is always „yes“ and the branch going sideways (usually right) is „no“.

4.5.2 links each function to one or more definitions in other parts of Subset 026 by referring to the numbers of the paragraphs. The flow charts I created are linked to 4.5.2 by using the same numbers as 4.5.2 refers to. These flow charts regard only the functions performed by on-board. The functions of trackside are not the scope of this thesis, so they are ignored.

I have found one error in 4.5.2. The Backwards Distance Monitoring function is referenced

to paragraph 4.4, but this paragraph contains definition of all modes, not related to backwards protection in any way. By analysing the text, I managed to find out that the authors of 4.5.2 must have meant paragraph 4.4.14.1.3.

The only exception is part 3.13 and parts related to it. Due to the complexity of speed and distance monitoring, it was decided to use a model released by ERA, called ERA Braking Curves Tool. [49]

The inputs of the calculation are train values (length, rotating mass, train type, braking position etc.), track values (target type, distance and speed, gradient profile, relocation balises position and accuracy) and brake parameters (mainly brake percentage). The calculation returns a matrix of values of distances for speed values with resolution to 0,1 km/h. The distances define the position of supervision and braking curves relative to the target point.

5.3.3.2 Transitions between modes (4.6)

The transitions are presented as a matrix. In each mode, certain conditions are controlled and if they are fulfilled, a transition to another mode is performed. The conditions are explained separately in form of text.

To ease the work of the developer programming the system, I translated these conditions into Czech. I also added explanations if I considered them necessary.

The rest of this section is clear and self-explanatory. I did not find it necessary to analyse it further.

5.3.3.3 DMI interactions (4.7)

The DMI itself is analysed by my colleague from the Transportation Laboratory. The interactions with DMI are specified inside the mode functions.

5.3.3.4 Acceptance of received information (4.8)

This part defines the management of received information for given level, transmission media and mode. Also the buffering of the information during level change is described. The form is partly plain text, partly tables. I consider the form of the definitions as clear, so I did not analyse this part further.

5.3.3.5 Stored information management during level change (4.9)

This rather short part is very clear and does not need any analysis.

5.3.3.6 Stored information management during mode change (4.10)

The changes of certain data are again presented as a table. The table is self-explainable.

5.3.3.7 Effect of exiting NP mode on stored information (4.11)

This part does not need any explanation.

5.4 Subset 026 Chapter 5

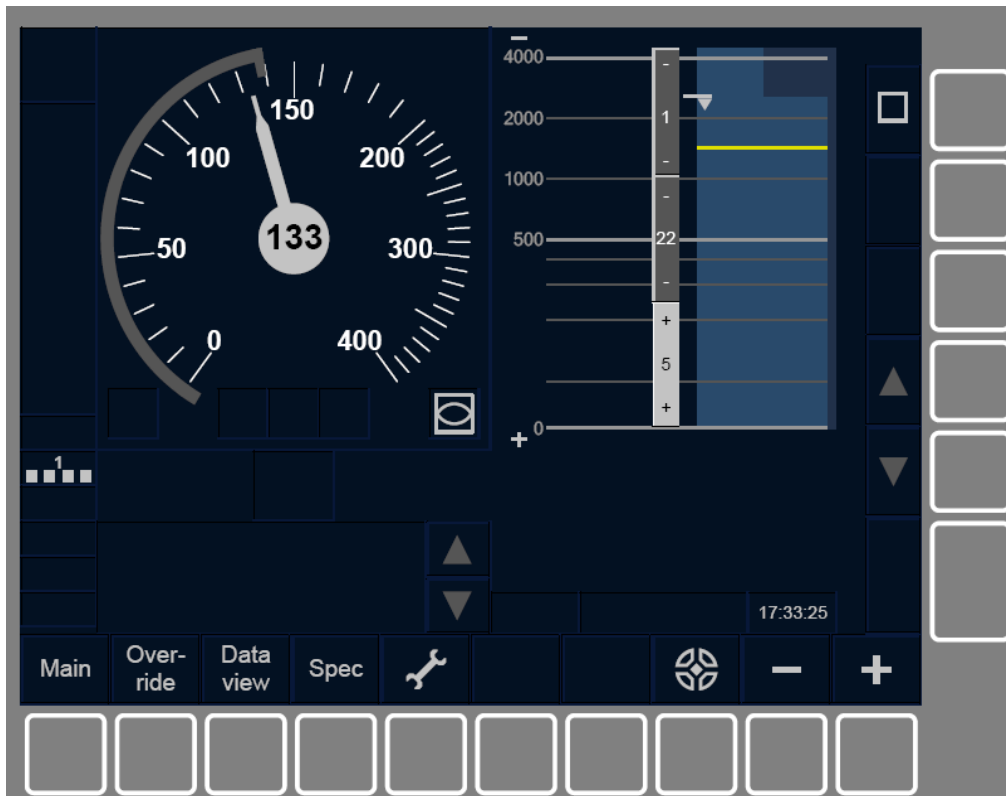
This chapter defines the procedures, for example Start of Mission, Override etc. Some of them are defined as flow charts, but due to the fact that the size of each page of the specification is limited to A4 format, the flow charts are not complete and are combined with explanations. Other procedures are defined as plain text. I transformed all the procedures into flow charts in similar manner as in case of the mode functions in Chapter 4.

Chapter 4 is sometimes linked to parts of Chapter 5, so I created flow charts from these parts to incorporate them into Chapter 4. These parts were not used when analysing the Chapter 5 alone. I created completely new flow charts for it.

The flow charts were created in the same manner as in 4.5.2 and do not need any further explanation.

5.5 ETCS DMI

The DMI is supposed to be based on the [41] specification. The document specifies the graphical layout and all the elements which may be displayed.



ETCS DMI [41]

The DMI shall be a 640x480 display equipped with 16 soft keys. Alternatively, a touch display may be used. The display is equipped with a loudspeaker. The minimal size of the image display area shall be 180x135 mm, which corresponds to 8,9" diagonal.

The type of device, which may be used for the DMI in case of the simulator, was described in the Cab construction – Displays chapter.

The DMI is not the scope of this thesis. It is currently under analysis by other worker in the Transportation Laboratory.

6 Scenarios

The simulation shall follow a particular scenario, which will be selected by the supervisor before the simulation is launched. The selection will depend on the primary purpose of the session.

The scenarios may be divided into groups, regarding the purpose of the scenario:

- training, used to teach the driver the skills and rules
- test of knowledge, evaluating the ability of an educated driver to use the operation rules during non-stressing situations
- endurance test, used to evaluate the driver's ability to operate the train correctly during stressing situations
- scientific test, which is assembled to examine an unknown phenomenon, e. g. ability of the driver to monitor the track when operating a DMI display

The definition of the scenario shall include starting parameters, proposed changes during the scenario and eventually the reaction of the driver which is regarded as satisfactory. The application of the changes may be specified by a timeline or may be performed manually by the supervisor.

The evaluation of the scenario after it is performed depends on the type of the scenario – whether it specifies the desired reactions of the driver or not. The driver shall be then informed about the results. If there are any proposals for enhancing the driver's abilities, they shall be told to them.

The rest of this chapter will propose some scenarios as examples.

6.1.1 Training

This case will be used for getting the person familiar with controlling the simulator and also for demonstration purposes for public, for example during an open day. The conditions shall be inherently daytime and full visibility, no timetable is used, the train route is set infinitely. The person may drive the train freely without any time limit. No changes and interventions shall be performed during the scenario.

6.1.2 Ride with a timetable

This scenario may be used to evaluate the ability to control the train during a standard ride. It may be also used for testing the impact of tiredness and stereotype.

A timetable is chosen and the person has to drive the train with respect of the timetable. The conditions are also chosen. The train route is set with dependence on the timetable, so the driver has to respect the signals. Abnormal situations do not have to be present in the simulation, as the goal of this scenario may be to bore and tire the driver. Abnormal situations would awake them.

6.1.3 Ride with a timetable and dangers

This scenario serves to evaluate the ability to cope with situations that endanger the train. The conditions may be the same as in the previous case with exception of the abnormal situations. The dangers may occur individually or in combination. They may be also

combined with some another scenario that distracts the driver from watching the track, for example some minor technical problem.

The danger scenarios may be provided in a form of list and the lecturer enters the simulation time in which they want to perform the danger scenario. Some of the possible dangers are presented in the following list.

The other input conditions may be the same as in the scenarios without a danger, e. g. the ride with a timetable is performed.

6.1.3.1 Obstructed level crossing

A level crossing occupied by a road vehicle is shown on the track. The driver is expected to activate the emergency brake and, depending on the type of the rail vehicle that is simulated, to either leave the cab or stay in place. This scenario may end either by colliding with the obstruction or with stopping the train safely. In case of collision, the impact shall be indicated acoustically. The final state of the simulation shall be reported.

6.1.3.2 Catenary defect

A droopy wire or similar defect is shown on some part of the catenary. The driver is expected to immediately pull down the pantograph, stop the train and contact the dispatcher. If the pantograph is not lowered before the train approaches the defect, a sound of impact shall be played and the pantograph shall be made unavailable. Also the traction power for the vehicle is cut. If it was lowered in time, the vehicle shall stay fully functional, but the driver must not continue driving before he contacts the dispatcher. It shall be reported whether the pantograph has been lowered in time or not.

6.1.3.3 Ambiguous signal

Some of the signals on the track is shown as displaying a dubious aspect or being completely dark. The reaction of the driver differs for the particular type of the signal and is described in the railway operation rules. For example in case of a main signal, the driver shall stop the train immediately unless the train dispatcher informed them in advance about the problem, in case of a distant signal, they may continue, but they must expect a Danger aspect on the next main signal. Ambiguous automatic block signal allows the driver to enter the following block, but obliges them to expect an obstacle on the track. In any case, the driver shall contact the dispatcher.

If the driver is informed about the faulty signal in advance, the form of this information is described by the operation rules.

6.1.3.4 Emergency brake activation

The automatic brake is deliberately set off. The brake behaves either as if a hole was present in its main pipe or as if a passenger activated an emergency brake lever. The air pressure in the main pipe shall be reduced to zero without any reason evident to the driver and the brakes shall be activated automatically. The driver must set the automatic brake controller to emergency brake position and deploy sanding. If the train is on a multi-track line, the driver has to set the marker lights of the locomotive to a warning sign. The driver shall contact the dispatcher as soon as possible. Any movement of the train is possible only after a permit is given by the dispatcher, who sets the emergency brake off and thus enables the main pipe to be filled.

6.1.4 Ride with a degraded situation

These scenarios present technical failures, which do not directly affect the safety of the train, but require the driver to use non-standard operation manners. As the failures usually disable some safety features, the driver is demanded to be more careful about the performed operations.

The manner of performing these scenarios may be the same as with the danger scenarios.

6.1.4.1 Loss of voice communication

The radio voice communication is suddenly lost. Either one or all means of radio communication (simplex, TRS, GSM-R) ceases to work. In this case, the driver shall behave in accordance with the regulations valid for the railway network that is simulated. This usually means that the driver continues their mission with accordance to the signals and tries to establish the communication or uses alternative means. If the signals are ambiguous or have to be precised by trackside personnel, the driver has to stop until the communication is established.

6.1.4.2 ETCS OBU failure

In this case the OBU falls into System Failure mode. This results in activation of the emergency brake. Once the train stops, the driver shall put the OBU into Isolation mode and continue the mission without the working ETCS. This condition applies some restrictions to the driver, mainly a certain speed shall not be exceeded if a working ATP system is not present on board of the train. The actual speed is specified in the operation rules of the railway and the limit applied in the Czech Republic is currently 100 km/h.

6.1.5 ETCS scenarios

To understand the terms used in this part, see chapter „ETCS Subsystem“ first. The scenarios simulate either standard ETCS operation or degraded situations.

6.1.5.1 Loss of communication with RBC

If the communication with RBC is partially or completely lost, the ETCS OBU enters the Limited Supervision mode. The extent of responsibility of the OBU and the driver over the train movement depends on the information that is left available.

6.1.5.2 Procedure Start of Mission

The mode of ETCS is SB and no communication with trackside is established. The driver activates the desk. The driver is requested to enter their ID if it is unknown. They are offered to enter Train Number and VBC. Then the procedure continues as defined by flow chart 5-4. It ends with entering certain Mode, depending on the conditions fulfilled.

The scenario may simulate a degraded situation where registration to radio network fails in Level 2 or 3. If the driver does not select mode SH or NL, other levels may be used if available (also Level 0). Entering Level 0 results in Mode UN. Level 1 enters Mode SR as the mission has to run in this mode until a balise is read. Entering Level 2 or 3 may also cause the Mode being set to SR. This happens in case that the RBC sends SR authorisation for any reason. RBC may also send OS, LS or SH MA. All these cases require acknowledgement from the driver.

6.1.5.3 Procedure Shunting initiated by driver

This procedure is described by flow chart 5-6, which is triggered when the driver selects Shunting and certain conditions are fulfilled. The only degraded situation is that the reply for Shunting request is not received from RBC. In that case, the session with RBC is terminated. The driver may then use Override to move the train.

The scenario may request the driver to perform a shunting movement with the train. The driver shall select Shunting and perform the operation as ordered by the train dispatcher. The driver shall use the signals valid for shunting.

Reverse movement of the train shall be performed with cooperation with the train dispatcher. The dispatcher sees the position of the train in the interlocking subsystem and tells the driver the remaining distance. The driver shall move the train slowly enough to be able to stop it before overrunning the end of the shunting area.

6.1.5.4 Procedure Override

This procedure is used to perform train movements in cases that would result in ETCS reaction that would stop the train, for example passing an EoA. The driver has full responsibility for the movement of the train in this procedure. It can be triggered by the driver if certain conditions are fulfilled, mainly the train speed has to be lower than Override speed limit. The mode may be changed to SR.

Once the Override is running, any emergency stop orders and transitions to Trip are revoked. The procedure ends when the maximal time or distance for running in Override elapses. This may be suppressed by the driver selecting Override again. Depending on the mode, other conditions may be checked causing termination of Override.

The scenario may simulate a burn-out bulb in a signal in a Level 1 area. The driver is informed by the train dispatcher about the problem and is ordered to use Override to pass the faulty signal. Once the train passes the signal, the driver shall sustain the Override procedure until a new signal with a proceed aspect is passed.

6.1.5.5 Procedure On Sight

This procedure is used to enable the movement of the train in cases when the trackside is not sure that the track ahead is free. The difference from the mode Staff Responsible used in Override is that it is commanded by trackside, not selected by the driver. The route is locked, but it may be occupied by another vehicle or other obstacle.

The OBU shall be in OS mode before entering the OS area. The driver is always requested to acknowledge the transition to OS mode. The transition may be performed either immediately or after the driver acknowledges. If the driver does not acknowledge in time, service brake is commanded and is released only after the acknowledgement is received from the driver. OS speed limit is checked by ETCS OBU.

The scenario is started by a situation that disables the trackside from checking the track occupancy, for example a faulty track circuit is simulated. The driver is required to drive the train in a way that they are able to stop the train safely in case that any obstruction is present on the track. The obstruction can actually be or not be present on the track. If the driver does not manage the train to stop before colliding with the obstruction, the scenario shall be considered as unsuccessful.

6.1.6 Other

In case of need, any other scenario shall be easily interpreted, so any other dependence can be studied.

7 Conclusion

I tried to provide a description of the simulator that would be as good as possible. On the other hand, it is very likely that there are some mistakes or inaccuracies in my thesis. These flaws will become evident only after the implementation of the simulator has become and it will be necessary to correct them. This is possible thanks to the fact that simulators can be generally easily modified. A verification would be necessary if this was not feasible.

The simulator will be almost certainly rebuilt in the future, because the speed of aging will be different for each of its components. Moreover, a new challenge to be simulated may appear, requiring the simulator to be modified.

The complex nature of the simulator requires that multiple people shall work on the implementation. Their cooperation will be crucial for a successful result.

8 Literature

- [1]: ŽATECKÝ, Petr. *Česko-anglický a anglicko-český slovník železniční zabezpečovací techniky*. AŽD Praha, 2005
- [2]: *Dopravní sál Fakulty dopravní*. [online]. 2016 [24. 11. 2016]. <http://dsfd.fd.cvut.cz/>
- [3]: JOHNSON, David M. *Introduction to and Review of Simulator Sickness Research*. U. S. Army Research Institute, 2005
- [4]: *Království železnic*. [online]. 2016 [24. 11. 2016]. <http://www.kralovstvi-zeleznic.cz/>
- [5]: ČD 23 687. *Zadávací dokumentace k veřejné zakázce*. ČD a. s., 2016
- [6]: *D1 - Dopravní a návěstní předpis*. SŽDC s. o., 2013
- [7]: *UIC 612 - Driver Machine Interfaces for EMU/DMU, Locomotives and driving coaches*. UIC, 2009
- [8]: *Bahn-Simulator | Die virtuelle Fahrschule für Lokführer*. [online]. Bild, 2015 [24. 11. 2016]. <http://www.bild.de/digital/multimedia/lokfuehrer/lokfuehrer-ausbildung-im-simulator-43713556.bild.html>
- [9]: SCHÄFER, Karsten. *Neuer Bahn-Simulator in Karlsruhe: Hier trainieren künftig Lokführer!* [online]. ka-news.de, 2015 [24. 11. 2016]. <http://www.ka-news.de/region/karlsruhe/Karlsruhe~/Neuer-Bahn-Simulator-in-Karlsruhe-Hier-trainieren-kuenftig-Lokfuehrer;art6066,1671351>
- [10]: *Bahn-Simulator - BR 185: Training & Schulung, Systemsimulation, private Anwendung*. [online]. Raildox GmbH., [24. 11. 2016]. <http://www.raildox.de/leistungen/bahn-simulator/>
- [11]: *LOCSIM: Der Loksimulator für Führerstandssimulationen und Zuglaufrechnungen*. [online]. LOCSIM, [24. 11. 2016]. <http://www.locsim.ch/>
- [12]: *Auf Führerstand und Simulator zum Rheinfall*. [online]. bahnreiseberichte.de, 2013, [24. 11. 2016]. <http://www.bahnreiseberichte.de/041-Fuehrerstandsmitfahrt/41Fuehrerstandsmitfahrt.htm>
- [13]: *Railway simulators*. [online]. Swiss Museum of Transport, [24. 11. 2016]. <https://www.verkehrshaus.ch/en/museum/rail-transport/railway-simulators>
- [14]: *Eine simulierte Führerstandsfahrt wie in echt*. [online]. BLS AG, [24. 11. 2016]. <https://www.bls.ch/d/reisen-ausfluege/aktuell-bahnsimulator.php>
- [15]: *Chemins de fer de Kaeserberg: The simulator*. [online]. CHEMINS DE FER DU KAESERBERG, 2013, [24. 11. 2016]. <http://www.kaeserberg.ch/en-us/the-simulator.aspx>
- [16]: , *ÖSTERREICH testet den U-Bahn-Simulator*. [online]. österreich.at, 2015, [24. 11. 2016]. <http://www.österreich.at/chronik/OeSTERREICH-testet-den-U-Bahn-Simulator/203949694>
- [17]: MARCHAL, Jean-Baptiste. *Aux manettes d'un train virtuel*. [online]. DH.be, 2015, [24. 11. 2016]. <http://www.dhnet.be/actu/belgique/aux-manettes-d-un-train-virtuel-55a212103570e4598ce5f0f6>
- [18]: *S'essayer à la conduite d'un train de travaux*. [online]. Infrabel, 2016, [24. 11. 2016]. <http://www.infrabel.be/fr/news/grand-succes-premier-saturday-job-fair>

- [19]: *SNCF : un centre de formation à grande vitesse*. [online]. La voix du nord, 2009, [24. 11. 2016]. http://photos.lavoix.com/main.php?g2_itemId=84536
- [20]: *Transport simulation*. [online]. Corys, 2016, [24. 11. 2016]. <http://www.corys.com/en/transportation-portail>
- [21]: *Simulateur de conduite d'engin moteur des CFL*. [online]. rail.lu, 2002, [24. 11. 2016]. <http://www.rail.lu/cflsimulateur.html>
- [22]: GALVIN, Kevin. *Train driver for a day.....virtually*. [online]. Irish Rail, 2014, [24. 11. 2016]. <http://www.irishrail.ie/blog/post?a=552>
- [23]: SHAFFER, Marie-Eve. *Une formation virtuelle pour les opérateurs d'Azur*. [online]. métro, 2014, [24. 11. 2016]. <http://journalmetro.com/actualites/montreal/525256/les-operateurs-de-metro-apprendront-virtuellement-a-conduire-les-voitures-azur/>
- [24]: *Indian Railways to get Australian Simulation Systems*. [online]. Rail News, 2015, [24. 11. 2016]. <http://www.railnews.co.in/indian-railways-to-get-australian-simulation-systems/>
- [25]: *Site Visit: EMU Simulator, Dry Creek Depot*. [online]. Engineers Australia, 2016, [24. 11. 2016]. <https://www.engineersaustralia.org.au/portal/event/site-visit-emu-simulator-dry-creek-depot>
- [26]: *A Tour of the Amtrak Training Facility*. [online]. 2001, [24. 11. 2016]. <http://www.weaverling.org/atc/>
- [27]: JAMIESON, Alastair, GOSK, Stephanie, JOHNSON, Alex. *Amtrak Crash: Simulator Shows How to Slow Train Ahead of Curve*. [online]. NBC, 2015, [24. 11. 2016]. <http://www.nbcnews.com/storyline/amtrak-crash/amtrak-crash-simulator-shows-how-slow-train-ahead-curve-n359406>
- [28]: *Rail System Simulators*. [online]. Simsoft, [24. 11. 2016]. <http://www.simsoft.com.tr/en/modelleme-simulasyon/rayli-sistem-simulatorleri/>
- [29]: *Railway (Tram) Simulator Systems*. [online]. Simsoft, [24. 11. 2016]. https://tr1053724107.trustpass.alibaba.com/product/50016507875-230298224/Railway_Tram_Simulator_Systems.html
- [30]: ŠKAPA, Petr. *Železniční doprava; učební text*. VŠB-TUO, 2007
- [31]: *EIRENE System Requirements Specification*. GSM-R Operators Group, 2014
- [32]: BULIS, Petr. *Zastavení vlaku povelom STOP v síti GSM-R*. ČD Telematika, 2015
- [33]: ZÍTKO, Martin. *Co spotřebuje vagón?* [online]. [24. 11. 2016]. <http://www.vagony.cz/vagony/energie.html>
- [34]: ČERNOHORSKÝ, M. *Parostroj, moravskoslezský železniční občasník*. [online]. [24. 11. 2016]. <http://parostroj.net/>
- [35]: HRUŠOVSKÝ, Ján. *Brzdiče hnacích vozidel ČSD*. NADAS, 1969
- [36]: *SR15(V). Popis brzd železničních vozidel*. ČD, 2002
- [37]: ZÍTKO, Martin. *Pneumatická část brzdy kolejových vozidel*. [online]. [24. 11. 2016]. <http://www.vagony.cz/pojezdy/brzda/pneumatik.html>
- [38]: *Stránky o prototypch a lokomotivních unikátech v ČR*. [online]. [24. 11. 2016]. www.prototypy.cz/
- [39]: KUBEC, Jiří. *Brzda nákladních vozů ČSD*. NADAS, 1991

- [40]: ŠEVČÍK, Karel, PELÍŠEK, Michal. *Návod k obsluze vozidla řady 640*. [online]. 2015, [24. 11. 2016]. <http://www.strojvedouciplzen.cz/index.php?page=menu&id=83>
- [41]: *ERA 015560, ETCS Driver Machine Interface*. ERA, 2014
- [42]: *Panel computers from the AP9xxx/APAxxx series*. [online]. AMIT Transportation, [24. 11. 2016]. <http://www.amit-transportation.cz/eng/transportation/vehicle-panel-computer.htm>
- [43]: *New robuste industrielle panneau pc / ordinateur intégré 10.1 polegada écran tactile avec Ram 2 Gb + SSD16Gb*. [online]. [24. 11. 2016]. <http://www.aliexpress.com/item/rugged-industrial-panel-pc-embedded-computer-10-1-Inch-Touchscreen-With-Ram-2Gb-SSD16Gb/32465633518.html>
- [44]: HORÁK, Pavel. *Modul STMLS*. AŽD Praha, 2009
- [45]: *Rozšiřující modul vlakového zabezpečovača MIREL VZI*. HMH, s. r. o.
- [46]: *The European Rail Traffic Management System: Deployment World Map*. [online]. [26. 2. 2016]. http://www.ertms.net/?page_id=55
- [47]: KONOPÁČ, Tomáš. *Návrh implementace systému ETCS do prostředí Dopravní laboratoře Fakulty dopravní*. 2011
- [48]: *yEd Graph Editor*. [online]. yWorks, 2016, [24. 11. 2016]. <https://www.yworks.com/products/yed>
- [49]: *ERA Braking curves tool handbook*. European Railway Agency, 2016
- [50]: DVOŘÁK, Pavel. *Trakční charakteristiky některých lokomotiv*. [online]. [24. 11. 2016]. <http://www.railian.com/teorie/tchlokomotiv.html>

9 List of appendixes

The appendixes are stored on the CD attached to this thesis. The CD contains 95 files with flow charts. The files can be opened with yEd 3.15.0.2.