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Specification and verification of energy consumption for railway rolling stock

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Specification and verification of energy consumption for railway rolling stock

Spécification et vérification de la consommation d'énergie pour le matériel roulant ferroviaire

Spezifikation und Überprüfung des Energieverbrauchs von Schienenfahrzeugen

This Technical Specification was approved by CENELEC on 2013-11-05.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

This document (CLC/TS 50591:2013) has been prepared by CLC/TC 9X/WG 11, "Energy Measurement on-board trains", of CLC/TC 9X "Electrical and electronic applications for railways".

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1 Scope

This Technical Specification is applicable to the specification and verification of energy consumption of railway rolling stock.

It establishes a criterion for the energy consumption of rolling stock to calculate the total net energy consumed, either at pantograph or from the fuel tank, over a predefined service profile, in order to assure that the results are directly comparable or representative of the real operation of the train. For this purpose this document takes into account the energy consumed and regenerated by the rolling stock.

This Technical Specification provides the framework which gives guidance on the generation comparable energy performance values for trains and locomotives on a common basis and thereby supports benchmarking and improvement of the energy efficiency of rail vehicles.

This Technical Specification does not cover specification for comparison of energy consumption with other modes of transportation, or even for comparison between diesel and electric traction, dealing only with the energy consumption of the Railway rolling stock itself. Consequently, this document is not applicable to the evaluation of the carbon foot print of the railway transportation system.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 590, *Automotive fuels — Diesel — Requirements and test methods*

EN 13129-2, *Railway applications — Air conditioning for main line rolling stock — Part 2 : Type tests*

EN 15663:2009, *Railway applications — Definition of vehicle reference masses*

EN 50163, *Railway applications — Supply voltages of traction systems*

EN 50463 (all parts), *Railway applications — Energy measurement on board trains*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE When possible, the following definitions have been taken from the relevant chapters of the International Electrotechnical Vocabulary (IEV), IEC 60050. In such cases, the appropriate IEV reference is given. Certain new definitions or modifications of IEV definitions have been added in this specification in order to facilitate understanding. Expression of the performance of electrical and electronic measuring equipment has been taken from EN 60359.

3.1.1
auxiliaries
equipment needed to operate the traction equipment, but not producing tractive or dynamic braking efforts themselves (e.g. cooling fans, oil and water pumps, and compressor)

Note 1 to entry: In the context of this Technical Specification, heating and/or air conditioning of the leading driver's cab is included in the auxiliaries.

3.1.2
comfort systems
all equipment consuming energy, belonging neither to the traction equipment nor to its auxiliaries, mainly in passenger cars (e.g. lighting, heating, air conditioning, toilets, information and entertainment systems, laptop supplies)

3.1.3
consist
group of vehicles which are not separated during normal operation or a single vehicle

3.1.4
contact line
CL
conductor system for supplying electric energy to a traction unit through current-collecting equipment

[SOURCE: IEC 60050-811:1991, 811-33-01, modified]

3.1.5
diesel multiple unit:
DMU
train having a fixed composition powered by one or several diesel engines having a fixed composition

3.1.6
electric traction system
railway electrical distribution network used to provide energy for rolling stock

Note 1 to entry: The system may comprise:

– contact line systems,

– return circuit of electric traction systems,

– running rails of non-electric traction systems, which are in the vicinity of, and conductively connected to the running rails of an electric traction system,

– electrical installations, which are supplied from contact lines either directly or via a transformer,

– electrical installations in power plants and substations, which are utilized solely for generation and distribution of power directly to the contact line,

– electrical installations of switching stations.

3.1.7
electric multiple unit
EMU
train having a fixed composition and getting its traction power from an external Electric traction system

3.1.8
heating, ventilation and air conditioning
HVAC
system to help maintain good indoor air quality through adequate ventilation with filtration and provide thermal comfort

3.1.9
infrastructure
fixed installations of the railway system (e.g. tracks, power supply, signalling, communication)

3.1.10
net energy
difference between the energy taken (consumed) from the Contact Line by the traction unit and the energy fed back (regenerated) into the Contact Line by the traction unit

3.1.11
rolling stock
general term covering all railway vehicles or consist of vehicles

Note 1 to entry: Rolling stock may be fitted with traction equipment.

3.1.12
service profile
outline of the expected range and variation in the mission with respect to parameters such as time, loading, speed, distance, stops, tunnels, etc., in the exploitation of the train

3.1.13
single-train simulation
simulation of the run of one train over a part of infrastructure, without inclusion of effects of other trains

3.1.14
railway system simulation
simulation of several trains over one or several parts of infrastructure (railway network), including effects of train performance, power supply characteristics, operational constraints (time table, conflicts between trains)

3.1.15
traction equipment
equipment directly needed to produce tractive or dynamic braking effort (e.g. transformer, converters, motors, gearboxes)

3.1.16
traction unit
railway vehicle or a fixed composition of vehicles with traction ability (e.g. locomotive, multiple traction unit)

3.1.17
train
consist ready for use, capable either of in-service operational mode or of out of service mode (pre-heating and pre-cooling, cleaning and parking)

3.1.18
vehicle
smallest part in a train, intended as a single vehicle (e.g. freight wagons, passenger coaches, locomotives)

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

All the abbreviations are listed in alphabetical order:

a.c.	Alternating Current
d.c.	Direct Current
DMU	Diesel Multiple Unit
EMU	Electric Multiple Unit
HVAC	Heating, Ventilation and Air Conditioning
LCC	Life Cycle Cost

4 General

Energy is an integral quantity. This means that the cumulated energy is the decisive factor. Realistic train operation always has to take place under the constraints of infrastructure and operational requirements. The defined timetable for the operation over a specified line plays an important role. This Technical Specification incorporates these conditions into a so-called “service profile” for the train.

This Technical Specification is therefore not a direct specification of detailed operational profiles and driving styles. Instead it provides a framework which allows freedom for the user to propose sound solutions integrating a given mix of energy efficient technologies and driving styles.

The energy consumption over such a service profile can be used as an input when assessing LCC. It can also serve as key documentation for the environmental performance of the train. This requires a well defined and harmonised methodology for specification and verification of the energy consumption. The selected approach has two steps:

1) simulation of the energy consumption of the train, over one or more simulation train runs;

2) verification of the simulation by undertaking test train runs.

Two different sorts of service profiles may be chosen:

a) user define service profiles based on data from a real railway line, normally one or several lines out of the railway network where the train will be operated;

b) standardised, service profiles, for the following categories for passenger service:

- suburban;
- regional;
- intercity (inter-regional);
- high speed;

and for the following types of freight service:

- mainline;
- shunting.

Definitions of relevant values for the typical service profiles and their parameters are given in annex B of this Technical Specification. The standard service profiles are characterised by definitions of standard values for the identified service types being typical (i.e. representative) – yet not real – of the type of railway service.

This means that it may not be possible to validate these on a real world track unless some adjustments of the verification results is undertaken to take account of the differences between the simulation and verification. However, these standardised service profiles are intended to be a common basis against which various trains can be simulated and simulation results compared.

In order to keep different characteristics, requirement and procedures manageable, the energy consumption of the whole train is subdivided into different aspects and handled separately:

- Traction equipment and auxiliaries necessary for traction without comfort systems;
- Only comfort systems (for all operating modes).

The following clauses show how to define the infrastructure (clause 5) and the operational and environmental conditions (Clause 6) for both simulations and verification tests. The simulations are specified in Clause 7 and verification tests in Clause 8. Finally post processing of test results is described in Clause 9.

5 Infrastructure description

5.1 General

The infrastructure shall be defined by the characteristics as specified in the following clauses. All values shall be given as a function of the distance (running path of the train).

The recommended resolution of position for track parameter changes (gradient, speed limit, curve radius, tunnel cross section) in longitudinal direction is one meter.

5.2 Longitudinal profile

The longitudinal profile shall be defined by the following required parameters:

- total distance of selected route or reference track from selected origin station to selected destination station [km] (ID I01, this identification number refers to the infrastructure parameter 01 in Annex A),
- height [m], as an absolute (above sea level) or relative value e.g. versus height of the start station (ID I02),

- gradient [–], as difference in height divided by difference of distance in longitudinal direction (ID I03).

ID I02 and ID I03 are correlated. Gradients may be omitted. If listed, it shall be checked that the integral of gradients along the track result in the correct difference of height between start and terminal station

5.3 Speed profile

The speed profile in [km/h] is defined by the required parameter: maximum speed profile at every location along the selected route or reference track (ID I04). The speed profile shall include the following criteria:

- Maximum speed for which the line, relevant to the profile, is planned.
- Permanent speed reductions due to curves, according to the required capabilities of the specified train. Example: tilting trains may have a higher permitted speed in some sections along the route than other trains.
- Non-permanent speed reductions due to signalling, according to conditions during verification runs or service operation of the train. Example: speed restrictions imposed by the changeover between two tracks shall be either specially marked, or already be included in the speed profile.
- Rules for safe operation. Example: if the operation rules require the target speed to be reached 100 m before a permanent speed restriction, this shall be included in the profile.

5.4 Curves

The following parameters shall be specified for curves: location and radius of each curve along the selected route or reference track [m] (ID I05).

Curves with a radius of more than 1 000 m are negligible.

5.5 Tunnels

The following parameters shall be specified for tunnels:

- Location and length [m] of each tunnel along the selected route or reference track (ID I06).
- Location and cross section area [m^2] of each tunnel along the selected route or reference track (ID I07). Very short tunnels with a length of less than 20 m and road bridges over the railway are negligible. Road bridges over the railway are considered as short tunnels with a length of less than 20 m.

5.6 Electric traction system

In case of electric trains, the following characteristics of the Electric traction system shall be defined by the required following parameters:

- nominal voltage (ID E01) and nominal frequency in case of a.c. (ID E02), according to EN 50163;
- mean voltage at the contact line (e.g pantograph) during operation of the train (ID E03), according to experience (measurements) in existing infrastructures, or as a result of total system simulations (for new infrastructure);

  NOTE The mean voltage at pantograph is normally not identical to the nominal voltage.

- position and length of neutral sections or phase separation sections (if applicable) along the selected route or reference track, which require the traction power to be cut (ID E04).

The parameters used to characterise the Electric traction system are defined in Table A.2.

5.7 Diesel fuel oil specifications

In case of diesel trains, the characteristics of the diesel fuel oil shall be defined according to EN 590.

6 Operational requirements

6.1 General

Two main phases during operation of a train are considered here:

- In service operation mode from origin to destination station including stand stills on the way and, if applicable, including HVAC. See 6.2.
- Out of service mode (e.g. pre-heating/pre-cooling, cleaning and parking/hibernate). See 6.3.

6.2 In-service operation mode

6.2.1 Train and propulsion system

A single-train run shall be specified. The specification shall include the train and its mechanical losses, the propulsion chain (electric, diesel-electric or diesel-mechanic) and all auxiliaries which are essential to operate the propulsion chain including control circuits for traction and signalling. Heating and/or air conditioning of the leading driver's cab is considered as part of the traction auxiliaries (to simplify the process for locomotives and during testing).

6.2.2 Timetable

The sensitivity of energy consumption versus travelling time is high. Therefore, the requirements on precision of the timetable are high as well.

The following required parameters shall be specified for the in-service operation mode:

- Stops/stations. The number and exact location of stations with planned stops (except departure and arrival station) (ID S01).
- Standstill time on the route. This is the total time elapsed for stopping times [s] at stations (wheels not in motion), during the run over the specified profile (ID S02). The train is fully operational, but e.g. with reduced auxiliary consumption (ventilation) and/or losses (traction converters blocked).
- Journey duration as total time elapsed (from wheels rolling at departure station to wheels stopped at arrival station) e.g. from time table (ID S03). The specification shall include the required time [s] between each start and stop, for a train run over the profile defined in Clause 5. During both simulation and verification, these times have to be held with high precision (see 7.2.2).

Journey durations and standstill times shall be specified as an integer number (whole number) of seconds.

6.2.3 Payload

EN 15663:2009 shall be used for reading and understanding of this clause.

The gross mass, and therefore the load, of a train have a significant influence on its energy consumption. The mass of the train shall be specified as follows:

a) Multiple units and passenger coaches, for the selected configuration: design mass [kg] in working order (i.e. dead mass, plus consumables, plus staff) plus normal operational payload or specified load conditions (see below).

b) Locomotives: design mass in working order.

c) A trailer consist as a load shall be homogeneous, i.e. shall consist of only one wagon or coach type with identical load in each . Preferred trailer vehicle types are single-deck or double-deck

passenger coaches (for passenger trains), or unloaded or loaded freight wagons. Preferred types of freight wagons are Eanos (open high-board wagons), Sgnss (container wagons), Shimmns (coil wagons) or Zans (tank wagons). The following values shall be specified for the trailer vehicles as a load:

1) mass [kg];

2) factor for rotating masses [-] or dynamic mass [kg];

3) running resistance [kN] versus speed [km/h] over the whole speed range used for the simulation and / or test;

d) Passenger load conditions: the total mass of passengers [kg] shall be specified according to the expected operation of the rolling stock (either as an average value or during specific peak / off-peak periods; parameter ID S05). For specific projects, it may be lower than the normal operational payload.

6.2.4 Driving style

The driving style of the train driver is not specified by this Technical Specification, even though it may have significant effect on the energy consumption and saving. The driving style (i.e. acceleration or deceleration at each point of the trip) should be chosen as a way to minimise the energy consumption of the operating train while respecting the following conditions:

- Safe operation of the train, under the rules applicable for the foreseen operation of the train. If any such rules exist, they have to be specified together with the infrastructure and timetable information.

- The specified timetable (ID S01 to ID S03) has to be held. Normal (or extra) reserves in the timetable, with respect to the performance of the train operation should be used for energy efficient driving.

6.2.5 Regenerative braking

For electric trains, if the regenerative brake is available, it shall be used as preferred braking system within the constraints of capability of the brake, timetable and applicable rules for safe operation of the train.

The calculation of the energy consumption shall be done as follows in cases where the electric traction equipment allows for regenerative braking:

a) For a.c. electrified railway systems: net energy at pantograph, i.e. fed back energy counted as negative without any other reduction factor than the one possibly imposed by the electric traction system itself (for example a part of the braking energy may be systematically consumed in dissipating loads even in regenerative mode);

b) For d.c. electrified railway systems, two calculations shall be made:

1) The first one in the same conditions as for a.c. railway systems.

2) The second one with the total braking energy consumed in the vehicle without any consideration of fed back energy. These two extremes correspond to fully regenerative and fully dissipative braking respectively.

The consumed and fed back energy at pantograph shall be identified separately for both a.c. and d.c. railway systems. It may depend on the individual project or economic rules in different countries how consumed and fed back energy is taken into account for life cycle cost (LCC) considerations.

The calculation of the energy consumption shall take into account the effect of any on-board energy recovery systems, e.g. the amount of braking energy stored in batteries or other devices for later use by traction or auxiliary systems or the possible use of the diesel engine losses for train heating.

6.2.6 In-service comfort functions

The performance of comfort functions during in-service operation is specified in the following two required parameters:

- comfort function duration in-service operation is defined as the duration for the total package of comfort functions in service operation: heating, ventilation, air-condition, lighting, entertainment and info panels (during summer and winter) per 24 h (ID S07) and measured in [hh:mm:ss], use total journey time/day unless specified otherwise;

- the load of the comfort function profile for in service operation is defined as the load profile for the total package of comfort functions in service operation: heating, ventilation, air-condition, lighting, entertainment and info panels (during summer and winter) per 24 h (ID S08) and measured in % of nominal effect of comfort functions. 80 % shall be used unless otherwise specified.

6.3 Out of service mode

6.3.1 General

The out of service mode are periods [h/day] where the train is stationary in depot areas, without staff or passengers being on board. Power supply to the parked train is either via normal circuits from the contact line, via shore supply or via diesel engines running in the train. The duration of these periods are important data for the design of the train and for determination of life cycle costs (LCC), but it is not necessary to fully respect them for the purpose of verification when applying the present Technical Specification.

For the definition of environmental conditions the following references to EN 13129-2 shall be used:

a) a: Heating mode: see Table 1, Zone II, 0 °C;

b) b: Cooling mode: see Table 2, Zone II, 28 °C.

The out of service mode covers essentially three levels of parked trains:

6.3.2 Pre-heating and pre-cooling

Pre-heating and pre-cooling for preparation of trains before in-service operation is defined by the following two required indicators:

- total average duration of the pre-heating or pre-cooling period (covering heating, ventilation, air-condition, lighting and other necessary auxiliaries) per 24 h during summer and winter (ID P01) and measured in [hh:mm:ss], use 30 min/d unless specified otherwise,

- load profile for the pre-heating or pre-cooling period (covering heating, ventilation, air-condition, lighting and other necessary auxiliaries) during summer and winter (ID P02) and measured in % of nominal effect of comfort functions. 80 % shall be used unless otherwise specified.

6.3.3 Cleaning of trains

Cleaning of trains before or after in-service operation is defined by the following two required indicators:

- Total average duration of the cleaning period (covering heating, ventilation, air-condition, lighting and other necessary auxiliaries) per 24 h during summer and winter (ID P03) and measured in [hh:mm:ss], use 1 h/d unless specified otherwise,

- Load profile for the cleaning period (covering heating, ventilation, air-condition, lighting and other necessary auxiliaries) during summer and winter (ID P04) and measured in % of nominal effect of comfort functions. 30 % shall be used unless otherwise specified.

6.3.4 Parking of trains

Parking of trains (hibernating) before or after in-service operation is defined by the following two required indicators:

- total average duration of the parking/hibernating period (covering heating, ventilation, air-condition, lighting and other necessary auxiliaries) per 24 h (during summer and winter) (ID P05) and measured in [hh:mm:ss], use remaining time [24 h – operational hours - h preparation – 1 h cleaning] unless specified otherwise,

- load profile for the parking/hibernating period (covering heating, ventilation, air-condition, lighting and other necessary auxiliaries) (ID P06) and measured in % of nominal effect of comfort functions. 10 % shall be used unless otherwise specified.

6.4 Environmental conditions

The environmental conditions, applicable to simulation and verification (see also Table A.5), are the following:

- Ambient temperature for energy consumption simulation without the comfort functions [deg C]; 15 °C unless specified otherwise to consider specific geographical locations (ID A01). For comfort functions only (6.2.6 and 6.3.2 to 6.3.4) use 0 °C, +15 °C and +30 °C, unless specified otherwise,

- Humidity [Relative humidity %]; 50 % all year round average humidity (ID A02),

- Intensity of sunlight [W/m^2]: 0 W/m^2, unless specified otherwise (ID A03),

- Average head wind: Simulation: 0 m/s (ID A04). Verification: actual wind speed lower than 5 m/s.

Other optional conditions:

- Ambient air pressure (ID A05), measured in hPa: Simulation (if relevant): international standard atmosphere 1013 hPa, unless otherwise specified (e.g. for mountain railways). Verification: uncontrolled. Special post processing/assessment if deviations between simulation and verification are claimed to originate from deviations in ambient air pressure,

- Minimum temperature, winter conditions (ID A06), measured in degrees Celsius,

- Humidity at winter conditions (ID A07), measured in relative humidity %,

- Maximum temperature summer conditions (ID A08), measured in degrees Celsius,

- Humidity at summer conditions (ID A09), measured in relative humidity %,

- Weather conditions: dry rails with good adhesion conditions.

It is recommended to ensure that the train is in a thermally stable condition already when starting the simulation or verification runs, as starting with a too cold or too hot train would significantly affect the results (traction chain losses, auxiliary power).

7 Simulation requirements

7.1 General

The simulation shall be based on the information provided in Clauses 5 and 6. The simulation shall cover the in service mode and the out of service mode: In service operation mode (train operation with passengers: from origin to destination station including stand stills on the way) and out of service mode (train operation without passengers: pre-heating/pre-cooling, cleaning and parking/hibernate).

7.2 In-service operation mode

7.2.1 Train and propulsion system

The simulation shall calculate the energy consumed and regenerated in case of electric traction or the fuel consumption in case of diesel traction, when operating the train over the defined route under defined operation conditions in accordance with Clauses 5 and 6.

7.2.2 Timetable

The following precision is required for simulation of the journey duration: +0/-N s for each section between two specified stops.

NOTE N is every number of seconds or percent, i.e. travel times are always allowed to be shorter, both in simulation and during verification.

The following precision is required as reference for simulation of the journey duration: ± 0 s (can be reached without extra effort).

7.2.3 Payload

Simulation shall be done according to specification in 6.2.3.

The simulation for passenger trains shall be done:

- for "individual profiles, i.e. profiles for a specific railway, with the specified load mass for passengers and input parameters specified in Annex A;
- for standardised profiles, i.e. synthetic profiles for the comparison of trains specified in Annex B, having the normal operational payload as defined in EN 15663:2009."

7.2.4 Driving style

Simulation shall be done based on conditions specified in 6.2.4.

7.2.5 Regenerative braking

The simulation shall be done based on conditions specified in 6.2.5.

7.2.6 Comfort functions (in-service)

Comfort systems shall be disregarded in the simulations of the train run.

This shall be done for the specified ambient temperature (6.4), and two different train speeds: standstill, and maximum speed of the train.

The number of passengers shall be specified in accordance with the normal operating conditions of EN 15663.

7.3 Out of service mode

The energy consumption per unit of time (i.e. power consumption) for a parked train shall be simulated for the three ambient temperatures specified in 6.4. The parameters used to calculate energy consumptions for parked trains are given in Table A.4.

7.3.1 Pre-heating and pre-cooling.

The simulation shall be done based on conditions specified in 6.3.2. For a standard simulation (Annex B) over 24 h a value of 30 min shall be applied for all train types except suburban trains which shall use 1 h (2 x 30 min) due to the two periods of peak/rush hours.

7.3.2 Cleaning of trains.

The simulation shall be done based on conditions specified in 6.3.3. For a standard simulation (Annex B) over 24 h a value of 60 min shall be applied for all train types.

7.3.3 Parking of trains (hibernating).

The simulation shall be done based on conditions specified in 6.3.4. For a standard simulation (Annex B) over 24 h a value of 4 h and 30 min shall be applied for all train types except suburban trains which shall use 4 h straight.

7.4 Environmental conditions

Simulation and calculation shall be done according to requirements specified in 6.4.

7.5 Documentation

The results of the calculations and simulations shall be documented in a report. The minimum requirements for the contents of the report are:

a) Information about infrastructure and operational input data according to Tables A.1 to A.5,

b) Key data of the train: length, mass, number of driven and not driven axles, tractive effort versus speed diagram, maximum mechanical braking effort,

c) Energy consumption [kWh or kg of fuel oil] of the traction equipment and auxiliaries, for the specified runs, separated into consumption during running and at standstill. Note that for d.c. railways, two values for the running phase shall be given (fully receptive and non-receptive power supply network during braking, see also 6.2.5).

d) Information about the use of on-board energy storage systems, energy management or other energy efficiency technologies,

e) Power needs [kW or kg of fuel oil/ h] of the parked train defined in 6.3.2 to 6.3.4,

f) For preparation of the tests: profile of speed versus distance, and tractive/braking effort versus distance for the simulated driving style,

g) In order to reach plausible results:

   1) the cumulated energy shall be separated into parts for potential energy (height difference), running resistance, mechanical brakes, traction chain losses plus auxiliaries, and braking resistor;

   2) any onboard energy storage device shall have the same energy content before and after the test.

8 Verification

8.1 General

The following clauses only contain specific conditions which shall be considered during preparation and performance of the tests. All conditions already specified in the clauses above apply as well, and are not repeated hereafter.

8.2 Infrastructure conditions

If the train run is specified for a real, existing railway line, this line shall be taken for the test. Infrastructure conditions shall be identical to the specification (Clause 5).

If the infrastructure has been changed between the simulation and the tests (e.g. between the bid phase and commissioning phase), and if this results in more restrictive conditions for the train run (e.g. lower permitted speed), the simulations shall be repeated prior to the tests, in order not to punish the train design for changes in infrastructure. If the conditions are less restrictive, the original profile shall be followed.

If the train run is specified for a typical standard profile (normative Annex B) tests shall be done on an infrastructure which has similar characteristics to as wide extent as possible, possibly by post-calculation if necessary. The simulations shall be repeated with the same simulation model for the

train, but with the infrastructure used for the tests. Comparisons between simulation and measurement shall then be done on the basis of same infrastructure characteristics.

8.3 Timetable verification

The following precision is accepted during timetable verification:

± 5 s (without correction/post processing) or +100 % to -50 % of each specified standstill interval (with correction/post processing of the measured energy).

Larger differences during verification may affect the thermal behaviour of the train and shall be assessed individually.

8.4 Environmental conditions

The environmental conditions are also defined in 6.4, together with those for simulation.

The following differences are allowed without further need for post processing of the results:

- Ambient temperature: ± 5 °C (for running, traction and auxiliary losses);
- Ambient temperature: ± 1 °C (for comfort systems).

8.5 Measurement equipment

For electric trains, the energy consumption shall be measured with equipment (transducers, recorders) which is independent from the equipment of the train. Exception: the same voltage and current sensors as mounted on the train can be used, if it fulfils the accuracy requirements as defined below.

The accuracy of the whole measurement chain shall follow EN 50463 (all parts).

Measurement options for diesel trains: diesel fuel oil flow meters or measurement of tanked fuel over the necessary number of test runs in order to achieve the accuracy. Measurements shall result in a total accuracy of within ± 2 % of fuel oil consumed.

8.6 Test rules

In addition to all requirements specified above (Clauses 5, 6, 7, 8.2 to 8.5), the test shall be performed according to the following rules:

a) a test plan has to be defined prior to the tests. This plan especially contains:

   1) the infrastructure conditions for the specific test,

   2) the environmental conditions,

   3) the speed profiles versus distance, and a description on how to instruct the driver to follow these profiles,

b) the train shall be in fully operational condition (e.g. no degraded modes in traction or auxiliaries) and in a controlled software status, with all parameters which are relevant for energy consumption being identical to those for later normal operation,

c) the train shall have the same load as for the simulations and shall be in thermally stable condition. For verification, the mass of the train shall be within ± 2 % of the mass specified for simulation,

d) the operation of the train by the train driver shall be done in the same way as during scheduled operation later; especially the blending between electric and mechanic brakes shall correspond to this principle,

e) the test shall be carried out three times in each direction, without significant disturbance of the specified speed versus distance profile (e.g. by red or warning signals),

f) the travel times specified in the timetable shall be strictly followed, with the precision as defined in 7.2.2. Shorter travel times as specified are not restricted,

g) comfort systems are switched off during the verification test runs, and tested separately. Such tests can be done during other test runs under suitable conditions, or in specialised facilities like climatic chambers,

h) measurements with the parked train (including traction auxiliaries as far as relevant) shall be performed separately as well, under similar conditions like for the comfort systems.

8.7 Documentation

The results of the verification measurements shall be documented in a report. The minimum requirements for the contents of the report are:

- key information about the train: vehicle number(s), software configurations. Mass of the train during the tests;
- key information about infrastructure and operational input data where applicable;
- description of the measurement equipment used;
- energy measured for “in service” and “out of service” phases. Power consumption of comfort systems and for the parked train. For the train runs, consumed and fed back energy shall be given separately;
- for the test runs: speed and tractive/braking effort versus distance;
- ambient and weather conditions during the tests;
- any observations during the tests which might have an effect on the interpretation of the test results.

9 Post processing

9.1 General

Ideally, no post processing of measured or simulated data is necessary. In this case, a final report, containing the comparison between simulation and measurement is issued, and the process is closed.

However, it might be difficult to fully control all conditions during tests in the real railway system, under the influence of other operations and weather conditions. Therefore, some post processing of the measurements, with or without repetition of simulations, can be tolerated, for the cases specified in the following subclauses.

9.2 Train data

For multiple units, no post processing due to deviations in train data (e.g. mass, running resistance, losses) is allowed. Differences in energy consumption, which originate from such deviations, clearly show a difference in design of the train, and will lead to a corresponding difference in energy consumption over the lifetime of the train.

For locomotives, deviations in the characteristics of the hauled train can be tolerated to some extent. This concerns mass and / or running resistance of the train. Post processing shall be tolerated for deviations up to ± 5 % of the mass or ± 15 % of running resistance of the train. In this case, the simulation shall be repeated with the modified characteristics of the train. The documentation shall give evidence that the model for the locomotive is completely unchanged for the repeated simulations.

9.3 Time and driving style

No post processing for deviations in travel times are allowed, except for extraordinary standstill times in freight services. The test shall be planned and carried out in a way that the tolerances specified in 7.2.2 can be met. The reason for this is that the dependency between travel time and energy

consumption is strongly non-linear, and very sensitive to some parameters such as use of braking system.

Standstill times can be corrected within the limits specified in 7.2.2 without further detailed analysis. Larger corrections can be tolerated, if an analysis shows that the train is still in sufficiently steady state thermal conditions during the next running phase.

9.4 Environmental conditions

Post processing of results with respect to the ambient temperature outside of the range defined in 8.4 shall be done by means of repetition of the simulations. In this case, the same temperature as during the tests is applied, with all other conditions unchanged. The documentation shall give evidence that the model for the train is completely unchanged for the repeated simulations. This post processing shall allow the tests to be performed during nearly any time of the year without delaying a project just for the reason of these tests.

Post processing for other environmental (wind, rail conditions) is not foreseen. Tests have to be planned and performed under conditions which are sufficiently identical to the specification.

9.5 Electric network characteristics

For both a.c. and d.c. networks, a correction due to a different mean value of the line voltage during the tests can be performed. In this case, the simulation shall be repeated with the identical model for the train, but the line voltage according to the values during the test. This voltage depends on the location and/or power of the train. The documentation shall give evidence that the model correctly represents changes in line voltage, but is completely unchanged otherwise for the repeated simulations.

For d.c. networks, the receptiveness of the network for regenerated energy can vary significantly. The tests shall be planned in such a way that full regenerative braking is applied. Differences during the tests would be seen from a higher line voltage than assumed for simulation, leading to a blending between regenerative and dissipative brake. Such a situation may be different from location to location (distance from substation, energy consumed by other traffic).

Post processing of the measured data (correction by comparison of corresponding simulations) or the additional measurement of energy consumed by the braking resistor (during the test runs) can serve to prove that the tested train corresponds to the specification. Evidence shall be given that the post processing and / or comparison are correctly done. Note that for the simulation the energy values for operation under both fully receptive and non-receptive network shall be computed (6.2.5).

Annex A
(normative)

Definition of standard parameters

A.1 General

This annex identifies and defines all necessary parameters referred to in the main text of this Technical Specification. The parameters are describing infrastructure, railway operation and rolling stock. They are divided into the following clusters and presented with definitions and measurement units in the tables below:

- Table A.1 — Infrastructure characteristics (I)
- Table A.2 — Electric supply system characteristics (E)
- Table A.3 — In service operation mode (S)
- Table A.4 — Parked train service mode (P)
- Table A.5 — Ambient conditions with seasonal changes (A)

Each parameter belongs to one category of either “required” or “optional”. In order to comply with this Technical Specification all parameters labelled “required” shall be applied and specified. Parameters labelled “optional” may be applied and specified upon decision by the user of this Technical Specification.

A.2 Infrastructure characteristics

Table A.1 lists the characteristics of the infrastructure. Each characteristic is identified by the letter I followed by two digits.

Table A.1 — Infrastructure characteristics

ID	Parameter	Definition	Measurement unit	Category
I01	Route length	Total distance of selected route or reference track from selected origin station to selected destination station	km	required
I02	Altitude profile (height)	The total height profile in meters above sea level along the selected route or reference track	m	required
I03	Altitude profile (gradient)	The gradient profile (slope) along the selected route or reference track	$^{0}/_{00}$	required
I04	Track speed profile	The maximum speed profile at every location along the selected route or reference track	km/h	required
I05	Curve radius	The exact location and radius of all curves along the selected route or reference track	m	required
I06	Tunnel profile (length)	The exact locations and lengths of all tunnels along the selected route or reference track	km	required
I07	Tunnel profile (cross section area)	The exact locations and cross section areas of all tunnels along the selected route or reference track	m^2	required

A.3 Electric supply system characteristics

Table A.2 lists the characteristics of the electric supply system. Each characteristics is identified by the letter E followed by two digits. It is not applicable to the diesel traction.

Table A.2 — Electric supply system characteristics

ID	Parameter	Definition	Measurement unit	Category
E01	Nominal voltage	Choice of the different standard traction systems, e.g. 750 V d.c., 1,5 kV d.c., 3 kV d.c., 15 kV a.c., 25 kV a.c..	V	required
E02	Nominal frequency	Choice of the different standard traction systems (d.c., 16,7 Hz, 50 Hz)	Hz	required
E03	Mean voltage at pantograph	Mean voltage measured at pantograph during operation of the train according to existing standard measurement protocol (EN 50163)	V	required
E04	Neutral sections	The exact location and length of all neutral/phase separation sections along the selected route or reference track	m	required

A.4 In service operation mode

Table A.3 lists the in service operation mode parameters. Each parameter is identified by the letter S followed by two digits.

Table A.3 — In service operation mode

ID	Parameter	Definition	Measurement unit	Category
S01	Stops/stations	Number and exact location of stations with planned stops (except departure and arrival station)	integer	required
S02	Stand still time on the route	The total time elapsed for stopping time at stations (wheel not in motion)	hh:mm:ss	required
S03	Journey duration	The total time elapsed (from wheels rolling at departure station to wheel stopped at arrival station) e.g. from time table	hh:mm:ss	required
S04	Load conditions in passenger service (multiple units)	Total pay load of passengers, e.g. average or all seats occupied (total weight of persons, average weight per person per service type)	t	required
S05	Load conditions in service (locomotives)	Total pay load (total weight hauled by locomotive): weight of wagons in-service plus passengers according to S08	t	required
S06	Passenger load conditions-occupancy according to number of seats (or standing capacity if applicable)	Total passenger occupancy rate e.g. average or all seats occupied	%	required
S07	Comfort function duration in service operation	Duration for the total package of comfort functions in-service operation: heating, ventilation, air-condition, lighting, entertainment and info panels (during summer and winter) per 24 h	hh:mm:ss	required
S08	Comfort function profile for in-service operation (load)	Cumulated load profile for the total package of comfort functions in-service operation: heating, ventilation, air-condition, lighting, entertainment and info panels (during summer and winter) per 24 h	% of nominal effect of comfort functions	required

A.5 Parked train service mode

Table A.4 lists the in service operation mode parameters. Each parameter is identified by the letter P followed by two digits.

Table A.4 — Parked train service mode

ID	Parameter	Definition	Measurement unit	Category
P01	Pre-heating and pre-cooling duration	Total average duration of the pre-heating and pre-cooling period before each in-service period begins per 24 h	hh:mm:ss	required
P02	Pre-heating and pre-cooling load profile	Load profile for pre-heating or pre-cooling before each in-service period	% of nominal effect of comfort functions	required
P03	Cleaning period duration	Total average duration of the cleaning mode period for 24 h	hh:mm:ss	required
P04	Cleaning period load profile	Load profile for cleaning mode period	% of nominal effect of comfort functions	required
P05	Parking period duration (hibernating)	Total average duration of the parking mode per 24 h	hh:mm:ss	required
P06	Parking period load profile (hibernating)	Load profile for parking mode period	% of nominal effect of comfort functions	required

A.6 Ambient conditions with seasonal changes

Table A.5 lists the ambient conditions parameters with consideration of the seasonal changes. Each parameter is identified by the letter A followed by two digits.

Table A.5 — Ambient conditions with seasonal change

ID	Parameter	Definition	Measurement unit	Category
A01	temperature	All year round average temperature	°C	required
A02	humidity	All year round average humidity	% relative humidity	required
A03	sunlight	Intensity of sunlight	W/m^2	required
A04	Head wind	Average head wind conditions in-service operation	km/h	required
A05	Ambient air pressure	International standard atmosphere	hPa	optional
A06	Minimum temperature (winter conditions)	Winter minimum temperature	°C	optional
A07	humidity (winter conditions)	Winter minimum humidity	% relative humidity	optional
A08	Maximum temperature (summer conditions)	Summer maximum temperature	°C	optional
A09	humidity (summer conditions)	Summer mean humidity	% relative humidity	optional

Annex B
(normative)

Definition of standard values for service profiles

B.1 General remarks

The standard service profiles defined in the following clauses are intended for the comparison of the energy consumption of trains, e.g. between the products of different manufacturers, under standardised conditions. Each profile consists of an infrastructure description (distances, speed limit) and a timetable. If only the infrastructure data is used, trains can be compared in view of their operational performance and energy consumption at shortest possible travel time. A comparison under equal operational conditions requires also the compliance with the given timetable requirements.

The profiles are defined in such a way that average values (e.g. route length, number of stops) correspond with typical values in the best possible way. For environmental conditions, the values given in 7.4 are applicable.

The profiles and corresponding requirements are valid for a complete train. For passenger traffic, this will normally be EMUs or DMUs, or a defined set of passenger coaches together with a locomotive. Therefore the running resistance of the coaches is part of the overall characteristics of the train. For freight trains, which are normally hauled by a locomotive, the parameters of a standard reference freight train are specified. The timetable requirements are independent from the length or mass of the train.

B.2 Suburban passenger traffic

Figure B.1 shows an example of SUBURBAN profile which contains 10 intermediate stops, with different spacing between the station and different speed limits along the line, see Table B.1. For each stop, the standstill time is defined. Otherwise, only the departure time at the first and the arrival time at the last station are defined and have to be carefully respected. Standstill times before departure at the first and after arrival at the last station shall be included in the evaluation of energy consumption, but are outside of the overall required journey time. Time reserves can be shifted from one to another section, as widely practiced for suburban traffic.

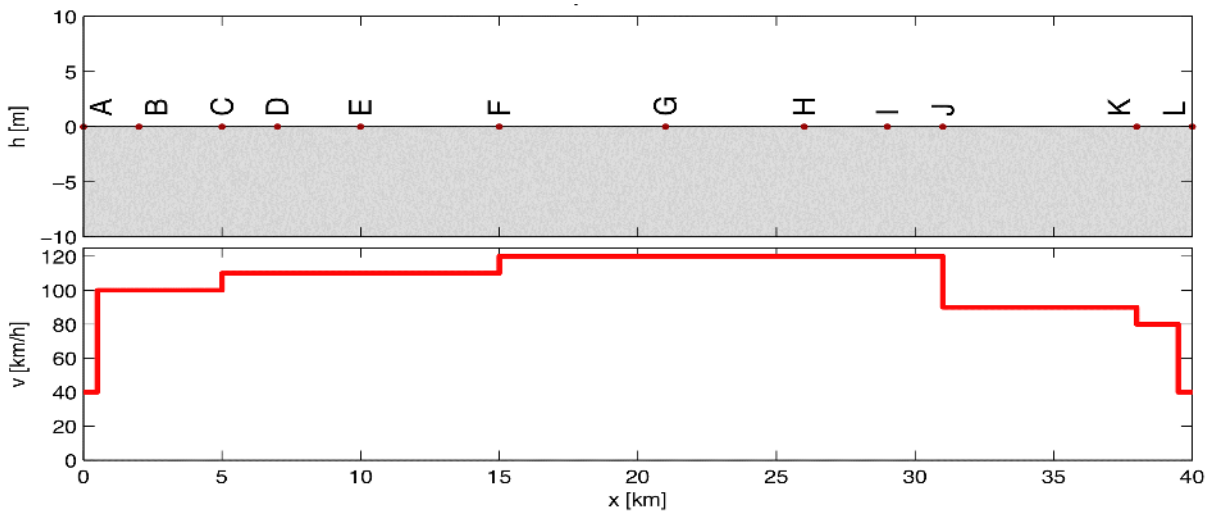

Figure B.1 — Standard profile SUBURBAN

Table B.1 — Data of the SUBURBAN profile

Station	Distance (km)	Height (m)	Speed limit (km/h)	Arrival (hh:mm:ss)	Stop	Departure (hh:mm:ss)
Station A	0,000	0	40		1:00	0:00:00
	0,500	0	100			
Station B	2,000	0	100		1:00	
Station C	5,000	0	100		1:00	
Station D	7,000	0	110		1:00	
Station E	10,000	0	110		1:00	
Station F	15,000	0	120		1:00	
Station G	21,000	0	120		1:00	
Station H	26,000	0	120		1:00	
Station I	29,000	0	120		1:00	
Station J	31,000	0	90		1:00	
Station K	38,000	0	80		1:00	
	39,500	0	40			
Station L	40,000	0		0:40:00	1:00	

B.3 Regional passenger traffic

Figure B.2 shows an example of REGIONAL profile which contains 13 intermediate stops, with different spacing between the station and different speed limits along the line, see Table B.2.

The profile is defined in the same way as for suburban passenger traffic. The timetable requirements shall be interpreted in the same way as specified there.

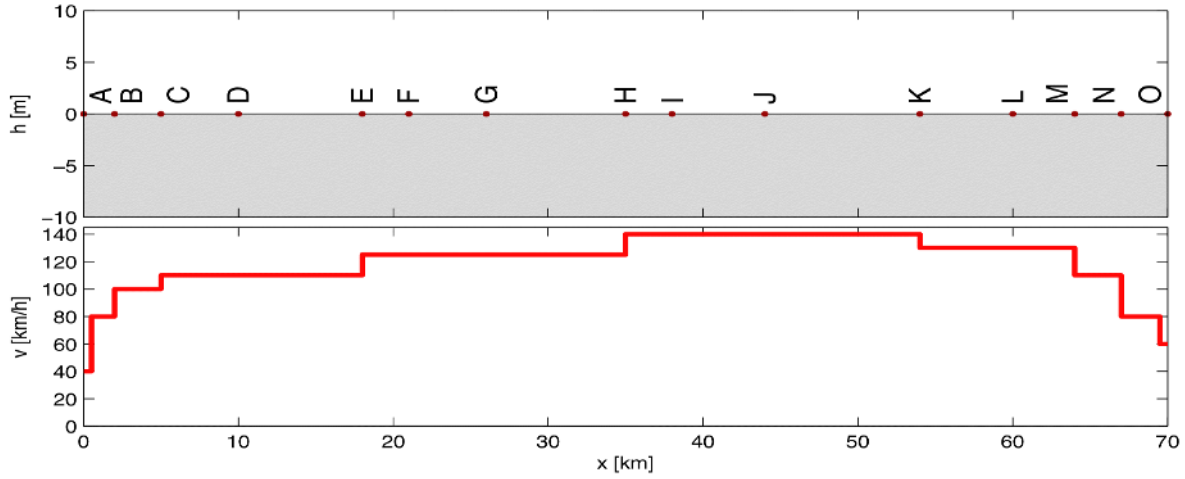

Figure B.2 — Standard profile REGIONAL

Table B.2 — Data of the REGIONAL profile

Station	Distance (km)	Height (m)	Speed limit (km/h)	Arrival (hh:mm:ss)	Stop	Departure (hh:mm:ss)
Station A	0,000	0	40		2:00	0:00:00
	0,500	0	80			
Station B	2,000	0	100		1:00	
Station C	5,000	0	110		1:00	
Station D	10,000	0	110		1:00	
Station E	18,000	0	125		2:00	
Station F	21,000	0	125		1:00	
Station G	26,000	0	125		1:00	
Station H	35,000	0	140		2:00	
Station I	38,000	0	140		1:00	
Station J	44,000	0	140		1:00	
Station K	54,000	0	130		2:00	
Station L	60,000	0	130		1:00	
Station M	64,000	0	110		1:00	
Station N	67,000	0	80		1:00	
	69,500	0	60			
Station O	70,000	0		1:01:00	2:00	

B.4 Intercity passenger traffic

The Figure B.3 shows an example of INTERCITY profile which contains 9 sections and 8 intermediate stops with different speed limits. On one section, a maximum speed of 200 km/h can be reached. A speed reduction and reacceleration to a higher speed occurs on some sections. The stopping time is longer for some stations than for others., see Table B.3.

The timetable requires the journey time to be hold not only for the total profile, but also for each individual section between two stations. The available journey time between the stations is shown in the last column of the timetable. Therefore, time reserves are not allowed to be shifted from one section to another, according to the normal practice in long distance traffic where connections with other trains have to be guaranteed.

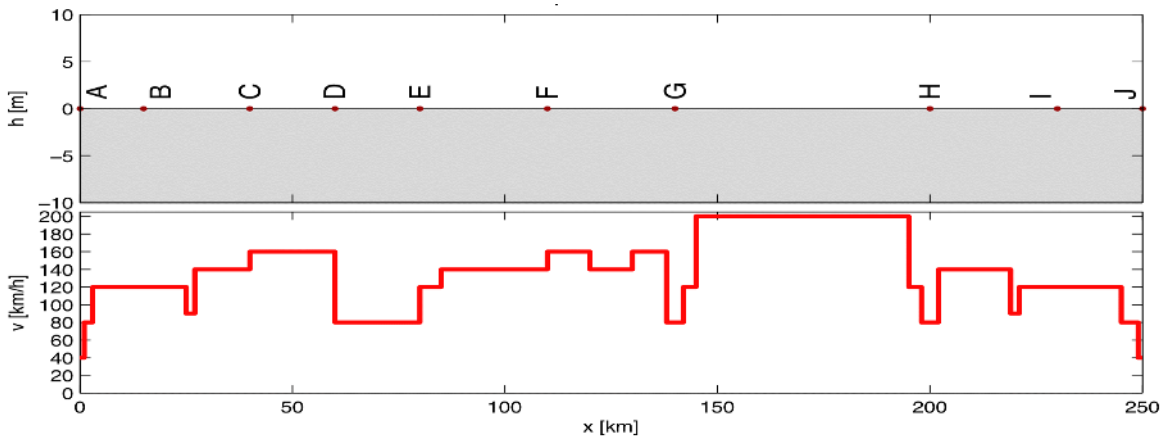

Figure B.3 — Standard profile INTERCITY

Table B.3 — Data of the INTERCITY profile

Station	Distance (km)	Height (m)	Speed limit (km/h)	Arrival (hh:mm:ss)	Stop	Departure (hh:mm:ss)	Travel
Station A	0,000	0	40		3:00	0:00:00	
	1,000	0	80				
	3,000	0	120				
Station B	15,000	0	120	0:11:00	2:00	0:13:00	11:00
	25,000	0	90				
	27,000	0	140				
Station C	40,000	0	160	0:28:00	2:00	0:30:00	15:00
Station D	60,000	0	80	0:40:00	2:00	0:42:00	10:00
Station E	80,000	0	120	0:59:00	3:00	1:02:00	17:00
	85,000	0	140				
Station F	110,000	0	160	1:18:00	2:00	1:20:00	16:00
	120,000	0	140				
	130,000	0	160				
	138,000	0	80				
Station G	140,000	0	80	1:36:00	3:00	1:39:00	16:00
	142,000	0	120				
	145,000	0	200				
	195,000	0	120				
	198,000	0	80				
Station H	200,000	0	80	2:04:00	2:00	2:06:00	25:00
	202,000	0	140				
	219,000	0	90				
	221,000	0	120				
Station I	230,000	0	120	2:23:00	2:00	2:25:00	17:00
	245,000	0	80				
	249,000	0	40				
Station J	250,000	0	40	2:39:00	3:00		14:00

B.5 High-speed passenger traffic

Figure B.4 shows an example of HIGHSPEED profile which consists of a high speed line with a maximum speed of 300 km/h over half of the total route length, plus connecting upgraded lines (with 220 km/h and 200 km/h) as well as a classical line between the departure station and the single intermediate stop, see Table B.4

This takes into consideration that high speed trains very frequently run over classical lines to make connections into major cities. The timetable requirements have to be interpreted in an identical way as for intercity passenger traffic.

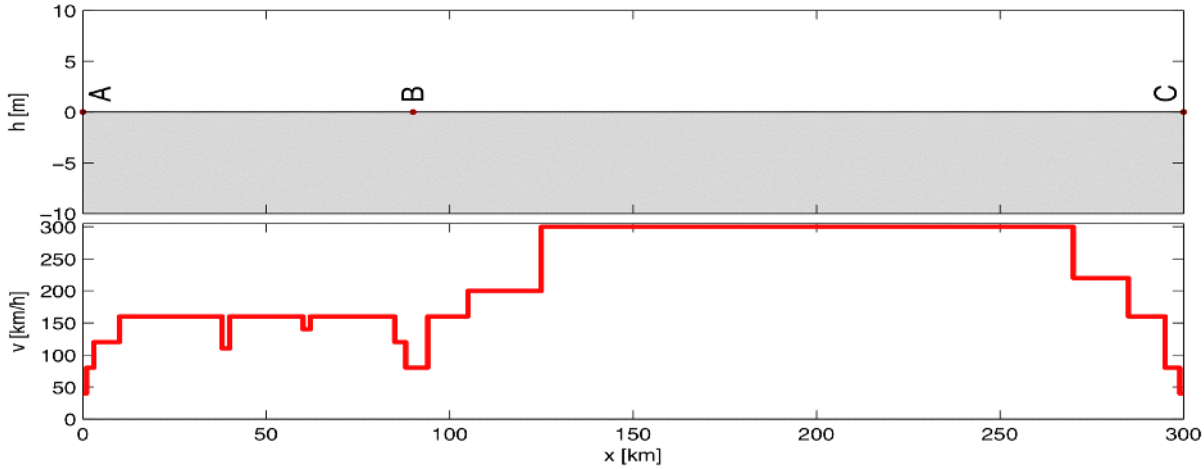

Figure B.4 — Standard profile HIGHSPEED

Table B.4 — Data of the HIGHSPEED profile

Station	Distance (km)	Height (m)	Speed limit (km/h)	Arrival (hh:mm:ss)	Stop	Departure (hh:mm:ss)	Travel
Station A	0,000	0	40		3:00	0:00:00	
	1,000	0	80				
	3,000	0	120				
	10,000	0	160				
	38,000	0	110				
	40,000	0	160				
	60,000	0	140				
	62,000	0	160				
	85,000	0	120				
	88,000	0	80				
Station B	90,000	0	80	0:42:00	3:00	0:45:00	42:00
	94,000	0	160				
	105,000	0	200				
	125,000	0	300				
	270,000	0	220				
	285,000	0	160				
	295,000	0	80				
	299,000	0	40				
Station C	300,000	0		1:47:00	3:00		62:00

B.6 Freight mainline

Figure B.5 shows an example of freight mainline profile over 300 km which includes three planned stops plus two stops in front of red signals, see Table B.5.

Two third of the line is horizontal track whereas the middle part includes a mountain passage. This reflects the fact that long distance freight train operation includes railway lines with significant gradients in many countries, not only through the Alps. The gradients of the profile are selected in such a way that a four-axle locomotive can haul the same train as the reference train with average mass as specified below. Although locomotives and wagons of many freight trains may be capable to run faster than 100 km/h, the profile is limited to 100 km/h, which is the maximum speed for most loaded freight trains according to lines and wagons of Class D (22,5 t axle load).

Timetable requirements have to be interpreted in the same way as for intercity passenger traffic. Train and timetable are applicable for electric trains or fast freight DMUs only. Trains hauled by diesel locomotives can not hold the timetable for the mountain section, unless they have an uneconomically high number of locomotives.

The allowed maximum dynamic braking effort of a locomotive shall not exceed 150 kN. The same value is applicable for more than one locomotive at a concentrated position in the train. For trains with distributed power, higher total dynamic braking efforts are admissible. However, the longitudinal forces inside the train have to be limited and shall not exceed 150 kN at any position within the train.

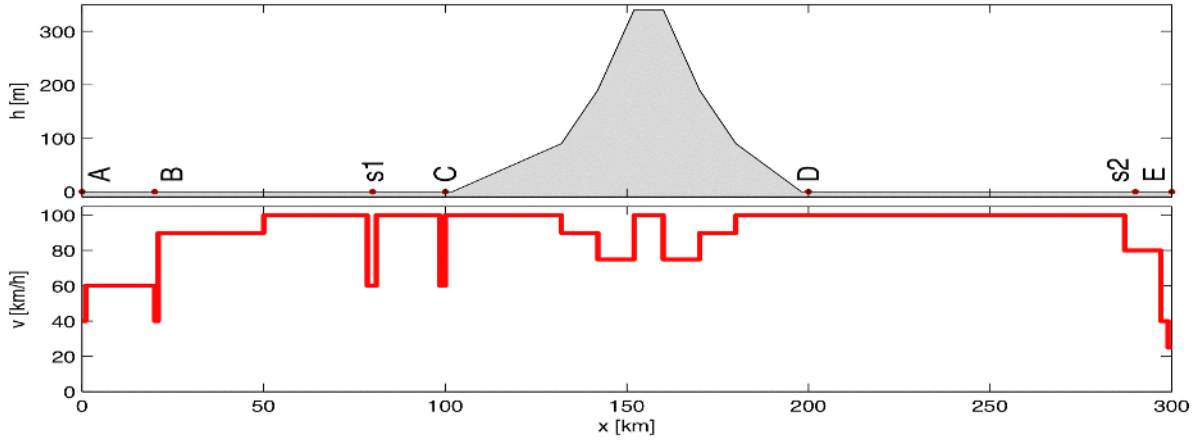

Figure B.5 — Standard profile FREIGHT mainline

Table B.5 — Data of the FREIGHT mainline profile

Station	Distance (km)	Height (m)	Speed limit (km/h)	Arrival (hh:mm:ss)	Stop	Departure (hh:mm:ss)	Travel
Station A	0,000	0	40		3:00	0:00:00	
	1,000	0	60				
	18,000	0	60				
Station B	20,000	0	40	0:24:00	2:00	0:26:00	24:00
	21,000	0	90				
	50,000	0	100				
	78,500	0	60				
Signal s1	80,000	0	60	1:12:00	1:00	1:13:00	46:00
	81,000	0	100				
	98,500	0	60				
Station C	100,000	0	100	1:29:00	5:00	1:34:00	16:00
	102,000	0	100				
	132,000	90	90				
	142,000	190	75				
	152,000	340	100				
	160,000	340	75				
	170,000	190	90				
	180,000	90	100				
	198,000	0	100				
Station D	200,000	0	100	2:51:00	5:00	2:56:00	77:00
	287,000	0	80				
Signal s2	290,000	0	80	3:59:00	1:00	4:00:00	63:00
	292,000	0	80				
	297,000	0	40				
	299,000	0	25				
Station E	300,000	0		4:13:00	3:00		13:00

Table B.6 lists the Train data.

This train intended to be hauled by one four-axle locomotive. For six-axle locomotives, a 50 % longer and heavier train shall be used. Note that the limits for longitudinal forces inside the train are not higher in this case.

Table B.6 — Train data of the FREIGHT mainline profile

Wagon type	Zans (tank car)
Number of wagons	18
Tara mass of the train (without locomotive)	423 t
Relative load	50 %
Gross mass of the train (without locomotive)	1026 t
Length of the train (without locomotive)	306 m
Factor for rotating masses	1,04
Specific running resistance, constant term	1,05 N/t
Absolute running resistance, quadratic term	48,77 N/(km/h)^2
Available braking effort, service brake (without locomotive)	800 kN

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