SLOVENSKI STANDARD
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Železniške naprave - Navodilo za uporabo simulacij - Navodilo o uporabi simulacij za dokazovanje skladnosti s tehničnimi in regulativnimi zahtevami ter o vnašanju in razvoju simulacijskih zahtev v standarde

Railway applications - Guidance for the use of simulations - Guidance for the use of simulations to demonstrate compliance with technical and regulatory requirements and on the introduction and development of simulation requirements into standards

Bahnanwendungen - Leitfaden für den Einsatz von Simulationen - Leitfaden für den Einsatz von Simulationen zum Nachweis der Einhaltung technischer und regulatorischer Anforderungen sowie zur Einführung und Entwicklung von Simulationsanforderungen in Normen

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This draft Technical Report is submitted to CEN members for Vote. It has been drawn up by the Technical Committee CEN/TC 256.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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European foreword

This document (FprCEN/TS 17833:2022) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This document is currently submitted to the Vote on TR.

1 Scope

The aim of this document is to help CEN/CENELEC Working Group convenors and experts to promote/develop simulation in their standards as an alternative to physical tests on the real system for proving conformity. It can also provide useful guidance to assessors in the railway sector in approving simulations where they are not yet specifically defined or where physical tests on the real system are not defined in standards. Consequently, this document is also relevant to companies developing and applying simulations with the intention to achieve their acceptance for the purpose of system validation. It is not intended to provide technical guidance on applying simulations in general.

Where simulations are already introduced in existing standards, this guide is not intended to modify the specified requirements. However, technical harmonisation between standards might benefit from this guide for the introduction of additional alternative methods for simulations.

This document principally covers:

— numerical simulation, using complex methods or using simple spreadsheets methods;

— hardware and software in the loop;

— mathematical models solved using numerical methods or iteration, including spreadsheets.

It does not cover the following, although the general principles outlined can be applied to these methods:

— laboratory tests of components;

— fatigue rig tests;

— model scale tests;

— mathematical models solved analytically.

NOTE Due to the limited experience in the railway sector in the application of data-based (as opposed to model-based) simulations, for example using artificial intelligence (AI), neural networks, big data, etc., this approach is not further developed at this stage in this document.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
simulation (action and object)
(action) use of a similar or equivalent system to imitate a real system so that it behaves like or appears to be the real system; (object) similar or equivalent system used to imitate a real system

Note 1 to entry: Simulation can be mathematical, analogue or scale modelling. Mathematical simulation includes analytical and numerical calculation.

[SOURCE, ISO 16781:2013, 2.9, modified, Note 1 has been added.]

3.2
numerical simulation
simulation based on numerical methods

3.3
test
technical operation that consists of applying to the object a set of environmental and operating conditions under a specified procedure.

Note 1 to entry: A test can be carried out to determine one or more characteristics of a given object, process or service according to a specified procedure. It can be used for different purposes (verifying requirements, calibration, test cases and correct implementation of a model, etc.).

Note 2 to entry: A test can be conducted on the real system, or by entirely or partially using simulation (simulation testing)

[SOURCE: IEV modified, ISO/IEC Guide 2 (13.1), notes 1 and 2 have been added]

3.4
simulation tool
in house, vendor or open source framework in which one may develop or embed models enabling the execution of tests. It can be software and/or hardware and parts of the real system can be installed in the tool.

3.5
model
mathematical and/or physical representation of a system or a process

3.6
numerical model
numerical representation of a mathematical model

3.7
verification (of simulation)
process of determining that a simulation in its tool environment produces expected results according to the underlying model

3.8
validation (of simulation)
process of determining the degree to which a model is an accurate representation of the real system in its environment

[ASME V&V 10 2006, modified] [ASME V&V 40 2018, modified]

3.9
system validation
process of proving conformity to system requirements, ensuring that the system is fit for its intended use in its intended operational environment

3.10
regression testing
testing required to determine that a change to a system (e.g. a model or a tool) has not adversely affected functionality, reliability or performance and has not introduced additional defects

[SOURCE, ISO/IEC 27034-7:2018, 3.15, modified.]

3.11
environment
external aspects influencing the behaviour of a system

3.12
user
entity using the simulation

3.13
certification
third-party attestation related to components, sub-systems or systems

3.14
hardware in the loop simulation
type of simulation, in which some *parts of the system or its environment* are implemented or modelled by real equipment

Note 1 to entry: Hardware in the loop simulations are characterised by a two-way coupling between the simulated and the real components.

[SOURCE: IEC 16781:2013, 2.5, modified, note 1 added]

3.15
software in the loop simulation
type of simulation, in which a software that is executable on the real system is interfaced with simulation models

4 Introduction

4.1 Background

The rationale for producing this document is the perception that physical testing on the real system for train, infrastructure and command and control system certification leads to:

— excessive costs;

— delays bringing products to market.

The use of simulation is widespread in the automobile and the aerospace sectors, both for design and validation. The challenge is for the European railway sector to examine its certification processes and allow for using simulation methods as well as physical testing on the real system for system validation, where it is possible and safe. In the majority of instances, the demonstration methods are defined in CEN and CENELEC standards.

At the JPC Rail (Sector Forum Rail) meeting in March 2018, the issue of promoting the use of simulation within the Railway Sector was raised. In response, three steps were proposed by CEN:

a) to set up a survey group to identify and ideally respond to transversal questions and needs to support WG Conveners and experts to introduce or to further define simulation requirements in their standards. It was foreseen that the outcome of the Survey Group would be a preliminary issue of a guide;

b) to urge current CEN and CENELEC Working Groups' conveners and experts to consider either introducing or further defining existing simulation requirements within standards under their responsibilities;

c) to invite the ERA and the EC to promote simulation approaches throughout the regulatory framework whenever possible.

4.2 Context

Historically, the demonstration of safety and conformity to standards for obtaining the certification of rolling stock, fixed installations, control-command systems and infrastructure has been mainly based on physical tests on the real system.

Although already widely used in the design and pre-validation of sub-systems, simulation is still relatively rarely applied to improve and accelerate the system validation phase, where physical tests on the real system are often required for compliance assessments.

There are several ways in which simulations can help improve the system validation phase. They can be used to better understand certain phenomena, enabling experts to study/explore a wider range of cases than those practicably covered by physical tests on the real system (which are limited by environment parameters such as weather, geographical range and configuration, boundary conditions etc.), and hence complement them. Another possibility is to use simulation in order to reduce the amount of physical testing on the real system, and to reduce delays bringing products to market. Use of simulation should not be limited to exploring system behaviour in fault free conditions; it may also be extended to consider failures or degraded modes.

Driven by the increase in simulation quality and reliability, the trend of evolution in the railway sector is towards the use of more simulation and to less physical testing on the real system. The regulations and the standards set requirements which have to be fulfilled. These may stipulate compulsory physical testing on the real system or leave significant room for simulation or fail to specify the method of demonstration at all.

5 Principles governing the use of simulation

5.1 General

Simulation can be used fully or partially to prove conformity (see example 1 in Annex A). For full simulation proofs, only results from simulation testing are used as the final means to prove conformity. In partial simulation proofs, physical tests on the real system or parts of it are required for some test cases.

It should be noted that, in most cases, the initial validation of the simulation model might require physical tests on the real system or parts of it (see Subclause 5.4).

Especially for design evolutions, where physical tests on the real system have already been conducted in a previous similar case, it may be feasible to fully prove conformity by simulation if changes to the system subject to testing remain within certain limits. For changes exceeding these limits, a partial proof by simulation can be feasible, (see example 2 in Annex A).

NOTE It is also possible to fully prove conformity by simulation without starting from a pre existing design.

It should be ensured that the simulation tool is compatible with the intended purpose of the simulation and that the models are representative of the real system in its environment. It is good practice to evaluate qualitatively and quantitatively the uncertainty and the sensitivity of the models (more information can be found in [1] and [2]). The user is responsible for critically interpreting the results obtained.

Despite being separated in the following paragraphs, the concepts of tool verification, user capabilities and model verification and validation are highly interconnected. Additional guidance can be found in Clauses 7 and 8.

The simulation tool should be verified for the particular use to which it is being applied. Good practice recommendations for the verification of simulation tools are given in Subclause 5.2.

Once the simulation tool is verified, it is necessary that measures are in place to ensure that the users of the tools have the expertise and knowledge to apply them. Good practice recommendations for demonstration of the skills necessary for users to use simulation tools and associated quality processes are given in Subclause 5.3.

The primary purpose of validating a simulation model is to generate sufficient confidence in it, in order to replace physical tests on the real system by simulations. This is further developed in Subclause 5.4.

Specific additional conditions for Hardware- and Software in the Loop are introduced in Subclause 5.5.

In Subclause 5.6, documentation requirements when using simulations are given.

5.2 Verification of simulation tools

Simulation tools consist of one or more components, which are interfaced in order to enable embedding the model(s) of the system to be tested and possibly parts of the real system. Those components can be software and/or hardware and their complexity may vary depending on the tool.

NOTE Software tools generally provide a library of tool-specific elementary models. They can range from simple models, such as mathematical functions, to complex ones, such as a set of physics.

In order to determine that a simulation in its tool environment produces expected results according to the underlying model, as a first step, the simulation tool should be verified for the particular use to which it is being applied. For tools consisting of several components, each component should be verified separately, and in combination, in order to verify their interfaces.

Verification should consider the accuracy, range of validity, boundary conditions and limitations of tool components and their interfaces, which should be appropriate for the intended purpose of the simulation tool.

The organisation performing tool component verification usually depends on its origin:

— for in-house simulation tools, it is the user organisation;

— for third-party simulation tools, it is the providing organisation;

— for open source simulation tools, it is, depending on the case, either an identified organisation or the user organisation.

The verification process should also cover configuration and change management of tool components, for example by performing regression testing during version changes and following updates to operating systems and to host machines.

In every case, the user should verify the complete simulation tool by applying specific reference cases, and checking the outputs against known results.

The part of the verification process performed in the user organisation should be traced and documented.

It is good practice to maintain a log of user experiences of the tool.

5.3 User capabilities/qualification

As well as verifying the simulation tool for the intended use, measures should be in place to ensure that the users of the simulations have the expertise and knowledge to set up and/or to apply them, and critically analyse and interpret the results. This is the responsibility of the user organisation.

The user should ensure that the adopted simulation tool is fit for purpose.

NOTE The user in this context can refer to a range of different people.

It is good practice to verify the user skills for setting up and/or applying simulations, for instance, by undertaking standard simulation test cases and recording skill levels.

Where relevant, it is good practice to maintain sufficient independence between designers and validation experts, to ensure confidence in the results. The degree of independence should be based on the safety impact of the intended use.

5.4 Verification and validation of simulation models

5.4.1 Verification of models

The second step of determining that a simulation in its tool environment produces expected results involves verifying the consistency of the different choices of modelling and particularly checking:

— the individual sub models of the system and its environment;

— the full model of the system in its environment;

— the simulation method and its numerical convergence.

5.4.2 Validation of models

A validation process should demonstrate that the simulation model sufficiently represents a reference system for different reference scenarios. This reference system might consist, preferably, of a physical test on the real system, or of a reduced scale test or a generic case (e.g. analytical, benchmark, etc.). If a model is an adaptation of, or similar to, a previously validated model, it may be possible to conduct a reduced validation. In this case, the rationale for the reduced validation should be made and documented.

Generally, validation should be performed for the entire model, where necessary after validating particular sub models individually.

The comparison between the simulation results and the reference system will give the level of confidence in the simulation. The validation includes performing investigations concerning uncertainties (e.g. accuracy, robustness and reproducibility). The domain of validity of the simulation should be given. (See e.g. examples 3 and 4 in Annex A).

Best practice for validation involves proper consideration of the uncertainties in both the simulation and in the reference system.

Validation of the simulation models should be documented as detailed in Subclause 5.6.

Particular attention should be paid to simulations of systems that have a safety function or a safety impact.

5.5 Specific additional conditions for Hardware- and Software in the Loop

The concept of 'Hardware in the Loop' (HiL) simulations is based on using real components or pieces of equipment directly interfaced with numerical simulation models (see example 5 in Annex A). The system and the environment are partly real and partly modelled. The real part of the system can be mechanical, electrical, electronic, etc.