# A facility for testing ERTMS/ETCS conformity and human factors

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**Abstract:**
The advancement of the European rail system into an interoperable system is currently taking place and evolves in several phases: the technical interoperability has to be fulfilled by the new European Train Control System (ETCS) and the European Rail Traffic Management System (ERTMS), the operational interoperability will be ensured by a set of harmonised European operational rules and the last step will be a harmonised safety philosophy with regards to technology as well as to human behaviour. Due to the safety-relevance of the railway operation, validation, tests and experiments can only partially be done on real tracks and should be done preferably in simulation laboratories. Nevertheless, the integrated European railway operation needs the validation that the operational rules as well as the safety philosophy and the relating operation of the personnel keeps the current level of operational safety, at least. This must be proven through experiments in laboratories.

In this contribution, a general purpose test facility for train control systems called RailSiTe® (Rail Simulation and Testing) is presented. This facility is based on a core simulation lab, which can be used for ERTMS/ETCS interoperability testing and which has been developed in accordance to the European specifications. Due to the generic and modular approach this RailSiTe® can also be used for validation of technical interoperability as well as operational rules and analyses of human factors. The RailSiTe® provides the full technical chain from the signaller's working place to the driver's desk including the simulation and visualisation of the environment. Equipment to observe physiological data can be added to the railway specific part to collect objective information about the workload and stress of the staff, especially in exceptional and unexpected situations. Psychological tools to acquire the subjective rating of the situation by the staff are present, too.

## 1. Introduction

Currently, the national railway systems across Europe are advanced to a harmonised and interoperable system. This complex and long-lasting process will be fulfilled in a lot of single steps; the three following ones are the major ones:

1) The technical interoperability will ensure that a train coming from one country going to another country can use the infrastructure with one single system.
2) The operational interoperability is based on the technical interoperability and will be created by a harmonised set of operational rules. The new or modified rules must be analysed with regards to the changed behaviour of the staff.
3) The safety of the operation must be analysed in the next step. This includes the extended analysis of the human influences, too.

Currently, the first implementations of the European Train Control System (ETCS) of the European Rail Traffic Management System (ERTMS) are being launched. In Spain, for instance, on the line from Madrid to Barcelona, on board units of different suppliers must be interoperable with trackside subsystems from another supplier. To avoid additional effort in time and cost, the interoperability of these components will be tested in a lab before the testing and operation on the track. Different tests have to be performed: tests of technical safety, reliability and availability on the one hand, test of operational safety and conformity with the specifications on the other hand.

Such a simulation environment which can cover both cases is the core of a railway laboratory, called RailSiTe®, which will be outlined in this contribution in the second section. In the third section, aims and approaches for the analysis of human influences as well as stress and workload will be discussed.

## 2. Concept and Architecture of the RailSiTe®

### *2.1 Concept*

The RailSiTe® is a multipurpose platform for scientific as well as for industrial experiments. The RailSiTe® provides the complete chain form the signaller to the train driver [MJL 2003]. The global approach is shown in the fig 1.

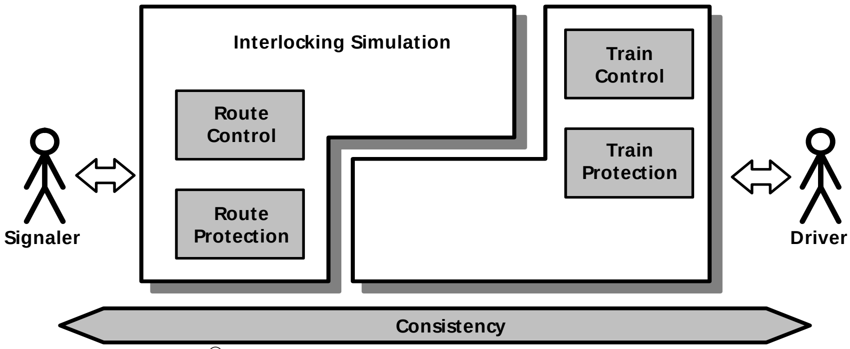


Fig. 1: RailSiTe® concept.

Due to the modular and flexible architecture the RailSiTe® can be used for several different purposes. Some of them are:

- The test of conformity with the requirements.
- The evaluation of operational safety of a complete railway operation control system.
- Performance evaluation of a modified or new train control system.
- Analysis of an automation concept for trains.
- Hardware-in-the-loop simulation including real parts of a system.
- Experiments related to usability, ergonomics and human factors of automation approaches.
- Experiments related to stress and workload of the operators.
- Experiments related to safety-critical errors of the operators.

The RailSiTe® is designed to fulfil both the requirements related to reproducibility as well as to flexibility. This is realised by a modular architecture.

### 2.2 *Error models and simulation of erroneous system behaviour*

The basic approach for the testing in a lab uses two kinds of experiments [Illgen *et al.* 2000]:

- The functional behaviour is tested against the functional requirements without introducing disturbances. This kind of experiments can be used, e. g., to test the conformity with the functional or technical system requirements.
- The behaviour is tested under the real, i.e., disturbed, environmental influences against the appropriate safety and availability requirements. This kind of experiment can be used to test operational safety or availability. The stability and performance of operation concepts can be evaluated as well.

The relevant sources and typical modes of errors or disturbances have been studied carefully. Some important sources have already been identified. All modules or subsystems which perform an information transmission in a continuous or discrete way will be equipped with technological error models. The basic classification contains five types of errors:

- Delay of a message
- Change of the sequence of messages
- Loss of a message
- Change of message content
- Sending of a wrong message

This behaviour can be represented, e.g., by fixed values calculated as a stochastic mean value or a stochastic value defined by a given distribution function. They can be independent of the environment or defined by location or time.

These different behaviours will be represented by specific “Transmission Error Modules” which can be chosen related to the purpose of the experiment. Their implementation will start with the definition of generic modules, which fulfil the basic error modes. Two basic generic error-modules are radio communication errors and transponder errors. For the use of testing they will be parameterised, e. g., to represent the behaviour of GSM-R or the Euro-Balise. In the following steps of implementation, these modules will be extended and refined.

### 2.3 *Test scenarios*

As mentioned before, experiments and tests can have different goals: performance of a train operation system or the conformity of a train control system with the specification. Even if the goals of the experiments or tests are different, the basis for all of them is basically the railway operation. The railway operation is represented by operational sequences, which can be concatenated to simulation train runs. For these train runs a description of the track is necessary. For the performance evaluation of a real line this description can be taken from the real line. For the evaluation of a system the use of track descriptions related to real lines is not efficient, because a lot of special operations are rare on real lines and there is a small number variation of operations on one line. The use of a generic track for time-efficient evaluation of a train control system safes time and effort. The generic track is based on the same operational scenarios as the simulation of the operation on a real line.

The scenarios, which are to be tested, can be classified in two classes: The operational scenarios, which test a specific operation situation. The interoperability scenarios are used to check the conformity of one implementation as well as the correct interaction of two or more implementations. The basic test sequences can be derived from a formal specification [Meyer zu Hörste *et al.* 2000], they can be written completely manually or they can be created in a mixed automatic and manual process.

### *2.4 Formalization of tests*

The reproducibility and the automation of tests lead to the need for a concept to formalise and to automate the test sequences. For instance the test cases of ERTMS/ETCS can be shown as a graph with approximately 1200 nodes. The manual generation of test sequences is not efficient and can lead to errors. The proof of completeness needs a lot of effort as well. To avoid this problem a specific algorithm based on graph theory has been used to improve the generation of test sequences.

### *2.5 Modularity*

The RailSiTe® environment is defined in a very modular way to ensure both the research aspect and the interoperability validation purpose. The infrastructure and the physical train are replaced by simulation modules. They generate the inputs needed to stimulate the train control system. All other inputs like route map, timetable and all kinds of drivers or operator inputs are sent by interface generators. All of them are acting in real time to ensure real time behaviour of the simulation environment.

The environment has not been created to fulfil certification purposes, but it can be used to analyse technical interoperability. An overview of the basic architecture of the first steps of implementation is given in *Fig. 2*.

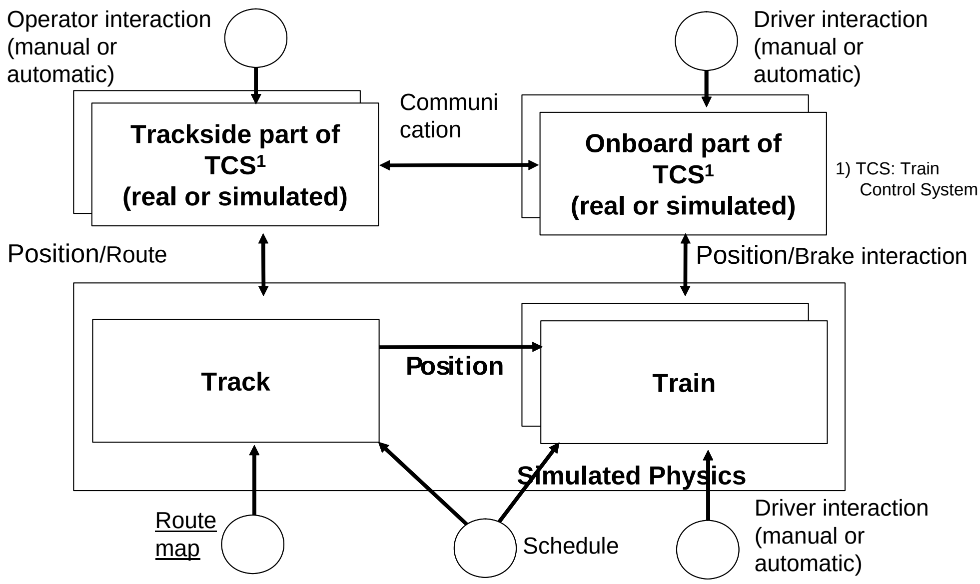


Fig. 2. Basic simulation concept of the RailSiTe®.

### *2.6 Steps of implementation*

Due to the complexity of the entire system, the start of operation is split into several steps. The implementation is based on the state of the art of train control systems.

*Step 1:* The on-board subsystem and the related simulation environment.

*Step 2:* The trackside subsystem with the related simulation environment, the interface of the interlocking and the connection to the on-board subsystem.

*Step 3:* Implementation and adaptation of a driver desk [EuDD 2003]. To fulfil the driving simulation, a driver's view visualisation will be added too.

*Further steps:*

- Connection to a level crossing simulation facility.
- Improvement of the interlocking interface.
- Implementation of the ERTMS/ETCS level 3 moving block functionality.
- Connection to a 3D-movement platform.

### *2.7 Hardware-in-the-loop simulation*

One of the applications described in section 2.2 is the hardware-in-the-loop simulation to check the conformity of a new or improved component of a train control system. Due to the modular set-up of the RailSiTe® the simulation of the on-board or trackside subsystem can be exchanged by a real system. A specific computer performs the interface adaptation for the real system.

Several configurations are relevant to check the interoperability, e.g., of ERTMS/ETCS on-board units (OBU) and Radio Block Centres (RBC):

- The evaluation of the interaction between one on-board part and one trackside part of a train control system. This configuration will be used to check the functionality and the conformity with the requirements. If the parts are implemented by different suppliers this configuration will be use to check the interoperability.
- Another configuration containing two on board parts and one trackside will be used to check the interaction of two trains over the common trackside.
- A third configuration with one on board unit and two trackside systems is implemented to evaluate the national or international hand-over of a train.

The RailSiTe® is prepared for two on board units and two trackside systems to have the possibility to implement all these configurations.

## 3. Analysis of human factors' influence on the operational safety

### *3.1 Aim and Objectives*

The railway operation has got – like all the modes of public transport – high safety requirements. They lead on the one hand to high technical safety and a complex safety case of new systems and on the other hand to the need of well-trained staff. The migration to a new technical system like ETCS as well as the modification of the operational rules can lead to hazardous situations. They can result from two reasons: First from the reason that the operator has to use a new, unfamiliar user interface. The second more important reason could be that a new safety concept is behind the new system and the accompanying operational rules, so that the operator has to change his behaviour generally.

Consequently the objectives for the design of new user interfaces, taking into account the knowledge about human factors, are twofold. One aim is the minimisation of risks and hazards linked to them. The other ambition is to create a convenient work place for the staff, to provide a healthy work environment. To reach these objectives the optimal workload for all involved persons needs to be found, and the work place has to be designed according to the needs of the activities to be carried out and the duration the personal has to be on its workplace. It is also not possible for the signaller as well as the driver to stop and have a look at the manual before taking the next action, which would cause unacceptable delays or even hazards.

### *3.2 Information about the performance of the operators*

The influence of these factors can be investigated by examination of several psychological and physiological data, gathered in tests in the laboratory.

The following list shows a number of information that are of interest for the design of the work places for driver and operator:

- response time;
- psychological and physiological demand (when is the staff mentally overloaded or underloaded);
- visibility of sings and signals;
- recognisability of given information (duration from perception of sign to recognition of information);
- unambiguousness and comprehensibility of information
- clearness and understandability of rules.

### *3.3 Approach*

A driver’s desk and an interlocking operator’s work place have been integrated in the lab for the analysis of human factors and ergonomics. The driver’s desk and interlocking operator’s work place will provide the possibility to record the performance data for the evaluation of operational scenarios and related instructions. Furthermore information about suitable designs for the work places, signs and signals can be obtained. In addition tests can be run to evaluate the performance of the personnel in normal and extreme operational and situational scenarios, while neither the personnel nor other persons nor material is in danger.

The research in the field of human factors in the railway domain will benefit from the knowledge of psychologists in the Institute of Transportation Systems of the German Aerospace Centre (DLR). For the analysis of human factors and ergonomics in the RailSiTe® the experience gathered by the institute’s staff in their work with driver assistance systems in the automotive field, the psychological examinations and evaluations of data, collected in field tests, will play an important role.

The possibility to investigate the behaviour of drivers and operators in a laboratory allows examining the behaviour of different persons in exactly the same reproducible scenarios and situations as often as necessary. It is also possible to change the scenario in small steps and examine the influence of every single change or the combination of certain factors. Furthermore the normal railway operation is not affected by the tests, i.e. no delays or hazards are caused by the tests.

By means of cameras and other sensors the reactions of the test persons are recordable. The recorded data can be evaluated from different points of view and provide real-time information about the reactions, while surveys during a test distract the person under evaluation from his task and questionnaires, filled in after the test, can provide only information retrieved from the memory of the interviewed.

Objectives of the investigations can be e.g.:

- The design of work places and driver desks,
- The design of signs and optical and acoustical signals,
- The avoidance of disadvantageous backgrounds for signs and optical signals,
- The optimisation of mental workload of operator and driver, to avoid mental overload and underload,
- The optimisation of operational rules, e. g. to minimise ambiguous rules and misunderstandings,
- The validation of usability, ergonomics and human factors of automation approaches,
- Experiments related to operational stress and workload of the operators,
- Experiments to safety-critical errors of the operators,
- Knowledge about the influence of medicinal drugs or alcohol.

To gather information about the performance of the personnel in normal as well as unusual situations examinations can be carried out as long-time stress tests. Also extreme situations with bad vision, limited adhesion or operational situations, such as many delays or blocked tracks, can be simulated by the appropriate behaviour of the simulator and the simulated environment. In this way situations can be found that cause high stress for the personnel and can particularly lead to human errors. With the knowledge gained from these examinations technical devices to support the staff in these situations by providing suitable help or information can be evaluated and optimised.

### *3.4 Sensors, measured data and methods*

For the examination of factors that influence the human behaviour and the performance, a variety of sensors can be installed in the laboratory, according to the requirements of the particular method of investigation. There are two different purposes for the use of sensors: first the acquisition of information about the facts the operator has recognised and done, and second the acquisition of the physical and psychological status of the operator.

For the first purposes are classical logging facilities used to log the inputs and outputs of the system, but in addition an eye tracking system can be used to acquire which events, system outputs and optical signals could be recognised by the signaller or driver.

In the special interest for the second purpose are data about the activity of muscles, in particular the heart, the resistance of the skin, the electrical activity of the brain, and the eyes. From these data information about the performance of the test person can be deduced. To gather these data a number of methods are feasible.

Other methods and tools coming from psychology can be used to identify the subjective rating of the situation.

## 4. Summary

One of the first independent operational labs for the testing of interoperability and conformity will be the RailSiTe® of the German Aerospace Center (DLR) in Braunschweig. In the RailSiTe® independent tests, e.g., of ERTMS/ETCS implementations and operational strategies according to the European Requirements and Standards can be performed. The train movement and the infrastructure are realised by means of simulation as well as all the inputs from the driver and the operator. As a basis for error representation and injection specific transmission error generators have been developed. For test automation specific concepts are used to ensure realistic and reproducible testing. For the evaluation of the human factors' influence on the safety of the operation a set of methods and tools coming from the psychology are prepared to be used in combination with the RailSiTe®.

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