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Database-supported methodical approach for the development of a toolchain for the evaluation of ATO functions using a scenario-based test methodology

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Abstract

Billions of test kilometres are required to validate highly automated driving functions. For economic and organizational reasons, this is not a sustainable solution. To give a remedy a scenario-based approach is pursued in which all possible eventualities are described in scenarios and first tested using simulative tools. Due to the large number of scenarios and the demand for completeness, it is necessary to establish a toolchain for accurate and efficient implementation. Before individual tools can be defined, the theoretical work steps and interfaces of the test methodology must be determined and specified. By reason of the small amount of measurement data available from the real railroad field, a knowledge and process orientated database-supported approach is followed. The generation of scenarios as well as the definition of requirements and the development of simulative and real tests are based on self-recorded measurement data and a well-founded knowledge base. In addition, when defining the chain links, it must also be considered that existing programs for simulating scenarios were primarily developed for the automotive industry. Adapted to existing toolchains from the automotive industry, an iterative test methodology for the evaluation of Automatic Train Operation functions is developed. The centre in the form of databases are the compiled data and insights of different chain links. At the beginning of the toolchain, prior test cases and measurements are performed in order to create a deep understanding of the specific railroad application and to fill the database with qualitative data. Following this, the scenario-based test approach is implemented and the execution of the defined test cases is realized iteratively as a simulation and in the field. In addition, two virtual data manipulation approaches are followed to increase

the level of reliability of the system under test. An evaluation of the tests and risk assessment determine the quality of the results and either lead to a contribution of the safety argumentation or extend the database with the gained knowledge.

Keywords: Scenario-based testing, test methodology, Toolchain, Automatic Train Operation, automated driving.

1 Introduction

The Paris Agreement [1] is the first-ever universal, legally binding global climate change agreement, adopted at the Paris climate conference (COP21) in December 2015 ratified by EU and its member states. As a result, the German Federal Climate Protection Act aims to reduce CO2 emissions from transport by 48% by 2030 [2]. Furthermore, greenhouse gas emissions from private motorized transport are approximately 3 times and from road freight transport approximately 6,6 times higher than from rail transport [3]. Hence, rail transport is the more environmentally friendly mode of transport. Nevertheless, in the years from 1991 to 2019, an increase of about 2% in proportionate passenger transport performance and even a loss of about 1,5% in freight transport performance took place for the German railroad [4, 5].

A look at EU-wide statistics shows a similar picture. Since 2010, the share of rail in freight transport in the EU-28 countries decreased by about 0,5%. Road freight transport has increased 1,7% in the same period. In passenger transport, railroads gained only 1% during the period, whereas private motorized transport showed almost no change in passenger cars and a small loss in buses [6, 7]. The German government aims to increase the share of rail freight transport [8] from 19% to 25% and double passenger haulage performance [9] by 2030. This increasment represents a major challenge when looking at the mentioned development of the last almost 30 years. Furthermore, the cost of marshalling of mixed freight trains share about one third of overall rail freight cost, based on [10] and [11].

For implementation, progress is needed in digitization and automation of the railway system. In the automotive industry, a trend towards automated driving functions has been evident for several years. Rail transport also offers great potential for automation, e.g. automatic train operation (ATO) over ETCS in main line service Particularly in areas where driving is on sight, such as marshalling yards, additional requirements on ATO systems occur.

To ensure automated systems are working safely and meeting all requirements, they must be tested extensively. The development of a test methodology for automated railroad vehicles is therefore a high demand.. However, the toolchain for testing ATO-functions must be developed for the special case of track-bound traffic and its particular requirements. Besides, the rather less advanced development of automation in rail transport compared to the automotive industry offers a challenge.

2 Methods

Toolchains are used as a common approach for testing highly automated driving functions. This involves a process description starting with the definition of the function to be tested and ending with the evaluation of an executed test case. The individual links in the chain can thus be considered and developed separately as standalones. The individual steps for testing a highly automated railway vehicle are listed below in their methodology.

Data handling is a key task for the development of the methodological toolchain. The most important source of data is an extensive knowledge database, which is essential for the definition and execution of further links in the chain. For this, an extensive accumulation of specific knowledge takes place through literature research, the state of the art, guidelines, process flows, experiences from similar projects and targeted inquiries and interviews. Another important aspect of data handling is the management of the recorded measurement data. In order to be able to use the data for all further links in the chain, it is restructured into a uniform format and stored in the database in a sorted manner.

Three test environments are applied to the test approach of automated rail vehicles. First, tests are conducted in a delineated real-world environment in order to collect impressions of the railway-specific application area. This testing field is also called Real-LAB. On the one hand, different sensor systems are tested for their suitability for railroad applications, and on the other hand, railway-specific objects are examined within the sensor system. In the actual test area, simulations in the LAB-environment as well as tests in the real FIELD-environment take place in a parallel iterative test run. This approach offers the possibility to test a large part of the tests cost-effectively in the simulation and, based on the results, to retest critical test cases in the field. In addition, tests are performed with manipulated data using Adversarial Examples, Explainable Artificial Intelligence and modified Lidar data.

Within the scenario-based approach the operational conditions are defined in a 6-layer model [12] adapted to the rail sector. The six layers are the rail-level, infrastructures, temporary changes of the first layers, objects and maneuvers, environment and digital information. All elements occurring in the operational area are captured, assigned to a layer and, if necessary, parameterized. On this basis, the scenarios are created in several degrees of abstraction, as comprehensively as possible, and stored in the database.

3 Results

In Figure 1 is shown the integrated methodical toolchain for a scenario-based testing method of automated rail vehicles. Within the toolchain, the individual links are brought together by defining interfaces to form the overall methodology. Each process step has a return to the database to expand it with the results and experience gained.

In the railroad sector, data sources of real measurement data are marginally small. For this reason, a process-oriented knowledge-based approach was used to generate the scenarios comprehensively. The railroad is structured as a separate transport network and operational regulations and processes apply to the execution of activities within railroad business. Thus, the tasks and derived use cases of the system under test can be easily defined, create a manageable framework of the scenario definition and are the basic input to the methodology and scenario generation.

The preceding step of the Real-LAB Testing allows on the one hand to test sensor technology for the applicability in the railroad environment and on the other hand to record qualitative measurement data.

Based on the information from the databases pass/fail-criteria are defined and in combination with the created scenarios extended to test cases. These form the input for the actual test implementation. A scenario editor maps the described situations in the simulation. For the extensive simulative test implementation, a photorealistic simulation is built using the recorded measurement data. Through parallel testing in the field, the knowledge gained there can be used to improve the simulation quality.

Using the pass/fail-criteria and the output of the simulation and field tests, an automated evaluation of the test cases can be performed.

Within the VAL project at the Institute of Vehicle Technology Nuremberg, the automation of a hump locomotive is being tested. The tool development is done under consideration of the tasks and requirements of the system. However, the individual chain links and interfaces are constructed in such a way that a testing of other systems or requirements can be easily extended.

Due to the development starting from the scenario definition up to the simulative test execution, interfaces can be defined and adaptations to other use cases in the railroad sector. The test methodology offers great potential for further expansion and creates a qualitative possibility to comprehensively test highly automated driving functions of rail vehicles according to a scenario-based approach.

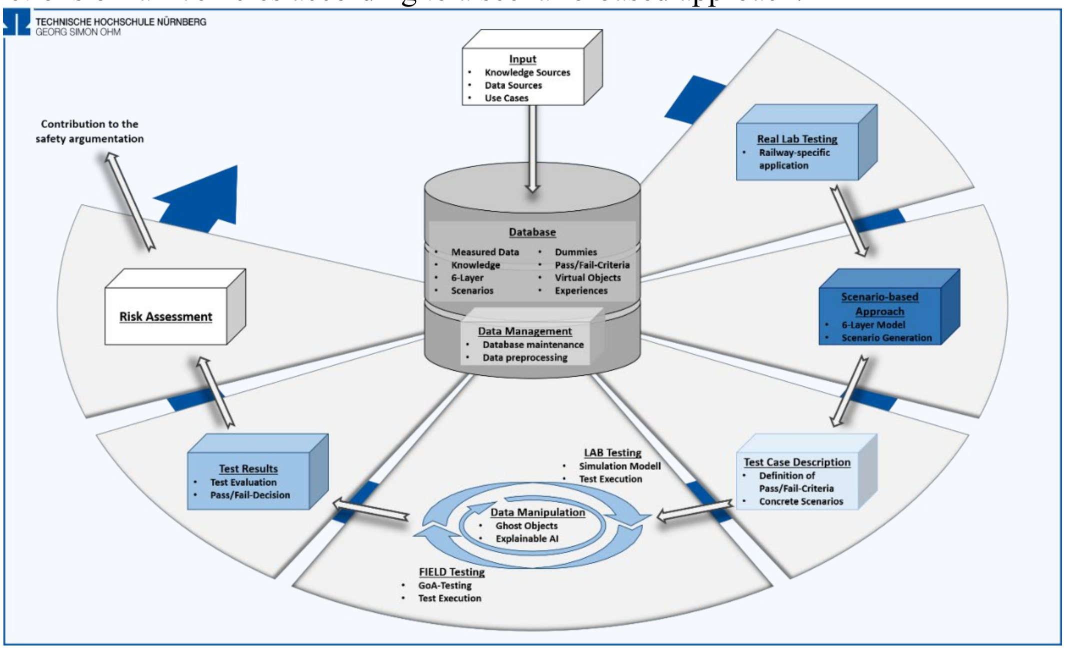

Figure 1: Methodological Toolchain for testing highly automated rail systems.

4 Conclusions and Contributions

The built toolchain offers the possibility to contribute to the safety argumentation of highly automated rail vehicles. Currently, the railroad sector is still at the beginning of extensive automation and it is necessary to develop reliable test methodologies. These can be a support in the further development of highly automated driving systems for rail vehicles.The test methodology to be applied is still under development and will be finalized within the VAL project. For the applications of the automated humping locomotive, the methodological approach promises a qualitative test result. However, the toolchain has to be examined for potential weaknesses within the development. In addition, the adaptability to other application areas and systems must be demonstrated and implemented.

In the current development process, it has already been possible to develop an extensive knowledge base and to establish the methodological approach for the process-oriented derivation of the scenarios. The 6-layer model adapted for use at the marshalling yard forms the basis of the scenario elements. Through extensive accumulation of the processes and tasks in shunting operations, it is possible to divide the system into several use cases. Based on the use cases and elements of the 6-layer model, an extensive scenario generation can be performed by a logical combinatorics.

The main focus in the current project step is on the development of the simulation environment. The resulting program in itself consists of several individual process steps. The system under test is provided as a black box for the simulation. In order to work independently of the test system, the simulation is developed as a closed-loop standalone and outputs system-dependent information via a defined interface. In addition to purely simulative tests, it is also possible to provide external interfaces and to enable hardware in-the-loop tests.

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