Digitalization and automation for driverless regional trains: The safe.trAln research project

Martin Rothfelder, Cornel Klein, Thomas Waschulzik, Marc Zeller | February 2023
Motivation and Context
Potential of digitalization and artificial intelligence for central aspects of rail transport

Tremendous pressure to **significantly reduce CO₂ emissions** in transport (the transport sector is expected to reduce its emissions by 40 to 42% compared to 1990 to 98 to 95 million tons of CO₂ in 2030

- Rail capacity
- Flexibility and comfort for the passenger
- Cost efficiency
- Availability
<table>
<thead>
<tr>
<th>Grade of Automation</th>
<th>Manual operation</th>
<th>Highly automatic operation</th>
<th>Fully automatic operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>GoA 1</td>
<td>Manual train operation with driver Supervision and control train operation (SCO)</td>
<td>Provision of driving recommendations for energy-optimized train runs</td>
<td>Driver drives completely manually</td>
</tr>
<tr>
<td>GoA 2</td>
<td>Automatic train operation with driver Semi-automated train operation (STO)</td>
<td>Automatic train operation after driver interaction</td>
<td>Obstruction detection by driver</td>
</tr>
<tr>
<td>GoA 3</td>
<td>Automatic train operation without driver Driverless train operation (DTO)</td>
<td>Automatic train operation</td>
<td>Central or automatic train dispatching</td>
</tr>
<tr>
<td>GoA 4</td>
<td>Automatic train operation without staff Unattended train operation (UTO)</td>
<td>Central monitoring or automation functions for handling of train disturbances and emergency situations</td>
<td>Train monitoring and intervention in emergency situations by driver or train attendant</td>
</tr>
</tbody>
</table>

**Steps in the introduction of highly and fully automated driving**

GoA Grade of Automation

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Potential of “Fully Automated Operation”

- Automatic obstacle and hazard detection as well as the reduction of unproductive times (paths from the train driver (TF) to and from the vehicle)

- Densification of the timetable, e.g., by splitting vehicles that would otherwise run in multiple traction or additional connections in off-peak times

- Increased flexibility in timetable design

- Faster achievement of normal operation in the event of malfunctions, as replacement vehicles are provided more rapidly
**Metro Traffic**

- One operator for infrastructure and trains
- Passenger transport only
- Identical trains with similar properties
- Simple infrastructure closed and access restricted
- Integrated systems - complete solution from one manufacturer

**Mainline**

- One operator for infrastructure and trains
- Mixed transport i.e. regional, express & freight transport
- Different trains with different properties
- Very complex infrastructure open and publicly accessible
- Network-wide interoperability - signal solutions from different manufacturers
Automation in the Railway Domain

GoA¹

0/1
- Metro Berlin
- High-speed: PZB/LZB/ETCS
- Commute: PZB/LZB/ETCS
- Siemens Tram Assist
- No product available today – R&D

2
- Metro Munich
- Thameslink: ATO over ETCS

3
- Metro Sofia CBTC
- London Docklands LRT
- Mireo2021
- Aixam “Real-labor” BS
- Thales R&D

4
- U-Bahn Nürnberg Driverless
- Metro Paris CBTC
- Rio Tinto AutoHaul Australia: ATO over ETCS
- Depot: AStrID
- Shunting
- Highly automated Commute: BerDiBa
- AST Demonstrator

¹ GoA – Grade of Automation (IEC 62290)
² ODD – Operational Design Domain – Operation conditions under which an autonomous system is specifically designed to function

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Establishment of a system for GoA 3/4 operation

Technical key challenge: Obstacle/object detection in a natural environment
Getting approval for a perception system is challenging!
Obstacle detection/AI

According to the current state of the art, we assume that e.g., obstacle detection can only be implemented using the methods of ML (Machine Learning – a field of AI Artificial Intelligence).

Legislation

- High-performance systems are highly intransparent
- New: European AI ACT-high-risk application
- Unclear regarding transparency, robustness

Transparency

- No established tools and processes
- Extensive research with little progress
- New error domain in assessment
- Research regarding transparency

Processes und tools

- Requirements for assessment
- Examples

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Integrated Development

...of guidelines and methods for the safety assurance of artificial intelligence in autonomous regional trains by the development

A Safe AI-based functions for a driverless regional train

B Method to enable the assurance of AI-based functions in terms of safety

C Guidelines and concepts to enable certification of AI-based functions in the railway domain

Proof

Of the feasibility of the guidelines and methods with a real case study
safe.trAIn takes up the results of current research and development activities and develops them further

**Rail**

**Shift2Rail** (Partner: DB, SNCF, Alstom, CAF, …)
- X2Rail, LYnx4Rail, Connecta
  - Conceptual development for GoA2-GoA4
- Tauro
  - Concepts for a future automated and autonomous European railway traffic

**BerDiBa**
- Digital twin for railway operations; Environment detection and obstacle detection in the railway domain using AI methods
- Participation of SMO in the consortium with TU Berlin (BBI)/DLR/DB Systemtechnik

**ATO-Sense & ATO-Risk**
- Development of a safety approach for automated rail vehicles

**Automotive**

**KI-Absicherung:**
- Methods to improve the performance of ML-based safety-critical functions (e.g., pedestrian detection)
- Generic strategies for deriving detailed acceptance criteria for ML-based automation function in cars
- Some methods can be transferred to safe.trAIn
- Knowledge transfer through joint project partners (Fraunhofer IAIS/IKS, Merantix Momentum, BIT Technology)
Planned Exploitation

Commercial Utilization

Automation solutions for the highly automated and driverless operation of rail vehicles
- Siemens collaborates closely with the railway companies DB and SNCF at EU level as part of Shift2Rail
- Development of tools for the development and validation of AI-based functions in the environment of safety-critical systems

Standardization

Safe.trAIn provides important contributions to current standardization activities
- **AI related standards**: ISO/IEC JTC 1/SC 42, ISO/TC 204, CEN/CENELEC JTC 21
- **Railway standards**: CLC/TC9X, IEC/TC9 with EN50126, EN50657, EN50129, TSI CCS 2022 of the ERA for offering rail vehicles on the market within Europe (CSM-RA)
- **DIN VDE SPEC**
The obstacle detection system will prevent harm from passengers in the vehicle and persons on the track.

Heavy obstacles include, but are not limited to trees, rocks, cars, trucks, other trains, flooding, landslide...

Persons on the track include, but are not limited to workers, trespassers, playing kids, ...

Current safety objective of the rail operation acc. to german regulations (e.g. DB RIL 408.2341)

The driver has to prevent harm from the train.

Probably needed for public acceptance of driverless train operation.

Further aspects to consider

Action
Stopping vs. braking vs. honking

Collision
Obstacle in-gauge vs. off-gauge vs. neighboring track

Track context
Free track vs. station-starting vs. station-approaching vs. level crossing...
Project goals – with main focus

Requirements

Project management

Standardization and dissemination

Methods to prove trustworthiness of AI-based functions

GoA 4 train architecture incorporating safe, AI-based functions

Virtual V&V platform, safety assessment

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WP 2: Overview/Preliminary Results

WP 2: Methods to prove trustworthiness of AI-based Functions

Goal:
Development of methods to ensure and verify the trustworthiness of AI functions, optimized for the use case of a driverless regional train and the criteria which need to be fulfilled for the safety assessment

- State-of-the-art analysis focused on different aspects of safety assurance methods for DNN
- Sub-work packages tackling the different aspects of safety assurance methodology for DNN
- Current key activities
  - Fault tree analysis based on the system architecture
  - Identifying possible Insufficiencies in the ML-Based Systems
  - Selecting & implementing metrics for argumentation on compensating these insufficiencies

Fault Tree Analysis

Identify ML-Insufficiencies
- Lack of performance
- Lack of robustness
- Lack of scenario coverage
- Etc. ...

Compensating Insufficiencies
- Performance metric
- Robustness metric
- Scenario coverage metric
- Transparency metric
- Etc. ...

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Work package 3: Overview/Preliminary Results

WP 3: Safety architecture for AI based functions of driverless regional train operation

**Goal:**
Development of integrated requirements and architecture incl. safety case for an AI based obstacle detection system of a driverless regional train

### Requirements
- Definition of requirements for a driverless train operation (incl. safety requirements)
- Definition of an AI based obstacle detection system of a driverless train (incl. safety requirements)
- Definition of ODD

### Architecture
Development of an architecture for an AI based obstacle detection system of a driverless train
- Architecture for:
  - Vehicle
  - Obstacle detection system
  - Sensor fusion
  - Sensor system

### Implementation
- Development of a hardware prototype for the sensor system
- Implementation of a safe obstacle detection system incl. safe sensor fusion and ML-functions

### Safety
Definition of a safety case for the architecture of a driverless regional train

- Challenge: Converge safety argumentation and safety architecture

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First draft of requirements

Challenge: Transfer qualitative requirements (derived from the performance of a driver) to measurable requirements for a system (What is hazardous?)

First draft of architecture with definition of interfaces between the building blocks

- Definition of camera criteria
- Testing of the impact of external conditions on the camera calibration

First draft of safety case concept

Challenge: Converge safety argumentation and safety architecture

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WP 4: Virtual V&V Platform, Safety Assessment

**Goal:** Development of a virtual V&V platform ("virtual test field") to evaluate the project results and to create and assess a safety case using the object detection of a driverless regional train as a case study

**First Results**
- Definition of a SafeMLOps process for autonomous regional trains
- Specification of a simulation-based “virtual test field” to create evidences for the safety case
- Creation of first test scenarios und setup of a tool-chain to create synthetic test data as input for the virtual test field

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Questions?

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