Knowledge-Based Approach to Generate Scenarios for Testing Highly Automated On-Sight Train Operations

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Abstract: Scenario-based test methods are cumulatively used for developing and testing highly automated railway vehicles, similar to the automotive industry. However, due to significant differences between the two technologies, existing approaches in the automotive sector cannot be directly applied to railways. Therefore, it is necessary to develop revised and new processes and methods that are tailored to the rail sector.
The primary step in scenario-based testing is to set up appropriate test scenarios. A significant challenge faced by the rail industry is the limited availability of measured data from actual railway operations. For this reason, knowledge-based data sources need to be primarily used and considered in the scenario generation process. This paper presents a basic approach to define sufficient quantity of test scenarios for highly automated railway vehicles, using as an example a sensor-supported system for on-sight train operation. The approach uses the system definition of the automated system as input, includes the operational design domain, and considers railway-specific data through formalities and knowledge sources. Scenarios are then systematically derived in three steps: description, combination, and derivation. In the end, a set of testable scenarios is generated that can be used for virtual and real field testing of automated train operations.

1 INTRODUCTION

The rail system is a high priority in the current focus of politics and society. The system offers low greenhouse gas emissions and high energy efficiency through the use of electromobility, as well as high levels of traffic safety and capacity with low land consumption for passenger and freight transport. Despite the social and global advantages, the proportion of rail passenger transport performance has stagnated in recent years, and rail freight transport has even decreased in Europe. This is primarily caused by the low economic performance of the rail system. However, Europe is expected to experience a significant increase in the rail sector. To manage this growth, rail transport must increasingly focus on digitalisation and automation. (Zintel et al., 2023).

The development of highly automated driving systems (HADS), has a high priority in current research and industry. In addition to, for example increasing driving comfort in the automotive sector and compensating for the lack of personnel in the railway sector, automation primarily improves the capacity of transport systems with at least same levels of safety and reliability. With the establishment of the SAE J3016 standard (SAE International, 2021) of the automotive industry in 2014 and the IEC 62290-1 standard (IEC, 2006) from 2006 as the Grade of Automation (GoA) level in the railway industry, both have created a detailed description and categorisation of HADS in terms of their degree of automation.

In addition to the focused development of HADS, extensive testing of these systems is necessary. Alternative test approaches, such as scenario-based testing, are increasingly coming into focus. For automotive, extensive research projects have already been launched, such as the Pegasus project family (Pegasus, 2020; VVM, 2022). Despite early high levels of automation, such as the first GoA4-System on the Port Island line in Kobe, Japan in 1981 (Powell et al., 2016), there are still few established research approaches or test methods and strategies for demonstrating the safe operation of Automatic Train Operation (ATO) Systems, especially for not restricted and intersection-free rail traffic. The similarities between the definitions of automation

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levels suggest comparable testing approaches. Also, the grade of complexity of ATO-Systems is comparable to that of automated road transport. There are parallels, particularly in the area of on-sight train operation, where similar sensor systems are used. The focus is on monitoring the environment and keeping the track clear. Established approaches and tools of the automotive industry can serve as inspiration, but different Use Cases (UC) and system boundaries require a review and revision as well as a derivation of new methods for the test process. When it comes to rail-bounded driving, it is important to consider additional knowledge sources and processes due to varying regulations, physical conditions, and UCs.

During test development, a strong focus is placed on the definition of appropriate scenarios. In this context, there are scenarios in rail traffic that are very similar to those in road traffic, such as situations involving signal detection, passing groups of people (station entrance, city traffic) or simple speed changes. However, typical road traffic manoeuvres and situations such as overtaking, following or mixed traffic (cars, cyclists, pedestrians, etc.) are only used to a limited extent in the rail sector or are not possible due to the system. In contrast, there is a greater focus on data and radio transmission scenarios or on monitoring the clearance gauge. Furthermore, the use of a separate traffic network, interfaces to other traffic participants (gated and ungated level crossings, entry and exit of passengers at regularly scheduled stops) as well as regulations in train operation (automatic train control, block signalling, train radio) have to be considered. Rail operations are limited due to the use of rail-bound vehicles and long braking distances caused by high masses and low coefficients of friction in wheel-rail contact. Equipping test vehicles and demonstrators and carrying out real field tests and measurements involves greater effort and cost in the rail sector. Rail vehicles can only be driven by trained personnel, and the availability of vehicles and track sections for system testing and data recording is also a major challenge. This has an impact on the paucity of real-world measurement data. Vehicle and environmental data from real drives and situations are a useful source for creating appropriate scenarios. In the automotive industry there are many data sets available, some of which are publicly accessible, due to extensive endurance campaigns (Guo et al., 2018). This input is not available in the rail industry, which is why it is not possible to derive test scenarios directly from measurement data.

Considering all the reasons mentioned above, this paper shows the current state of research on a methodological approach for the knowledge-based generation of sufficient scenarios for testing ATO. The focus here is on the aspect of perception in on-sight train operation, in which the driver has full responsibility for track monitoring in the non-automated case. The objective of this paper is to demonstrate a method comparable to the state of the art in the automotive industry and to advance the development and testing of HADS for rail vehicles. At the beginning some basic information about scenario-based testing are mentioned. Afterwards the generation process for relevant railway scenarios is introduced.

2 SCENARIO-BASED TESTING

Due to reasons of economy, clarity, time efficiency, and organization, conventional test approaches, such as distance-based testing, are no longer practical. Instead of executing millions of test kilometres in the real world, potential eventualities in the application field of the HADS are described as completely as possible through different scenarios. These are tested in a coordinated process first in a virtual environment and additional partially in the field. (Schuldt, 2017). The sections below provide basic information on the term of a scenario and scenario generation methods.

2.1 Scenario Characterization

To gain a better understanding of a scenario, the terms scene, scenery and situation are described. A scene is a snapshot of the environment, including the scenery, dynamic elements, actors, and watchers. The scenery contains the stationary elements that make up the fundamental environment of the scene. Finally, the situation describes the functional information through the scene, such as interactions and states of different movable elements, as well as missions or tasks. Starting with an initial scene, changes described by the situation and ending with a final scene, a scenario is a temporal development of scene elements. Different scenes are combined by actions and events. (Ulbrich et al., 2015).

The description of a scenario can be presented at different levels of abstraction, depending on the specific UC. In the Pegasus project, three scenario levels were defined based on the work of (Bagschik et al., 2017). The functional scenario provides the most abstract description, where the situation is specified in a semantic form. The logical scenario then concretises the semantic variables using parameter spaces. Finally, the concrete scenario is formed as an instance of the logical scenario using a variation of these parameters. All variables have detailed parameters, and the scenario is fully described. (Bagschik et al., 2017; Pegasus, 2020).

2.2 Scenario Generation Methods

There are several cross-domain approaches to derive scenarios. This paper focuses on methods of the automotive sector because of its thematic proximity to railways. The survey conducted by (Riedmaier et al., 2020) provides a general overview of scenario generation and presents various approaches to derive scenarios. In particular, data-based and knowledge-based approaches have proven to be effective for scenario generation.

To create a set of scenarios from recorded field data, a sufficient amount of real driving data must be available. Recording this data requires extensive endurance projects and data management. The use of real driving data ensures that all derived scenarios are realistic and applicable. However, it is important to note that the scenario set only covers what the data set includes, and critical situations may be missing.

In the knowledge-based approach, having a solid foundation of knowledge data is essential. The information collected from various sources must be linked appropriately to generate scenarios. One common method is the use of an ontology (Bagschik et al., 2018). Other approaches include equivalent or specially developed combination languages (Fremont et al., 2018). At (Menzel et al., 2018), a detailed example of the knowledge-based generation process is mentioned based on (Bagschik et al., 2018). Semantic scenarios are generated using an ontology, specified with the 6-Layer Model presented in (Scholtes et al., 2021) and then converted into concrete test scenarios for use in OpenSCENARIO (ASAM e. V., 2024) by parameterizing the semantic variables. To utilize the distinct advantages of data-based and knowledge-based scenario generation, (Hao et al., 2023) propose an approach that combines both methods.

Based on current research and definitions, a railway-specific approach for scenario-based testing is introduced, taking into account the requirements of the railway system and the challenges of data generation. The following chapter presents the developed method and its individual components.

3 GENERATION OF RELEVANT RAILWAY SCENARIOS

ATO can be used for different fields of application. A methodical approach for the development of a tool chain for scenario-based testing of ATO-Systems was presented at (Greiner-Fuchs et al., 2022). Based on this, our paper outlines a method for generating appropriate scenario sets. Figure 1 shows the proceeding of the Scenario Generation. The following subsections present the current state of our research on the knowledge-based scenario generation process. First, based on the ATO-System, the associated Operational Design Domain (ODD) is discussed. This is followed by the process of creating a knowledge-based dataset of the necessary scenario elements. The Scenario Description is then introduced as the basis for Scenario Combination. During this part, the combinatorics and actual generation are discussed, from which the scenario set is finally created. Lastly, the derivation of concrete test scenarios is described.

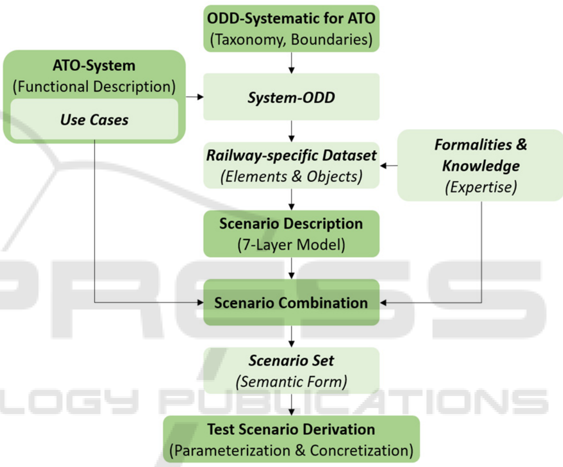

Figure 1: Proceeding of knowledge-based Scenario Generation for ATO-Systems.

The structure should ensure a high degree of automation and be used for different kind of ATO-Systems. The challenge is to fully integrate and consider all necessary knowledge sources while ensuring consistency throughout the scenario generation process. In our research, the focus is on the evaluation of automated on-sight train operation that work in combination with sensor units. In main line operation, the use of visual track monitoring is limited due to the long braking distances. Nevertheless, there are still situations that require sensor-based environment detection in driverless operation. These include, for example, shunting movements for train preparation, monitoring train entry and exit at platforms, or critical situations where safe operation cannot be guaranteed by train control. In addition to main line operations, other important applications include operating in shunting yards, industrial and port facilities, and the operation of trams or other slow-moving rail vehicles. For the application testing of the method, we focus on automated shunting operations (ASO).

3.1 Operational Design Domain

The first step of the generation process, located in the upper part of Figure 1, is to define the boundaries and scope of the HADS. For this purpose, an ODD of the ATO-System is formulated. Within the ODD, the area of application of the HADS is determined, thus defining the conditions under which the system can be used. For automotive applications in this purpose, the PAS 1883 standard (British Standards Institution (BSI), 2020) defines the fields of scenery, environmental conditions and dynamic elements. The standard provides a taxonomy as a basis for setting up the System-ODD.

For the formulation of a railway-specific ODD-Systematic the PAS 1883 standard is used as input and system definitions from current research on ATO applications are analysed. Initial approaches to the definition of an ODD in rail transport can be found, e.g., in (Tonk et al., 2021), where a proposal for the definition of an ODD for securing remote driving trains based on the PAS 1883 standard was introduced. Another approach by (Meng et al., 2021) presents an ODD for high-speed ATO-Systems in the context of an analysis of derived scenarios.

In the test development of the ASO-System, we created a first draft of an ODD, which is shown in Table 1. The ODD is based on the PAS 1883 standard, with specific adaptations and extensions for the field of ASO. In relation to the functional requirements of the system, implicitly the specifications, as well as the operational area as shunting yard in Germany, the individual aspects of this ODD are determined. The three categories scenery, environmental conditions and dynamic elements are defined to the extent necessary to represent the scope and operating conditions of the ASO-System. Amongst the surroundings, conditions and occurring elements under which the system is to function faultlessly, information is provided on data

Table 1: ODD for Automated Shunting Operations.

Scenery		
Zones	Shunting Yard (arrival tracks, hump, distribution zone, classification tracks)	
	Defined Areas (geo-fenced area: shunting yard munich north, interference zones)	
Drivable Area	Type (EBO rail network: shunting yard track)	
	Geometry (horizontal plane: straight, curve; transversal plane: single track, banking; longitudinal plane: up-slope, down-slope, level plane)	
	Rail Specification: • rail dimensions (standard gauge) • clearance gauge (G2 big boundary) • rail system (rail type: standard rail; sleeper type: wood, concrete, none; track bed: ballast, slab track)	• regular track and counter track • parallel sections • multi-rail track (two-rail track) • rail colour (steel/rust)
	Signs: • regulatory signs (track-side signals: Hp0, Hp1, Hp2, Sh0, Sh2, Hp0 with Sh1, HP00 with Sh1) • warning sings (tail light)	
	Surface Type (rail)	
	Surface Features (rail position error, plant covering)	
	Induced Track Surface Conditions (icy, flooded railways, mirage, snow on drivable area, standing water, wet track, surface contamination)	
Junctions (switch, straight diamond crossing, diamond crossing with slips)		
Special Structures (bridges, pedestrian crossings, ungated level crossings, rail infrastructure, fences)		
Fixed Track Structure (buildings, lamp pole, catenary, gantry, vegetation)		
Temporary Track Structures (construction sites, speed restriction section, materials, cargo)		
Accidents (fire, derailed vehicles, catenary hanging down, foreign object at catenary, overturned structure)		
Environmental Condtions		
Weather (wind, precipitation, temperature)		
Particulates (non-precipitating water droplets or ice crystals, sand and dust, smoke and pollution, volcanic ash)		
Illumination (day, night or low-ambient lighting condition, cloudiness, artificial illumination)		
Connectivity	Communication (vehicle to infrastructure, train control system: GSM-R, hump automatic)	
	Positioning (GNSS (Global Navigation Satellite System), landmarks, balise)	
Dynamic Elements		
Operational Mobility	Non-railway Dynamic Elements (density of agents, volume of traffic, flow rate)	
	Railway Agents (train occurrence on sidings, train movement, train length)	
	Agent Types (vulnerable users, animals, railway vehicles, street vehicles)	
	Presence of Special Vehicles (emergency vehicles, auxiliary railway vehicles)	
	Parked Stationary Vehicles and (moveable) Objects (wagons, skid)	
Subject Vehicle		

communication, details on the missions and movements of the ego-vehicle and other dynamic elements. Besides the functional description of the ASO-System, it is also useful to derive its specific UC. These are complementary to the definition of the System-ODD and also serve to derive the test scenarios in an efficient manner. (Hofmeier et al., 2022) describes how UCs for the example of ASO can be derived.

Further research will define a railway-specific ODD-Systematic with the assistance of the ODD for ASO. This taxonomy must be able to map ODDs from all areas of rail transport and represent the limits and scope of a specific ATO-System.

3.2 Railway-Specific Dataset

The System-ODD in combination with railway-specific knowledge sources are used to create a dataset that forms the foundation for the Scenario Description. The dataset must include all entities required for testing in various scenarios. This encompasses a comprehensive list of necessary static and dynamic objects associated with the defined ODD, as well as descriptions of the track topologies to be considered. The dataset thus serves to specify the aspects defined in the System-ODD and provides the foundation for Scenario Generation. The structure and process for filling the dataset can be used across different ODDs, but a separate or customized dataset must be created for each specific ODD.

To achieve comprehensive ODD-specific test case coverage, it is essential to aim for a high degree of completeness when setting up the dataset. This task requires the use of multiple data sources to populate the dataset. For our example of ASO at a German shunting yard, this analysis will consider operational and situational conditions through formalities and guidelines such as the train service instruction (DB Netz AG, 2021), signal regulation (DB Netz AG, 2020), and railway construction and operating regulations (Eisenbahn Bau- und Betriebsordnung: EBO, 1967), as well as existing operational datasets and expert knowledge. Additionally, exceptional cases and potential errors in regular operation will also be taken into account. This will be achieved through the use of statistics on accidents and operational analyses. Examples of well-known sources include the investigation reports of the German Federal Bureau of Railway Accident Investigation and its open dataset on hazardous incidents in railway operations that have been finally investigated (BEU, 2024). Own experiences from system development and recorded data during our research are also considered. Furthermore, small existing public and self-collected measured datasets are used as a supplement. However, the current amount of data is insufficient for a complete measurement-based derivation of scenarios. Therefore, the data serves only as an additional source of knowledge.

3.3 Scenario Description

To set up scenarios, a logical process is used based on the collected objects in the dataset. Following the 6-Layer Model (Scholtes et al., 2021), a railway-specific Scenario Description was published by (Greiner-Fuchs et al., 2023). In this description, a model for rail transport is developed and extended specifically for the example of ASO to the 7-Layer Shunting Model. The model provides the fundamental framework for an organized scenario layout. The entities from the railway-specific dataset are assigned to seven distinct layers. The sorting process is performed simultaneously with the dataset creation, resulting in a sorted database that can be directly applied to the method.

Starting with Layer 1 “Railway system and signals”, the scenario's scenery is first defined. Layer 2 “Stationary objects” defines all non-moving objects that occur in the environment of the situation. Layer 3 “Temporary changes of Layers 1, 2 (& 4)” contains temporary deviations from the previous layers, e.g. due to a tree falling onto the track or also derailed railway vehicles. Last mentioned are usually assigned to Layer 4 “Dynamic objects”, which contains all movable elements. Weather, light and soil conditions can be found in Layer 5 “Environmental conditions”. Layer 6 “Digital information” deals with digital data such as localisation signals, digital maps or the status of railway traffic lights. In addition, Layer 7 “Shunting order” has been added for the ASO-System as a higher-level information and status layer. The shunting order describe the work tasks and the associated movement of the locomotive, including data on the driving route, travel speed in various track sections and track release notification. In addition, indirectly safely occurring objects, such as wagons or shunting staff, can be derived for scenario definition.

When using the method, it is possible to create a wide variety of scenarios based on the sorted database. Thereby, a scenario can always consist of a defined number of objects per layer. The use of this ordered approach is shown in the following Scenario Combination.

3.4 Scenario Combination

The complete scenario set is created by following the structuring and sorting of the scenario description above. Starting from the lowest level of abstraction, the scenarios are implemented in semantic form according to (Bagschik et al., 2017). To achieve this, a program flow combinatorics is developed, which is shown in Figure 2 as a simplified flowchart. In the following, the individual steps of combinatorics are listed and the chosen order of the object combination is explained.

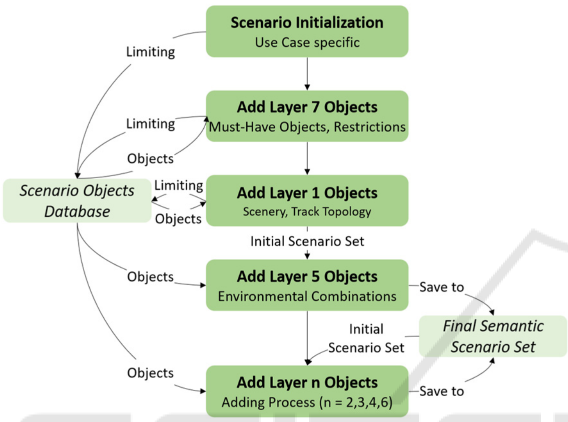

Figure 2: Flowchart - Combination Process.

The first step is the Scenario Initialization, where basic information of the scenario is generated. The objects in the database are also pre-filtered directly, referenced to the specific UC. Unnecessary entities are removed from the combinatorics to increase the relevance of generated scenarios. Based on the UC, additional information through Layer 7 is determined. Safely occurring objects are added to the combinatorics and defined limits, such as speed specifications, are set. The starting conditions of the ego vehicle are also specified. The inclusion of these additional information enables a more targeted and efficient scenario generation. The track topology and scenery are created using the objects specified in Layer 1. During the combination process, the objects are linked in advance and saved as a "Map". These are generated to cover the spatial operation area of the HADS. In addition, the restriction of certain objects from appearing in the defined area limit the object database. By combining the conditions of the UC, Layer 7 definitions and maps, an initial set of scenarios is created. This set is used as input for the subsequent combination process.

During the part of adding Layer 5 objects, each initial scenario is combined with all possible and sensible environmental conditions, following specific rules to ensure logical conditions. For instance, the occurrence of snow is excluded in combination with high temperatures. Each final scenario requires precisely one environmental condition to guarantee unambiguous definitions. This leads to the first final set of semantic scenarios. The objects from the remaining layers are added in ascending order, using the most recent semantic scenario set as input. The newly created scenarios are saved to the scenario set and used as additional initial input for the next layer. Rules for adding the objects are also established with the help of the knowledge sources.

For Layers 2 – 4, the first step is to determine the potential placement of the new object within the scenario. This is achieved by developing a logic of referencing. Starting from the initial position of the ego vehicle, objects are positioned laterally and longitudinally to the movement path. Simultaneously, a check is carried out to identify specific object combinations or irrelevant constellations. It is important to avoid conflicts by ensuring that no position in the scenario is filled twice. Certain objects may have limitations or specific rules depending on their intended use. For instance, there may be a predetermined maximum number of an object allowed in a given scenario, or restrictions on its possible positions. In the case of Layer 3 objects, it is important to use a reasonable combination to determine the maximum number of temporary changes that can occur simultaneously. When dealing with Layer 4 objects, it is also important to consider their movement. Dynamic objects may have a defined trajectory and move within the scene. It is essential to avoid unwanted collisions between objects and ensure that the movement vectors and trajectory paths are properly set up. Furthermore, the mobility of the objects enables additional positioning in relation to the object's orientation and pose. In the final combination section, Layer 6 objects are included. These objects are intangible and do not appear in the scene, but describe states and changes in state of existing objects or provide additional information for the automated system.

Our research currently focuses on elaborating specific combinatorics for ASO. Using the described procedure and the predefined object database, a first approach to completeness can be established. However, it is necessary to set up the combination rules in a well-founded and comprehensible manner and to justify any limitations. The implementation of combinatorics is dependent on the defined ODD and knowledge base. These affect the limitations of the database during the combination steps, as well as the specific rules for adding objects. The basic structure of the combination process can be applied to various ATO-Systems, but object-related specifications and rules must be adapted or supplemented accordingly. In the end the output is a final semantic scenario set that serves as input for further Test Scenario Derivation.

3.5 Test Scenario Derivation

In order to execute test cases, both in the field and in a virtual environment, it is necessary to concretize the abstract semantic scenarios. According to (Menzel et al., 2018), therefore first logical and then concrete scenarios are generated by parametrization. Based on this reliable process, the derivation of test scenarios is described in the final step of the Scenario Generation.

To implement parameterization, each semantic variable must be assigned a defined parameter space that outlines different states of the description. For example, this enables more detailed specification of object properties such as size, speed, and positioning. By defining an increment within the parameter spaces, specific values can be assigned to each variable, allowing for the generation of concrete scenarios for each logical scenario. Finding the appropriate step size is crucial as it greatly impacts the number of concrete scenarios. It is important to strike a balance between generating useful diverse scenarios and avoiding situations that are only slightly diffuse. When establishing a meaningful and logical definition and differentiation in the parameter space, it is important to consider the influence of knowledge sources.

At present, we have analysed the derivation of concrete test scenarios in theoretical form. We are developing a demonstrative combinatorics based on our example of ASO. Based on a first proven semantic scenario set, concrete scenarios will be derived and tested in a railway-specific virtual environment (Schäfer et al., 2023).

4 CONCLUSION

The testing of HADS in rail transport is still in its infancy. New and customised methods need to be developed and proven in practice. This paper presents a general process and structure of knowledge-based railway scenario generation. A proceeding for defining and deriving scenarios in a systematic, step-by-step manner has been introduced. However, further research and work are required to elaborate on the individual sub-steps, in order to verify the methodological approach using the example of ASO. The level of detail in the ODD and the dataset derived from knowledge should be regularly reviewed. The combinatoric requires a formal definition of how individual objects are linked in a given scenario. Specific rules are established based on the knowledge sources to manage this data linkage. For this purpose, a semantic description language is used to define the dependence of the objects. The implementation of the semantic language for the combination needs to be examined more closely. It is crucial to determine whether an ontology or another semantic conversion would be more efficient. Moreover, the combination process must consider object placement and object variation in more detail. It is important to clarify how much variability in object positioning and appearance is required to cause a significant difference in the scenario. This directly affects the number of scenarios generated and the performance of the combinatorics.

Once the process has been fully developed, it is essential to demonstrate its applicability for scenario-based testing. For the ASO example, it is necessary to create a comprehensive scenario database, test it, and evaluate it in a virtual test environment. The results will be used to verify the meaningfulness and representativeness of the generated scenarios, as well as their direct transferability to the field test. Currently, the method offers a theoretical approach to generate specific scenarios in the railway sector. However, it is crucial to conduct thorough virtual testing and practical evaluation to confirm its effectiveness.

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REFERENCES

ASAM e. V. (2024). *ASAM OpenSCENARIO® DSL*. https://www.asam.net/

Bagschik, G., Menzel, T., & Maurer, M. (2018). *Ontology based Scene Creation for the Development of Automated Vehicles*. https://arxiv.org/pdf/1704.01006.pdf

Bagschik, G., Menzel, T., Reschka, A., & Maurer, M. (2017). *Szenarien für Entwicklung, Absicherung und Test von automatisierten Fahrzeugen*. https://www.pegasusprojekt.de/de/lectures-publications

BEU. (2024). *Bundesstelle für Eisenbahnfallunter-suchung*. https://www.eisenbahn-unfalluntersuchung.de/EUB/DE/Publikationen/publikationen_node.html

British Standards Institution (BSI). (2020). *Operational design domain (ODD) taxonomy for an automated driving system (ADS). Specification*. BSI Standards Limited. https://www.bsigroup.com/en-GB/

DB Netz AG. (2020). *Richtlinien 301 – Signalbuch: Ril301*. DB Kommunikationstechnik GmbH. https://www.dbinfrago.com/web

DB Netz AG. (2021). *Richtlinie 408—Züge fahren und Rangieren: Ril408*. DB Kommunikationstechnik GmbH. https://www.dbinfrago.com/web

Eisenbahn Bau- und Betriebsordnung: EBO, Bundes-gesetzblatt II (1967). https://www.gesetze-im-internet.de/ebo/EBO.pdf

Fremont, D. J., Yue, X., Dreossi, T., Ghosh, S., Sangiovanni-Vincentelli, A., & Seshia, S. A. (2018). *Scenic: Language-Based Scene Generation*. Electrical Engineering and Computer Sciences University of California at Berkeley. https://www2.eecs.berkeley.edu/

Greiner-Fuchs, L., Schäfer, S., Hofmeier, T., & Cichon, M. (2023). 7-Layer Shunting Model: Generische Szenariobeschreibung automatisierter Rangierfunktionen. *International Rail Symposium Aachen*, *4. Band*. https://doi.org/10.18154/RWTH-2024-00257

Greiner-Fuchs, L., Schäfer, S., Hofmeier, T., & Cichon, M. (2022). Database-supported methodical approach for the development of a toolchain for the evaluation of ATO functions using a scenario-based test methodology. *Proceedings of the Fifth International Conference on Railway Technology: Research, Development and Maintenance*. https://doi.org/10.4203/ccc.1.13.4

Guo, J., Kurup, U., & Shah, M. (2018). *Is it Safe to Drive? An Overview of Factors, Challenges, and Datasets for Driveability Assessment in Autonomous Driving*. http://arxiv.org/abs/2311.10937

Hao, K., Liu, L., Cui, W., Zhang, J., Yan, S., Pan, Y., & Yang, Z. (2023). *Bridging Data-Driven and Knowledge-Driven Approaches for Safety-Critical Scenario Generation in Automated Vehicle Validation*. http://arxiv.org/abs/2311.10937

Hofmeier, T., Greiner-Fuchs, L., Schäfer, S., & Cichon, M. (2022). *Task analysis of a shunting locomotive to derive use-cases for scenario based tests of ATO Functions*. 9th Auto Test Conference, Stuttgart. https://www.researchgate.net/

IEC. (2006). *IEC 62290-1:2006 Railway applications – urban guided transport management and command/control systems – part 1: System principles and fundamental concepts* (IEC 62290–1).

Meng, Z., Tang, T., Wei, G., & Yuan, L. (2021). Analysis of ATO System Operation Scenarios Based on UPPAAL and the Operational Design Domain. *Electronics*, *10*(4). https://doi.org/10.3390/electronics10040503

Menzel, T., Bagschik, G., Isensee, L., Schomburg, A., & Maurer, M. (2018). Detaillierung einer stichwortbasierten Szenariobeschreibung für die Durchführung in der Simulation am Beispiel von Szenarien auf deutschen Autobahnen. *Workshop Fahrerassistenzsysteme und automatisiertes Fahren*, *12*. https://www.uni-das.de/

Pegasus. (2020). *Projekt zur Etablierung von generell akzeptierten Gütekriterien, Werkzeugen und Methoden sowie Szenarien und Situationen zur Freigabe hochautomatisierter Fahrfunktionen*. https://www.pegasusprojekt.de

Powell, J. P., Fraszczyk, A., Cheong, C. N., & Yeung, H. K. (2016). Potential Benefits and Obstacles of Implementing Driverless Train Operation on the Tyne and Wear Metro: A Simulation Exercise. *Urban Rail Transit*, *2*(3–4). https://doi.org/10.1007/s40864-016-0046-9

Riedmaier, S., Ponn, T., Ludwig, D., Schick, B., & Diermeyer, F. (2020). Survey on Scenario-Based Safety Assessment of Automated Vehicles. *IEEE Access*, *8*. https://doi.org/10.1109/ACCESS.2020.2993730

SAE International. (2021). *SAE J3016*. 2021 SAE International/ISO. https://www.sae.org/content/12-03-01-0003/

Schäfer, S., Greiner-Fuchs, L., Hofmeier, T., Koch, P., & Cichon, M. (2023, April). Virtual Validation Method of Automated On-Sight Driving Systems for Shunting Operations. *BOOK OF ABSTRACTS*. 10th International Conference on Railway Operations Modelling and Analysis (ICROMA), Belgrade, Serbia. https://doi.org/10.37528/FTTE/9788673954677/RailBelgrade.2023.ZE

Scholtes, M., Westhofen, L., Turner, L. R., Lotto, K., Schuldes, M., Weber, H., Wagener, N., Neurohr, C., Bollmann, M. H., Kortke, F., Hiller, J., Hoss, M., Bock, J., & Eckstein, L. (2021). 6-Layer Model for a Structured Description and Categorization of Urban Traffic and Environment. *IEEE Access*, *9*. https://doi.org/10.1109/ACCESS.2021.3072739

Schuldt, F. (2017). *Ein Beitrag für den methodischen Test von automatisieren Fahrfunktionen mit Hilfe von virtuellen Umgebungen*. http://publikationsserver.tu-braunschweig.de/

Tonk, A., Boussif, A., Beugin, J., & Collart-Dutilleul, S. (2021). Towards a Specified Operational Design Domain for a Safe Remote Driving of Trains. *Proceedings of the 31st European Safety and Reliability Conference (ESREL 2021)*. https://doi.org/10.3850/978-981-18-2016-8 504-cd

Ulbrich, S., Menzel, T., Reschka, A., Schuldt, F., & Maurer, M. (2015, September). Defining and Substantiating the Terms Scene, Situation, and Scenario for Automated Driving. *2015 IEEE 18th International Conference on Intelligent Transportation Systems*. https://doi.org/10.1109/ITSC.2015.164

VVM. (2022, September 28). *Verification Validation Methods*. VVM Projekt. https://www.vvm-projekt.de/

Zintel, M., Pluchet, J., Hensler, A., Bamberger, V., Baron, R., & Watson, S. (2023). *Rail 2040*. Arthur D. Little. https://www.adlittle.com/sa-en/insights/report/rail-2040