
# Ph01T0001 DL Operational Design Domain

**Version 2.0**

## Documentation Information

| | |
|---|---|
| **Contract Number** | 101069595 |
| **Project Website** | www.safexplain.eu |
| **Contratual Deadline** | 31.03.2024 |
| **Dissemination Level** | SEN |
| **Nature** | R |
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| **Keywords** | AI, Operational Design Domain |

This project has received funding from the European Union's Horizon Europe programme under grant agreement number 101069595.

# 1 Table of Contents

# 2 Review / Modification History

| Version | Date | Description Change |
|---|---|---|
| **V2.0** | 15/02/2024 | Changes Applied as a result of TÜV Review 2024-01-19 |
| V1.0 | 01/12/2023 | First version after complete internal review |
| V0.2 | 20/10/2023 | Modifications and improvements based on internal review |
| V0.1 | 01/10/2023 | First draft |
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| | | |

*Note: The paragraphs/name of the project/Rev./Ref./history table in **blue** must be replaced with the information for the specific project. The paragraphs written in **red** are instructions that can be used as a guide, so they must be deleted.* It is important to note that this template should be used as a baseline, providing a framework for the information to be collected, but they should not limit the scope of information nor guarantee that fulfilling them is sufficient. The required information is specific to the application and domain.

# 3 Objective

The objective of this document is to define the environment conditions in which the system will operate, the Operation Design Domain (ODD), thus defining the scope in which safety requirements will be described.

# 4 Scope

This document focuses on defining the ODD in which the Deep Learning (DL) constituent will operate.

# 5 Related Documents to be Considered

This document is grounded in the following references:

- *Methodology for Assurance of Machine Learning for use in Autonomous Systems* (AMLAS v1.1 [1]). AMLAS offers guidance on systematically integrating safety assurance into the development of machine learning (ML) components.
- *A Framework for Automated Driving System Testable Cases and Scenarios* [2], which is a research report describing a framework for establishing sample preliminary tests for Automated Driving Systems (ADS). As stated by the report abstract: *the focus is on light-duty vehicles exhibiting higher levels of automation, where the system is required to perform the full dynamic driving task, including lateral and longitudinal control, as well as object and event detection and response*.
- SMIRK: A machine learning-based pedestrian automatic emergency braking system with a complete safety case [3]. This research prototype supports the verification and validation of safety-critical systems with ML components and includes examples of interest for this document.

The present template is based on ODD defined by [2] in compliance with the environment description of AMLAS v1.1 [1], and integrates examples from [3].

# 6 Description of the Operation Design Domain

In accordance with the research report *"A Framework for Automated Driving System Testable Cases and Scenarios"* [2], the ODD "*describes the specific operating domains in which the ADS is designed to function. The ODD will likely vary for each ADS feature on a vehicle and specifies the condition in which that feature is intended and able to operate with respect to roadway types, speed range, lighting conditions, weather conditions, and other operational constraints"*.

The ODD should be described using a collection of the following table template. As many tables as necessary can be used to specify each category.

*Table 1. Table template to describe the ODD*

| Title of the concept to be considered | |
|---|---|
| Attribute or characteristic 1 | Value of the attribute 1 |
| Attribute or characteristic 2 | Value of the attribute 2 |
| Attribute or characteristic 3 | Value of the attribute 3 |
| … | … |

The ODD is described following three main categories that define the boundaries within which the system can safely operate:

- Scenery (zones, drivable area, junctions, basic structures, special structures, temporary rail structures, …)
- Environmental conditions (weather, particulates, illumination, connectivity, …)
- Dynamic elements (types of movable objects, movable objects characteristics, …)

Scenery is composed by spatially fixed elements of the operating environment, while dynamic elements are movable elements that can be operating on the scenery.

Following an example of an ODD description for the railway domain is fulfilled according to the following top-level categories, and some example sub-categories:

1) Scenery
   a) Physical infrastructure
   b) Operational constraints
   c) Zones
2) Environmental conditions
   a) Weather
   b) Particulate
   c) Illumination
   d) Connectivity
3) Dynamic elements
   a) Object types
   b) Object characteristics

The subsequent sections provide a more in-depth exploration of these categories, offering table templates and examples. However, depending on the domain and system, the definition of the ODD may involve other sub-categories.

## 6.1 Scenery

### 6.1.1 Physical Infrastructure

Physical infrastructure refers to facilities and systems that the autonomous system needs to function and serve its goal. Technical structures typically characterize physical infrastructure, for example, in the case of road transport, such as roads, bridges, tunnels, water supply, sewers, electrical grids, telecommunications, etc., or for example, in the case of railways transport, tracks, signals, stations, platforms, bridges, tunnels, electrical grids, telecommunications, etc. Safety Functions of the Autonomous System being defined may depend on such infrastructure elements, which are a critical part of the ODD environment.
As an example, tables showing the physical infrastructure for the case of an autonomous train are shown below. The physical infrastructure may be subdivided into as many categories/types as considered relevant to the scope of the safety functions.

*Table 2: Types of tracks.*

| Types of Tracks | |
|---|---|
| Single track | Y |
| Double track side by side | N (two tracks in parallel) |
| Multiple tracks in stations | N (multiple tracks in a station) |
| Other | N |

*Table 3: Types of environments/zones around the tracks.*

| Types of Environments/Zones Around the Tracks | |
|---|---|
| Station area | Y (underground or surface with left/right multiple platforms and multiple tracks) |
| Underground tunnel | Y (well illuminated for cameras, with single or double parallel track) |
| Surface urban area | Y (open without fences, city tramway type with single or double parallel track) |
| Surface industrial area | Y (open industrial buildings, warehouses, with single or double parallel track) |
| Surface countryside area | Y (open green fields, trees, forest, with single or double parallel track) |
| Surface Tunnel | Y (well illuminated for cameras with single or double parallel track) |
| Overhead lines | Y (bridges) |
| Other | N |

*Table 4: Station platform signals.*

| Station Platform Relevant Signals | |
|---|---|
| Train cabin stop point signal/landmark | Y (black square car stop/yellow multiple line pattern) |
| Train cabin stop point signal/landmark | Y (black square car stop/yellow multiple line pattern) |
| Platform along signal | Y (yellow continuous line along platform) |
| Station entrance semaphore | Y (red/green) |
| Station exit semaphore | Y (red/green) |

*Table 5: Track side signals.*

| Track Side Relevant Signals | |
|---|---|
| Semaphore | Y (red/green) |
| Speed limitation signal | Y (circle with red border) |
| Speed recommendation signal | Y (inverted triangle with yellow border) |
| Train road crossing barriers | Y |
| Other | N |

### 6.1.2 Operational Constraints

When designing and testing systems involving the use of AI, operational constraints need to be considered, such as speed limits, traffic characteristics, construction, etc. Safety systems are required to operate under these constraints that must be defined carefully.
Some examples of the operational constraints are listed below for the case of an Autonomous Train as an example.

*Table 6: Speed limits.*

| Speed Limits | |
|---|---|
| Minimum Speed Limit | 0 km/h |
| Maximum Speed Limit | 90 km/h |
| Maximum Speed Limit entering station | 30 km/h |
| Maximum Speed Limit exiting station | 30 km/h |
| Other | N |

As another example, for the case of road transport, the table below shows traffic operational constraints:

*Table 7: Traffic conditions.*

| Traffic Conditions | |
|---|---|
| Traffic density | No other traffic |
| Altered (Accident emergency vehicle, construction, closed road, special event) | N |
| Other | N |

### 6.1.3 Zones

Systems operation may be limited, spatially by zones. The boundaries of these zones may be fixed or dynamic, and conditions that define a boundary may be based on complexity, operating procedures, or other factors. One example, in the road transport area is work zones, in which cones may replace double yellow lines, bollards may replace curbs, and construction worker hand signals may overrule traffic lights [2].

Some examples of zones are listed below for the case of an ADS (examples taken from [3]). These zones may be subdivided into as many categories/types as are considered relevant.

In the example below the system is required to operate under standard zones, for example, urban traffic. However, it must also be specified that the system will not operate in some special zones. Therefore, the tables specifying those zones not covered must also be defined (tables below).

*Table 8: Geofencing.*

| Geofencing | |
|---|---|
| Urban Traffic | Urban Traffic |
| School Campuses | School Campuses |
| Retirement Communities | Retirement Communities |
| Fixed Route | Fixed Route |
| Other | Other |

*Table 9: Traffic management zones.*

| Traffic Management Zones | |
|---|---|
| Temporary Closures | N/A |
| Dynamic Traffic Signs | N/A |
| Variable Speed Limits | N/A |
| Temporary or Non-Existent Lane Marking | N/A |
| Human-Directed Traffic | N |
| Loading and Unloading Zones | N |
| Other | N |

## 6.2 Environmental Conditions

Environmental conditions can impact visibility, sensor precision, vehicle maneuverability, communications systems, etc. This section must define the environmental conditions under which the safety function is required to operate.

Some examples of environmental conditions are listed below for the case of an autonomous train. These conditions may be subdivided into as many categories/types as are considered relevant.

### 6.2.1 Weather

*Table 10: Weather/light conditions.*

| Weather/Light Conditions | |
|---|---|
| Sunny | Y |
| Wind | Y |
| Rain | Y |
| Snow | N |
| Sleet | Y |
| Temperature | Y |
| Hail | Y |
| Other | N |

*Table 11: Weather-induced track conditions.*

| Weather-Induced Track Conditions | |
|---|---|
| Standing Water | Y |
| Flooded Tracks | Y |
| Snow on Road | N |
| Other | N |

### 6.2.2 Particulate

*Table 12: Particulate matter.*

| Particulate Matter | |
|---|---|
| Fog | Y |
| Smoke | Y |
| Smog | N |
| Other | N |

### 6.2.3 Illumination

*Table 13: Illumination.*

| Illumination | |
|---|---|
| Day Surface track (Between 500 and 1500 lm) | Y |
| Underground track (lights: Overhead, lateral lights) | Y |
| Dawn | N |
| Dusk | N |
| Night (less than 100 lm) | Y |
| Streetlights | Y |
| Headlights (Regular & High-Beam) | Y |
| Oncoming train lights (Overhead Lighting, Back-lighting & Front-lighting) | Y |
| Other | N |

### 6.2.4 Connectivity

Connectivity and automation are increasingly being integrated into systems involving the use of AI, especially in autonomous systems with the objective of improving safety, mobility, and, for example in the case of ADS, providing a better driving experience. As an example, [2] provides guidance for ADS systems, as shown in the table below:

*Table 14: Communication*

| Communication | |
|---|---|
| V2V communications (e.g., DSRC, Wi-Fi), emergency vehicles | Y |
| Traffic density information, Crowdsourced data (e.g., Waze) and V2I | N |
| Remote Fleet Management System, a vehicle may be supported by an operations center that can perform remote operation | Y |
| Other | N |

However, as another example, in this case in the area of railway transport, the emergency brakes safety function to be activated when a person/obstacle is detected in the track, is a safety function that cannot rely on any external connectivity. Even in this case, the connectivity section of this document must be fulfilled to state that the safety functions don't rely on external connectivity. Below are example tables with all items defined as N or N/A.

*Table 15: Trains.*

| Trains | |
|---|---|
| Train to Train communication | Y |
| Train to Station | Y |
| Other | N |

*Table 16: Communication-Based Train Control (CBTC)*

| CBTC | |
|---|---|
| Does the safety function require communication with CBTC? | Y |
| Other | N |

*Table 17: Infrastructure Sensors.*

| Infrastructure Sensors | |
|---|---|
| Work zone alerts | N |
| Routing and incident management | N |
| Other | N |

*Table 18: Digital infrastructure.*

| Digital Infrastructure | |
|---|---|
| GPS | Y |
| 3-D Maps | Y |
| Weather Data | Y |
| Infrastructure Data | Y |
| Other | N |

## 6.3 Dynamic Elements

### 6.3.1 Object Types

Systems performing visual perception tasks must detect and respond to certain objects to properly navigate within an ODD. This category of the ODD identifies objects that can reasonably be expected to exist within the ODD. For example, in the case of autonomous train operation, a pedestrian may be expected on surface tracks but rarely on underground tracks.

Some examples of objects (obstacles in this case) are listed below for the case of an autonomous train. These objects may be subdivided into as many categories/types as considered.

*Table 19: Obstacle types*

| Obstacle Types | |
|---|---|
| Humans | Y |
| Big animals | Y |
| Unclassified objects | Y |
| Trucks/cars/motorcycles/bikes | Y |
| Other | N |

### 6.3.2 Object Characteristics

*Table 20: Obstacle speed characteristics*

| Obstacle Speed Range | |
|---|---|
| Humans speed | [0, 30] m/s |
| Big animals speed | [0, 45] m/s |
| Unclassified objects speed | 0 m/s |
| Trucks/cars/motorcycles/bikes speed | [0,120] m/s |

*Table 21: Obstacle dimension characteristics*

| Obstacle Dimension | |
|---|---|
| Humans dimension | 0,50 x 2,00 x 0,5 m |
| Big animal dimension | 1,00 x 0,50 x 1,00 m |
| Unclassified objects dimension | 1,50 x 1,50 x 1,50 m |
| Trucks/cars/motorcycles/bikes dimension | 2,00 x 2,45 x 8,20 m |

In the Annex A: ODD Examples of this document, it is provided an example of how to fill this template in a railway domain application.

# 7 Acronyms and Abbreviations

Below is a list of acronyms and abbreviations employed in this document:

- ADS – Automated Driving Systems
- AI-FSM – Artificial Intelligence - Functional Safety Management
- AMLAS – Assurance of Machine Learning for use in Autonomous Systems
- CBTC – Communication-Based Train Control
- DL – Deep Learning
- ODD – Operational Design Domain
- ML – Machine Learning

# Bibliography

[1] Habli, Richard Hawkins and Colin Paterson and Chiara Picardi and Yan Jia and Radu Calinescu and Ibrahim, «(AMLAS), Guidance on the Assurance of Machine Learning in Autonomous Systems,» *arXiv,* 2021.

[2] E. Thorn, S. C. Kimmel y M. Chaka, «A Framework for Automated Driving System Testable Cases and Scenarios,» 2018.

[3] M. B. J. H. Kasper Socha, «SMIRK: A machine learning-based pedestrian automatic emergency braking system with a complete safety case,» *Software Impacts,* vol. 13, 2022.

# Annex A: ODD Examples

The current version of this document provides a brief and limited example in the railway domain that can be used as baseline to define the specific ODD application, while future versions will include examples in the automotive and aerospace domains.

## A1: Railway Domain

The following tables define an ODD for a railway use case. The ODD is described with the following classification:

- Scenery

| Speed Limits | |
|---|---|
| Minimum Speed Limit | 0 km/h |
| Maximum Speed Limit | 90 km/h |
| Maximum Speed Limit entering station | 30 km/h |
| Maximum Speed Limit exiting station | 30 km/h |
| Minimum Speed Limit (standstill) | 0 km/h |

| Distance Threshold limit | |
|---|---|
| Distance threshold (warning) | [1001,1500] m |
| Distance threshold (warning & reduce) | [701, 1000] m |
| Distance threshold (breaking activation) | 700 m |

| Zones | |
|---|---|
| Surface | Yes |
| Countryside road | Yes |
| Surface station area | Yes |
| Tunnels | No |

| Types of tracks | |
|---|---|
| Single track | Yes |
| Multiple tracks | Yes |

- Environmental conditions

| Weather | |
|---|---|
| Rain | No |
| Fog | No |
| Sunny | Yes |
| Clear day | Yes |
| Cloudy | Yes |

| Illumination | |
|---|---|
| Daylight | [400 lm, 15000 lm] |

- Dynamic elements

| Objects | |
|---|---|
| Animals | Cow, dog, bird |
| Person | Yes |
| Vehicles | Car |
| Others | Yes |

## A2: Automotive Domain

The following tables define an ODD for a Automotive use case. The ODD is described with the following classification:

- Scenery

| Speed Limits | |
|---|---|
| Minimum Speed Limit | 0 km/h |
| Maximum Speed Limit | 130 km/h |

| Driveable area | |
|---|---|
| Highway | Yes |
| Urban road | Yes |
| Country road | Yes |
| Parking | Yes |
| Shared space | Yes |

| Drivable area geometry | |
|---|---|
| Straight roads | Yes |
| Curves | Yes, curve radius shall be greater than TBD m |
| up-slope | Yes, slope-gradient shall be lower than TBD m |
| down-slope | Yes, slope-gradient shall be lower than TBD m |

| Drivable area lane specification | |
|---|---|
| Lane type | Traffic lane, bus lane |
| Lane dimensions (lane width) | comply with the regulations in force in each state |
| Lane colour | White, yellow, blue |

| Distance Threshold limit | |
|---|---|
| Distance threshold (warning) | TTC == 3 s |
| Distance threshold (breaking activation) | TTC == 2 s |
| Lateral offset | Yes, lateral offset with target vehicle shall be lower than 1.5 m |

| Drivable area surface | |
|---|---|
| Loose (gravel, earth, sand) | No |

| | |
|---|---|
| Segmented (concrete slabs, granite setts, cobblestones) | Yes |
| Uniform (asphalt) | Yes |

| **Types of tracks** | |
|---|---|
| Single track | Yes |
| Multiple tracks | Yes |

- Structures

| **Special structures** | |
|---|---|
| Bridges | Yes |
| Pedestrian crossings | Yes |
| Tunnels | Yes |

- Environmental conditions

| **Weather** | |
|---|---|
| Rain | Yes, vehicle and VRUs are at least 30% visible and lane are visible |
| Fog | Yes, vehicle and VRUs are at least 30% visible and lane are visible |
| Sunny | Yes, sun angle greater than X° |
| Cloudy | Yes, vehicle and VRUs are at least 30% visible and lane are visible |
| Snow | Yes, vehicle and VRUs are at least 30% visible and lane are visible |

| **Weather-Induced Track Conditions** | |
|---|---|
| Sand and dust | Yes, vehicle and VRUs are at least 30% visible and lane are visible |
| smoke and pollution | Yes, vehicle and VRUs are at least 30% visible and lane are visible |

| **Illumination** | |
|---|---|
| Day Surface track (Between 500 and 1500 lm) | Yes |
| Underground track (lights: Overhead, lateral lights) | Yes |
| Night (less than 100 lm) | No |

- Dynamic elements

| **Objects type** | |
|---|---|
| Animals | Yes |
| Humans | Yes |
| Vehicles (Trucks/cars/motorcycles/bikes) | Yes |

| Obstacle Dimension | |
|---|---|
| Animals | Exposure time is more 3s and the size is more than 80cm |
| Humans | Exposure time is more 3s and the size is more than 80cm |
| Vehicles (Trucks/cars/motorcycles/bikes) | Exposure time is more 3s and the size is more than 80cm |