[L8.9] OPERATIONAL DESIGN DOMAIN

ODD – State of the art

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Keywords: Automated Driving Systems (ADS), Operational Design Domain (ODD), Taxonomy, Modeling, Implementation, System Resilience

Abstract. This document focuses on the definition of the Operational Design Domain (ODD) of automated driving systems. First, a study of the definitions and implementations of the ODD proposed in the literature, both in the academic and institutional fields, is presented. Then, based on this analysis of the existing literature, an exhaustive taxonomy of the ODD and a high-level vision of the implementation of this ODD are defined.

Résumé. Ce document porte sur la définition du domaine opérationnel (ODD, Operational Design Domain) des systèmes de conduite automatisés. Dans un premier temps est présentée une étude des descriptions et des mises en œuvre de l'ODD proposées dans la littérature, tant dans le domaine académique qu'institutionnel. Dans un second temps, grâce à cette analyse de l'existant, une structuration exhaustive de l'ODD et une vision haut niveau de la mise en œuvre de cet ODD sont définis.

Version	Date	Auteurs	Relecteurs	Note
V1	30/09/2021	Leo Mendiboure (UGE) Amira Chouchane (UGE) Abdelmename Hedhli (UGE) Pierre Jouve (STRMTG)	Sylvain Belloche (CEREMA) Paul Guillemard (CEREMA) Julien Niol (APSYS) Rafael de Sousa Fernandes (UTAC)	
V2	22/10/2021	Leo Mendiboure (UGE)		Conclusion
V3	25/10/2021	Leo Mendiboure (UGE)	Pierre Jouve (STRMTG) Abdelmename Hedhli (UGE) Rafael de Sousa Fernandes (UTAC)	Keywords + Abstract

Table des matières

1 INTRODUCTION

The operational design domain (ODD) defines the conditions under which a driving automation system is designed to perform the dynamic driving task (DDT).

Beside the automation level, the ODD description is the key point of the Automated Driving Systems (ADS) performance. The capacity of ADS to safely perform the dynamic driving task is demonstrated within the particular operational conditions limited by the ODD. Where a Level 5 ADS won't have any ODD limitation, the level 3 or 4 will have ODD limitations such as speed range, environmental conditions, traffic conditions or road conditions. Therefore, the ODD will have to be monitored and any ODD exit must lead to a DDT fallback.

The definition of ODD must therefore allow to describe in an unambiguous manner the external world within which the ADS can perform the DDT. The way (e.g. terms, scales, quality…) the ODD is described will be used widely throughout the whole ADS specification, design, validation and operation phases, making it a founding milestone of the process.

2 METHODOLOGY

2.1 Taxonomy

Defining a taxonomy of the basic terms used in the description of an ODD is a fundamental task. Indeed, the taxonomy defines operational world models and terms for specifying driving scenarios and their attributes. The ODD taxonomy for the ODD definition will enable ADS manufacturers to specify and implement safety requirements in their designs, and allow users, operators and regulators to reference set of ODD attributes and performance requirements in their procurements. It will also enable ADS manufacturers, developers and suppliers of components and subcomponents to define the operating capability and assemble sets of evidence that will improve confidence in the safety of the resulting product (such as component specifications) and in the data obtained from appropriate test and verification activities. For this purpose, a state of the art has been established for ODD taxonomy based on academic, standard, institutional and Work Group (WG) documents.

2.2 Reading template

A reading template has been defined and used for each document to be analyzed. The aim of this reading template was to provide a homogeneous and consistent reading of the above-mentioned documents. The template has been designed around the following set of criteria:

- Reference paper: Title, authors, year, organization….
- Document category: academic, standard, institutional and WG,
- Definition used for the ODD: is that of [11] (SAE-J3016) or different from [11],
- ODD metrics: deal with both how thoroughly the ODD has been validated as well as the completeness of the ODD description.
- Keywords: allows to specify the themes of the document and for a selective reading.
- Related terms: terms linked to the definition of the ODD which uncover its limitations or its areas of inclusion.
- Components, Under Categories and Elements: Tree Classification of the ODD attributes.

3 BIBLIOGRAPHIC REVIEW PROCESS

3.1 List of documents

The table (Table 1) below shows the list of documents that have been considered in our bibliographic review. The reading template defined in section 2.2 has been used for each of these documents.

Table 1: List of documents related to the ODD taxonomy

N°	Reference	Type
1	PAS 1883:2020 Operational Design Domain (ODD) taxonomy for an automated driving system (ADS) – Specification. The British Standards Institution 2020. [1]	Standard
2	Operational Design Domain for Testing of Autonomous Shuttle on Arterial Road. The Journal of The Korea Institute of Intelligent Transport Systems, 19(2), pp.135-148. Kim, H., Lim, K., Kim, J. and Son, W., 2020. [2]	Institutional
3	A framework for automated driving system testable cases and scenarios. Thorn, Eric, et al. No. DOT HS 812 623. United States. Department of Transportation. National Highway Traffic Safety Administration, 2018. [3]	Institutional
4	6-Layer Model for a Structured Description and Categorization of Urban Traffic and Environment. Scholtes M, Westhofen L, Turner L et al. Institute for Automotive Engineering (RWTH Aachen), *IEEE Access* 9 (2021): 59131-59147. [4]	Research
5	Ontology based Scene Creation for the Development of Automated Vehicles. Gerrit Bagschik, Till Menzel and Markus Maurer. Institute of Control Engineering Technische Universit¨at Braunschweig. [5]	Research
6	An Ontology-based Approach to Generate the Advanced Driver Assistance Use Cases of Highway Traffic. Wei Chen and Leila Kloul. 10th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management. Sep 2018, Seville, Spain. [6]	Research
7	Deliverable D4.1 Description and Taxonomy of Automated Driving Functions. Griffon, T., Sauvaget, J. L., Geronimi, S. and Brouwer, R. (2019). [7]	Research
8	Cooperative Automated Driving for managing Transition Areas and the Operational Design Domain (ODD). Proceedings of 8th Transport Research Arena TRA 2020, April 27-30, 2020, Helsinki, Finland. [8]	Research
9	Operational Design Domain for Automated Driving Systems - Taxonomy of Basic Terms. Czarnecki Krzysztof, 2018. [9]	Research
10	Best practice for designing an operational design domain: conceptual framework and lexicon. Automated Vehicle Safety Consortium (AVSC), 2020. [10]	WG

3.2 Bibliographic Review - Standards related Documents

Table 2: Reading template for Document [1]

Reference Paper	PAS 1883:2020 Operational Design Domain (ODD) taxonomy for an automated driving system (ADS) – Specification. The British Standards Institution 2020 [1]	
Category	Standard	
Definition (ODD)	SAE-J3016	
Metrics	Not defined in this document	
Key words	Operational Design Domain (ODD), automated driving system (ADS), generic taxonomy, minimum safety requirements.	
Related terms	Not defined in this document	
Components	Sub Categories	Elements
Scenery	Zones	Geo-fenced areas, traffic management zones, school zones, regions or states, interference zones
	Drivable area	Drivable area type (motorways, radial roads, distributor roads, minor roads, slip roads, parking, shared space), drivable area geometry (horizontal plane, transverse plane, longitudinal plane), drivable area lane specification (lane dimensions, lane marking, lane type, number of lanes, direction of travel), drivable area signs (information signs, regulatory signs, warning signs), drivable area edge (line markers, shoulder (paved or gravel), shoulder (grass), solid barriers (e.g. grating, rails, curb, cones), temporary line markers), drivable area surface (drivable area surface type/ features/conditions)
	Junctions	Roundabout (signalized, non-signalized and normal/compact/double/large/mini), intersections (T-junctions, staggered, Y-junctions, crossroads, grade separated)
	Fixed road structures	Buildings, street lights, street furniture (e.g. bollards), vegetation.
	Temporary road structures	Construction site detours, refuse collection, road works, road signage
	Special structures	Automatic access control, bridges, pedestrian crossings, rail crossings, tunnels, toll plaza
	Weather	Wind, Rainfall (light, moderate, heavy, violent, cloudburst), snowfall

Environmental conditions	Particulates	Marine (coastal areas only), non-precipitating water droplets or ice crystals (i.e. mist/fog), sand and dust, smoke and pollution, volcanic ash
	Illumination	Day (sun elevation, sun position), night, cloudiness (clear, partly cloudy, overcast), artificial illumination
	Connectivity	Communication (V2V/V2I), positioning (Galileo, GLONASS, GPS).
Dynamic elements	Traffic	Density of agents, volume of traffic, flow rate, agent type, presence of special vehicles (e.g. ambulances or police vehicles).
	Subject vehicle	Speed, pre-defined routes

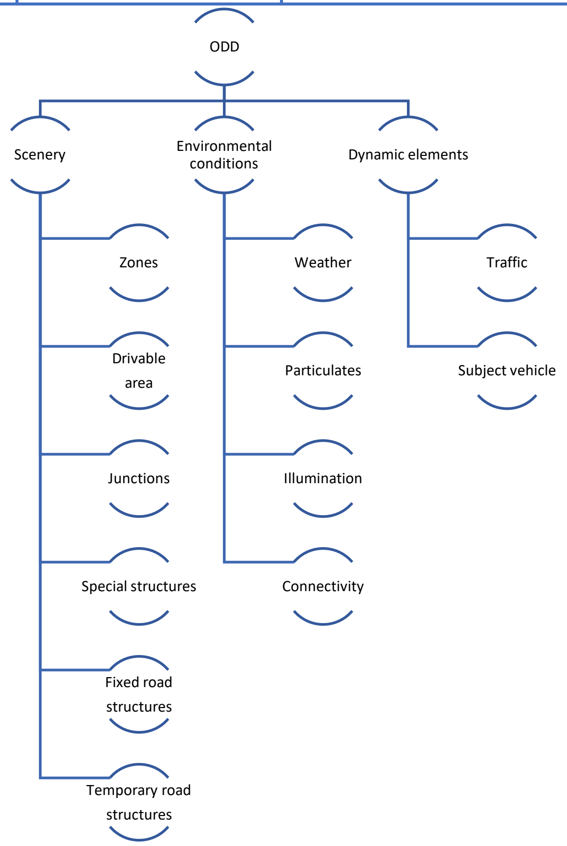

Figure 1: Synthetic view of the ODD described in [1]

3.3 Bibliographic Review - Institutional related Documents

Table 3: Reading template for Document [2]

Reference Paper	Operational Design Domain for Testing of Autonomous Shuttle on Arterial Road. The Journal of The Korea Institute of Intelligent Transport Systems, 19(2), pp.135-148. Kim, H., Lim, K., Kim, J. and Son, W., 2020. [2]	
Category	Institutional	
Definition (ODD)	SAE-J3016	
Metrics (Safety)	Arbitrary definition of acceptable or unacceptable conditions for the autonomous vehicle for each Component / Sub-category. For example, for ‘‘Geometric Factors -> Road Surface’’ : Asphalt – Concrete (‘‘Available Autonomous Driving’’) vs Unpaved – break (‘‘Unavailable Autonomous Driving’’)	
Key words	Operational design domain (ODD), Autonomous shuttle, Arterial road, Road condition, Autonomous driving system	
Related terms	Not defined in this document	
Components	Sub Categories	Elements
Geometry Factors	Link	Urban and suburban (Type 1 to 3), Highway, Urban Highway, Motorway, Underground Roadway, Overpass, Ramp
	Node	Roundabout, Three-way intersection to over five-way intersection
	Road Surface	Asphalt, Concrete, Unpaved Road, Break Road
	Number of Lanes	One-way to over five-way
Operational Factors	Traffic Signal	Provision or not of information related to network utilization
	Road operation	General Road Section, Senior Zone, School Zone, Zone 30, Illegal Parking Area
	Traffic Condition	LOS A – F
	Time Period	Morning Peak, Non-Peak, Afternoon Peak, Midnight (Illumination)
Environmental Factors	Weather	Sunny, Rain, Fog, Snow

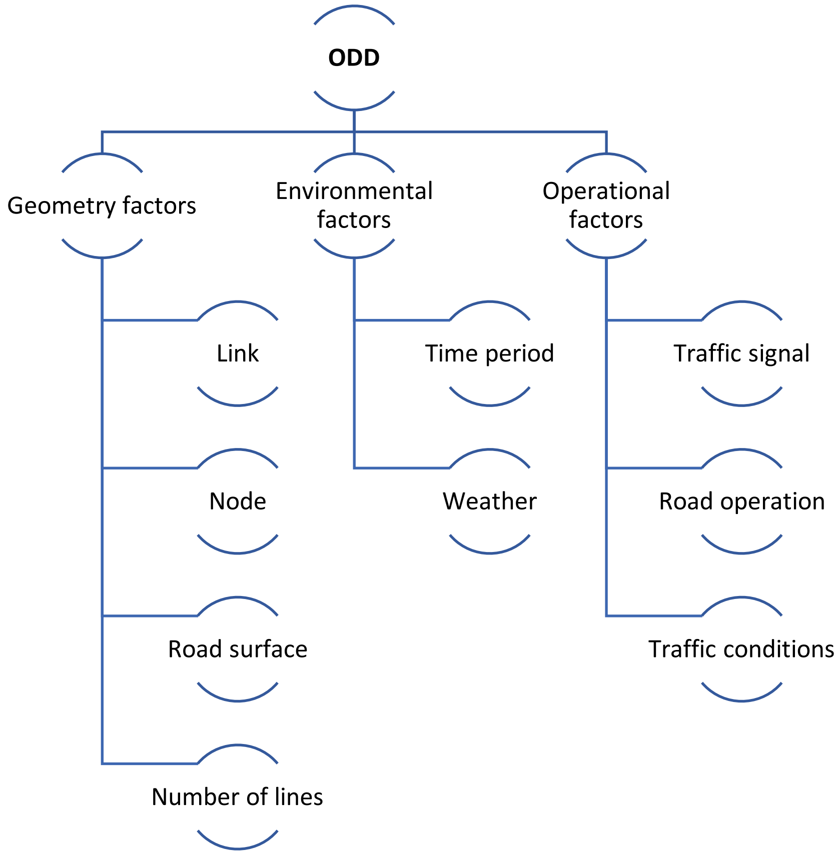

Figure 2: Synthetic view of the ODD described in [2]

Table 4: Reading template for Document [3]

Reference Paper	Thorn, Eric, et al. A framework for automated driving system testable cases and scenarios. No. DOT HS 812 623. United States. Department of Transportation. National Highway Traffic Safety Administration, 2018. [3]	
Category	Institutional	
Definition (ODD)	SAE-J3016	
Metrics	Metrics identified in this document are related to Fail-Operational and Fail-Safe mechanisms for an ADS. ADSs will use FO and FS mechanisms when the system does not function as intended. These mechanisms enable an ADS to attain a Minimal Risk Condition that removes the vehicle and its occupants from harm's way, to the best extent possible. Identified metrics are: Disengagements (A disengagement is defined as the Subject Vehicle (SV) safety driver deactivating the ADS feature being evaluated and taking manual control of the SV. The location and manner of the disengagement should be included in the experimenter's notes), Separation Distances (The separation distances are the distances between the SV and each of the POVs. The minimum separation distances (closest approach) should be identified, as well as the separation distances being observed as a continuum) and Deceleration Rate (The deceleration rate is the rate of change of speed of the vehicle (presumed that the vehicle slows down in this case). Ideally the rate of change would be smooth, as opposed to an abrupt deceleration as the SV reaches the parking location.	
Key words	automated driving systems, fail-safe mechanisms, object and event detection and response (OEDR), tests, operational design domain (ODD)	
Related terms	OEDR (OBJECT AND EVENT DETECTION AND RESPONSE) refers to "the subtasks of the Dynamic Driving Task that include monitoring the driving environment (detecting, recognizing, and classifying objects and events and preparing to respond as needed) and executing an appropriate response to such objects and events (i.e., as needed to complete the DDT and/or DDT fallback"; SAE International, 2016). OEDR capabilities will play a key role in developing sample tests for ADS. Relevant elements for OEDR: Sensing (radar, cameras, etc.), Perception (object segmentation and classification, etc.), World modeling (persistent data mapping, dynamic obstacle tracking, etc.), Navigation and planning (path planning, motion control commands, etc.) OEDR analysis (OEDR behaviors, appropriate responses) are based on the ODD analysis (baseline set of ODD elements) and Driving Scenario Analysis (expected hazards, unspecified/unexpected events, interactions prioritization based on risks – frequency & severity) MRC (Minimal Risk Condition) refers to a condition to which a user or an ADS may bring a vehicle after performing the DDT fallback in order to reduce the risk of a crash when a given trip cannot or should not be completed. Transition to MRC: Return Control to Fallback-ready User (Return longitudinal and lateral control to human occupant/driver (while providing sufficient warning)) or ADS Implements Minimal Risk Maneuver (Implement lateral and/or longitudinal control actions to achieve a minimal risk condition)	
Components	Sub Categories	Elements
Physical Infrastructure	Roadway Types	Divided highway, undivided highway, arterial, urban, rural, parking, multi-lane, single lane, high-occupancy vehicle (HOV)

		lane, on/off ramps, emergency evacuation routes, one-way, turn-only lanes, private roads, reversible lanes, intersections (signaled, Uturns, 4-way/2-way stop, roundabout, merge lanes, turn-only lanes, crosswalk, toll plaza, railroad crossing)
	Roadway Surfaces	Asphalt, concrete, mixed, grating, brick, dirt, gravel, scraped road, partially occluded, speed bumps, potholes, grass
	Roadway Edges	Line markers, temporary line markers, shoulder (paved or gravel), shoulder (grass), concrete barriers, grating, rails, curb, cones
	Roadway Geometry	Straightaways, curves, hills, lateral crests, corners (regular, blind corners), negative obstacles, lane width
Operational Constraints	Speed Limit	Minimum and maximum speed limit (absolute, relative to speed limit, relative to surrounding traffic)
	Traffic Conditions	Minimal traffic, normal traffic, bumper-to-bumper/rush-hour traffic, altered (accident, emergency vehicle, construction, closed road, special event)
Objects	Signage	Signs (e.g., stop, yield, pedestrian, railroad, school zone, etc.), traffic signals (flashing, school zone, fire department zone, etc.), crosswalks, railroad crossing, stopped buses, construction signage, first responder signals, distress signals, roadway user signals, hand signals
	Roadway Users	Vehicle types (cars, light trucks, large trucks, buses, motorcycles, wide-load, emergency vehicles, construction equipment, horse-drawn carriages/buggies), stopped vehicles, moving vehicles (manual, autonomous), pedestrians, cyclists
	Non-roadway Users Obstacles/Objects	Animals (e.g., dogs, deer, etc.), shopping carts, debris (e.g., pieces of tire, trash, etc.), construction equipment, pedestrians, cyclists

Connectivity	Vehicles	V2V communications (e.g., DSRC, Wi-Fi), emergency vehicles
	Traffic Density Info	Crowdsourced data (e.g., Waze) and V2I
	Remote Fleet Management System	A vehicle may be supported by an operations center that can perform remote operation
	Infrastructure Sensors and Comms	Work zone alerts, vulnerable road user, routing and incident management, GPS, 3-D high-definition maps (Ellichipuram, 2016), pothole locations, weather data, data on the cloud, etc.
Environmental Conditions	Weather	Wind, rain, snow, sleet, temperature
	Weather-Induced Roadway Conditions	Standing water, flooded roadways, icy roads, snow on road
	Particulate Matter	Fog, smoke, smog, dust/dirt, mud
	Illumination	Day (sun: overhead, back-lighting, and front-lighting), dawn, dusk, night, street lights, headlights (regular and high-beam), oncoming vehicle lights (overhead lighting, backlighting, and front-lighting)
Zones	Geo-Fencing	Central business districts, school campuses, and retirement communities
	Traffic Management Zones	May include temporary lane closures, dynamic traffic signs, variable speed limits, temporary or non-existent lane markings, human-directed traffic, loading/unloading zones
	School/Construction Zones	Dynamic speed limit, erratic pedestrian and vehicular behaviors
	Regions/States	Any legal, regulatory, enforcement, tort, or other considerations
	Interference Zones	Tunnels, parking garages, dense foliage, limited GPS due to tall buildings, atmospheric conditions

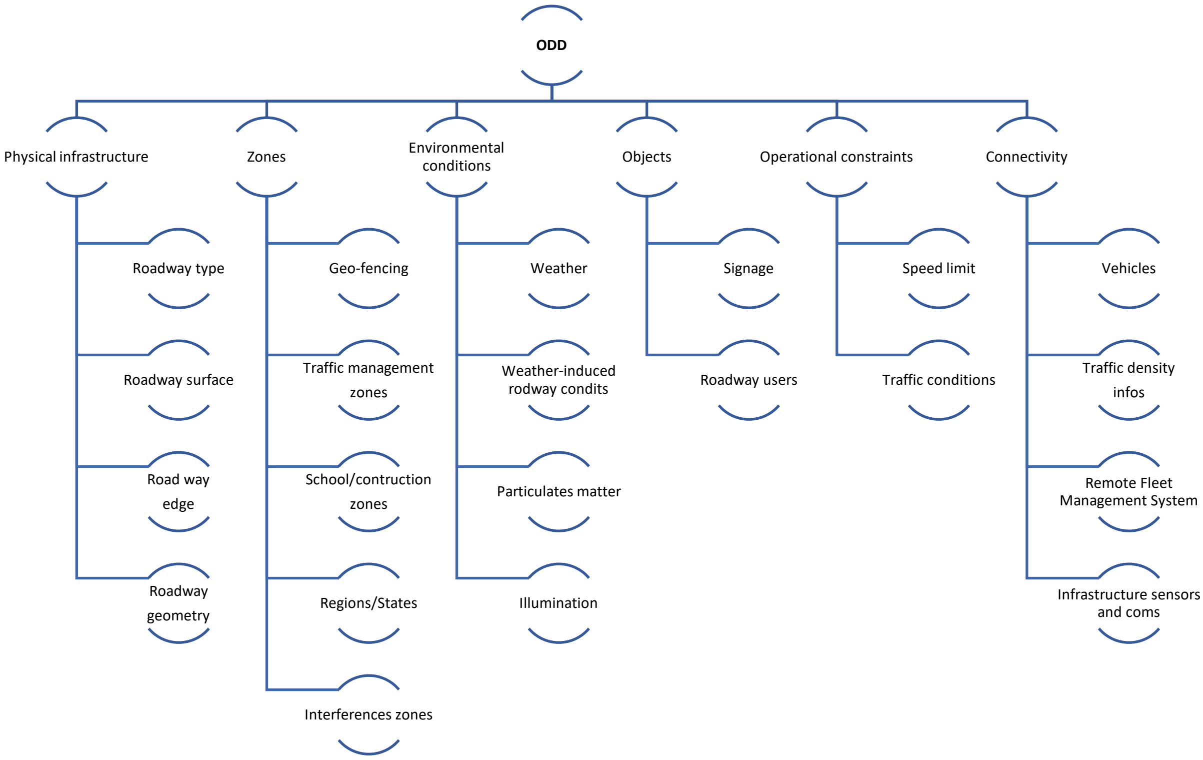

Figure 3: Synthetic view of the ODD described in [3]

3.4 Bibliographic Review - Academic related Documents

Table 5: Reading template for Document [4]

Reference Paper	6-Layer Model for a Structured Description and Categorization of Urban Traffic and Environment. Scholtes M, Westhofen L, Turner L et al Institute for Automotive Engineering (RWTH Aachen). [4]	
Category	Academic	
Definition (ODD)	Default ODD definition (SAE J-3016) Note: Components presented are defined in an ontology describing more than only ODD. They are globally presented, even if some may not be relevant. Elements presented are only examples collected from the paper but not the complete ontology.	
Metrics (Safety)	The paper intends to rely on an ontology to generate scenes within the ODD. The safety of the generated scenes is not assessed in the paper and no metrics are proposed to measure if the ODD is safe or not for the vehicle	
Key words	Ontology, Scenes	
Related terms	The paper introduces the notion of scene as defined in the SOTIF (ISO/PAS 21448) The scene describes where the autonomous is evolving in terms of static elements (such as weather, road configuration, lanes, obstacles…) and mobile elements (other vehicles, pedestrians…).	
Components	Sub Categories	Elements
Road network and traffic guidance objects	Geometry, Topology, Topography	Roads, Shoulders, Sidewalks, Parking spaces, roundabouts, traffic islands, bus stops
	Road markings	Stop lines, crosswalks, parking zones, keep-out areas
	Road surface	Asphalt, cobblestone, gravel, damages, potholes, speedbumps
	Traffic Signs	Traffic Signs (direction, city limits, tourist), Traffic Lights, Delineator, Beacons
Roadside Structures	Roadside Structures	Buildings, Walls, Fences Vegetation, Trees, Bushes Guardrails, Concrete Barriers, Impact attenuators Street Lamps, Advertising Boards, Pillars Bus shelters, Fountains
Temporary manipulation of 1 and 2	Roadwork related changes	Roadwork signs, Temporary markings, covered markings, fallen trees, road contamination

Dynamic Objects	Traffic Participants	Vehicles, Pedestrians, Trailers, Motorcycles, Bicyclists, Trams
	Dynamic and movable objects	Animals, Miscellaneous objets (tree falling, ball, can…)
Environmental conditions	Weather	Precipitation, Wind, Road Weather (dry, wet, icy…)
	Lighting	Daylight illumination, Shadows, Artificial lighting
Digital information	Digital Map data	
	V2X communication	State of traffic lights, V2X messages, cellular network coverage

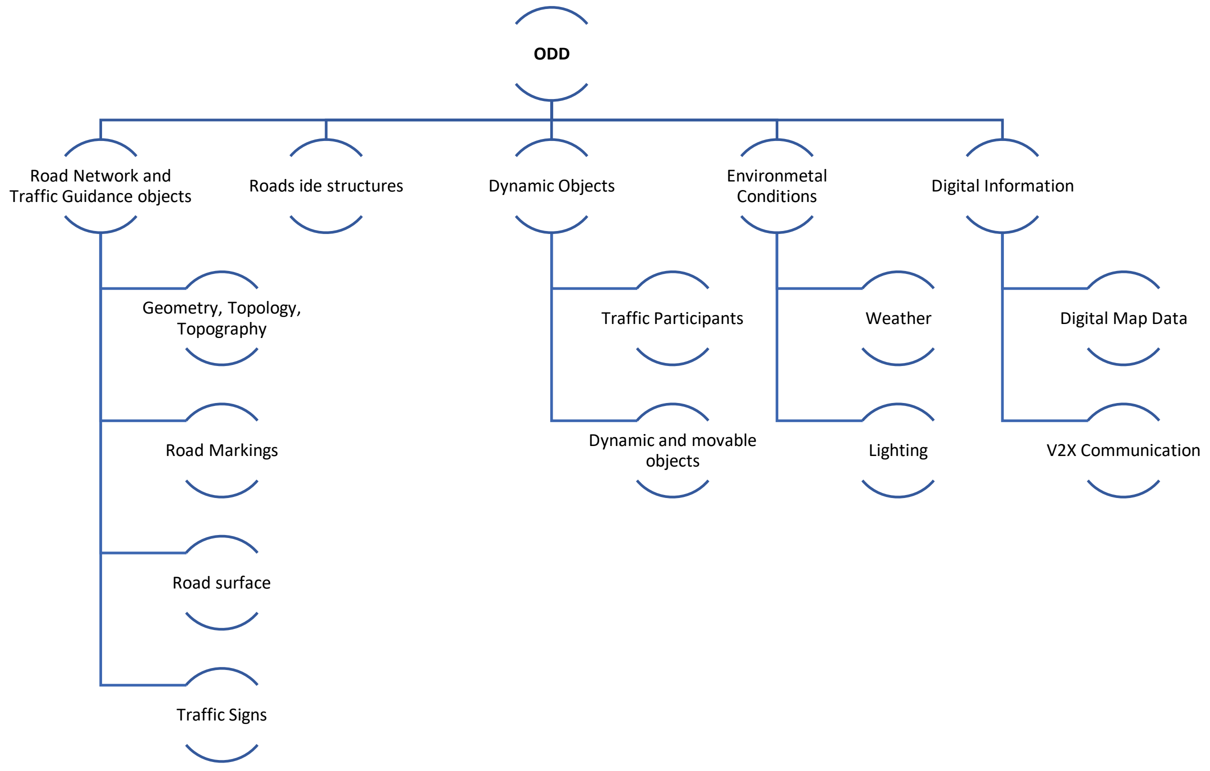

Figure 4: Synthetic view of the ODD described in [4]

Table 6: Reading template for Document [5]

Reference Paper	Ontology based Scene Creation for the Development of Automated Vehicles Gerrit Bagschik, Till Menzel and Markus Maurer Institute of Control Engineering Technische Universit¨at Braunschweig. [5]	
Category	Academic	
Definition (ODD)	Default ODD definition (SAE J-3016) Note: Components presented are defined in an ontology describing more than only ODD. They are globally presented, even if some may not be relevant. Elements presented are only examples collected from the paper but not the complete ontology.	
Metrics (Safety)	The paper intends to rely on an ontology to generate scenes within the ODD. The safety of the generated scenes is not assessed in the paper and no metrics are proposed to measure if the ODD is safe or not for the vehicle	
Key words	Ontology, Scenes	
Related terms	The paper introduces the notion of scene as defined in the SOTIF (ISO/PAS 21448) The scene describes where the autonomous is evolving in terms of static elements (such as weather, road configuration, lanes, obstacles…) and mobile elements (other vehicles, pedestrians…).	
Components	Sub Categories	Elements
Road Level	Geometry, Topology	Straights, Curves, Clothoids
	Quality, Boundaries (surface)	Lanes, Hard shoulder
Traffic infrastructure	Boundaries (structural)	Solid lines, dashed lines, solid crash barriers
	Traffic signs, Elevated Barriers	
Temporary manipulation of 1 and 2		It describes changes that may be applied temporarily on road level and traffic infrastructure (significant duration >1 day)
Objects	Static, Dynamic, Movable	Cars, Trucks, Cyclists
	Interaction, Maneuver	Drive Up, Follow, Approach, Pass, Lane Change, Turn, Turn Back, Safe Stop
Environment	Weather, lighting, other surrounding conditions	Rain, Snow, Sun Day, Night Monday, Tuesday…

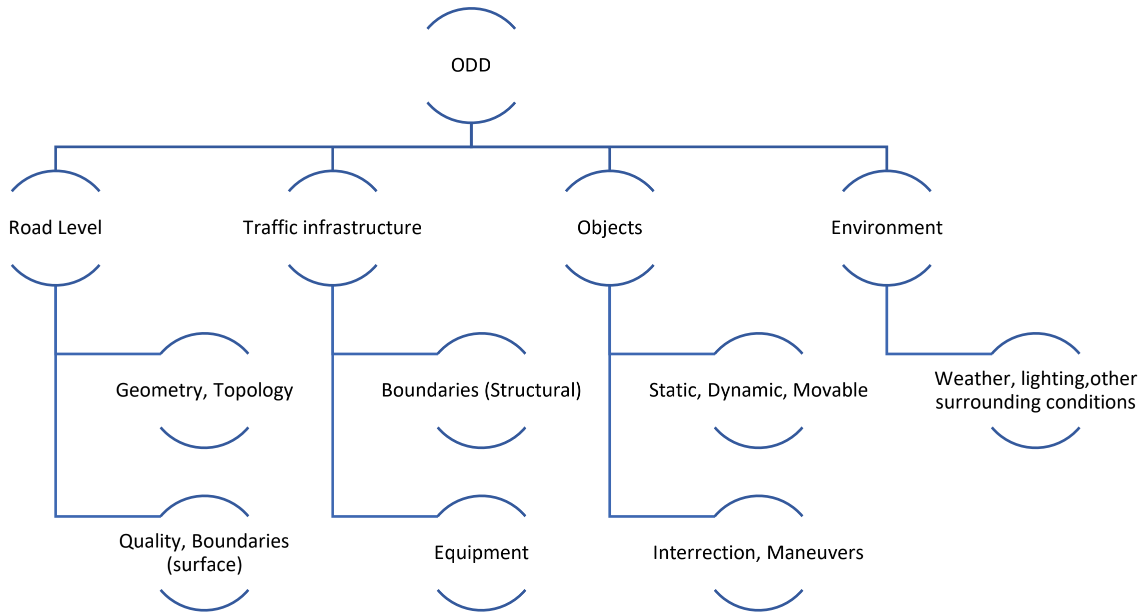

Figure 5: Synthetic view of the ODD described in [5]

Table 7: Reading template for Document [6]

<table>
<tr><td>Reference Paper</td><td colspan="2">Wei Chen, Leila Kloul. An Ontology-based Approach to Generate the Advanced Driver Assistance Use Cases of Highway Traffic. 10th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management., Sep 2018, Seville, Spain. [6]</td></tr>
<tr><td>Category</td><td colspan="2">Academic</td></tr>
<tr><td>Definition (ODD)</td><td colspan="2">Default ODD definition (SAE J-3016)
Note: Components presented are defined in an ontology describing more than only ODD. They are globally presented, even if some may not be relevant.</td></tr>
<tr><td>Metrics (Safety)</td><td colspan="2">The paper intends to rely on an ontology to generate scenarios within the ODD. The safety of the generated scenarios is not assessed in the paper and no metrics are proposed to measure if the ODD is safe or not for the vehicle</td></tr>
<tr><td>Key words</td><td colspan="2">Highway, Weather, Ontology, Use Cases</td></tr>
<tr><td>Related terms</td><td colspan="2">The paper introduces the notion of scene, scenario and use case as defined in the SOTIF (ISO/PAS 21448)
The scene describes where the autonomous is evolving in terms of static elements (such as weather, road configuration, lanes, obstacles…) and mobile elements (other vehicles, pedestrians…).
The scenario is a succession of scenes, each new scene is deduced after an event (either from the ego vehicle or a configuration change in static or mobile elements)
The use case is a scenario instantiated regarding the autonomous vehicles' characteristics.</td></tr>
<tr><td>Components</td><td>Sub Categories</td><td>Elements</td></tr>
<tr><td rowspan="4">Physical Infrastructure (Highway only)</td><td>Road Part</td><td>Segment, Branch divergence, Branch convergence, Entrance Ramp, Exit Ramp,</td></tr>
<tr><td>Roadway</td><td>Entrance Lane, Exit Lane, Taper, Acceleration Section, Deceleration section, Main Lane, Through Lane, Median, Shoulder (Left/Right, Hard/Soft, Paved/Unpaved)</td></tr>
<tr><td>Zone</td><td>Toll, Tunnel, Bridge, Roadwork, RestArea, EmergencyRefugeArea, RunawayTruckRamp</td></tr>
<tr><td>Equipment</td><td>Barrier, Fence, Lighting, EmergencyPhone, DangerSign, PrioritySign, PrescriptionSign, IndicationSign, Arrows, Chevrons, LongitudinalMarking</td></tr>
<tr><td>Environmental conditions</td><td>Weather</td><td>Daylight, Temperature, Pressure, Humidity, Wind, Precipitation (rain, snow, hail), Fog, Haze</td></tr>
<tr><td rowspan="2">Vehicle configuration</td><td>Devices</td><td>Windscreen Washer, WindscreenWiper, ParkingLight, HeadLight, DirectionLight (Left/Right), FogLight (Front/Rear), ReversingLight, BrakingLight</td></tr>
<tr><td>Actions</td><td>Run, Start, Stop, Accelerate, Brake, Release, ChangeLane (GoLeft/GoRight), TurnOn, TurnOff, Entrance, Exit</td></tr>
</table>

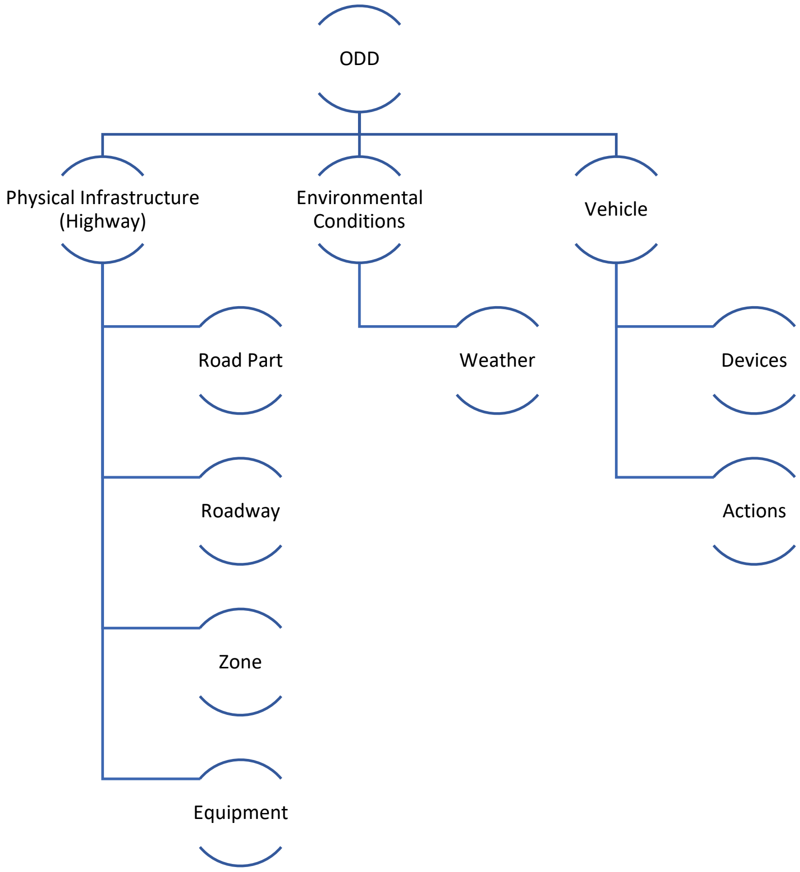

Figure 6: Synthetic view of the ODD described in [6]

Table 8: Reading template for Document [7]

Reference Paper	Deliverable D4.1 Description and Taxonomy of Automated Driving Functions. Griffon, T., Sauvaget, J. L., Geronimi, S. and Brouwer, R. (2019). [7]	
Category	Academic	
Definition (ODD)	SAE-J3016	
Metrics	Not defined in this document	
Key words	ODD, Taxonomy, Vehicle functionalities (car following, lane change, speed, etc.), driver role (monitoring of the environment, take-over request, etc.)	
Related terms	Not defined in this document	
Components	Sub Categories	Elements
Environment – Road	Road type	Motorway, urban road, parking area, etc.
	Surface condition	Good, bumpy, etc.
	Geometry	Straight, curved, inclined, etc.
	Test sites accessibility	Private area, public area
	Road characteristics	Lane dividers, bicycle lanes, intersections, etc.
Environment – Traffic	Planned traffic conditions	Flow, mixed traffic, automation only, etc. Possible slow or stationary traffic, working zone, non-motorized road users, etc.
Environment – Visibility	Weather conditions	sun, fog, rain, snow, etc.
	Lighting conditions	Day, night, etc.
	Obstacles	Vehicles, Infrastructure, etc.

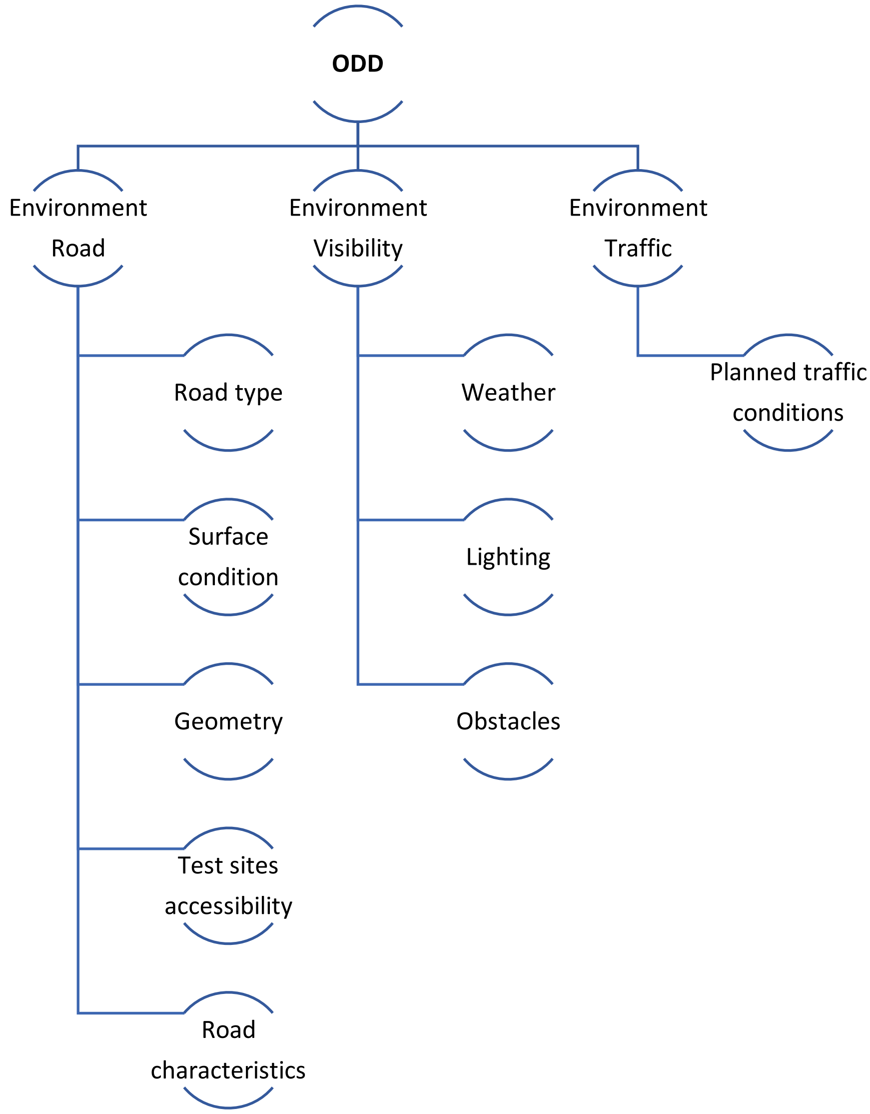

Figure 7: Synthetic view of the ODD described in [7]

Table 9: Reading template for Document [8]

Reference Paper	Cooperative Automated Driving for managing Transition Areas and the Operational Design Domain (ODD), Proceedings of 8th Transport Research Arena TRA 2020, April 27-30, 2020, Helsinki, Finland. [8]	
Category	Academic	
Definition (ODD)	SAE-J3016	
Metrics	Not defined in this document	
Key words	Automation, Connectivity, Infrastructure, Transition of control, Traffic management, operational design domain (ODD), Guideline, Roadmap	
Related terms	Transition of Control (ToC): handover between automated and non-automated driving state Minimum Risk Maneuver (MRM)	
Components	Sub Categories	Elements
Vehicle automation capabilities (Automation levels)	Driving tasks	Longitudinal and lateral control, etc.
	Related functions	Perception, planning and execution
Scene	Access	Restricted, shared, open
	Intersections	Cross traffic: yes/no
	Behavior	Homogeneous /heterogeneous behavior (of other road users)
Physical infrastructure measures	Road surface	
	Road markings	
	Traffic signs and signage	
	Physical separators	
	Road furniture	
Digital infrastructure measures	Infrastructure-to-vehicle communication services	Information, warnings, regulations, etc. (roadside sensing, cooperative perception, digital maps, dynamic digital information, etc.)

Situational / environmental conditions	Planned/unplanned cases	Traffic, incidents, weather conditions, road layout (e.g. gradient and curvature), obstructions blocking vision, light, etc.
Geofenced areas / roads	Automation eligible road	Type of road, geographical area, etc.
Vehicle / system operational performance	Vehicle/service performance expectations	Travelling comfort, driving speed (and thereby the travel time), number of stops, number of handovers of control, number of minimum risk maneuvers, etc.

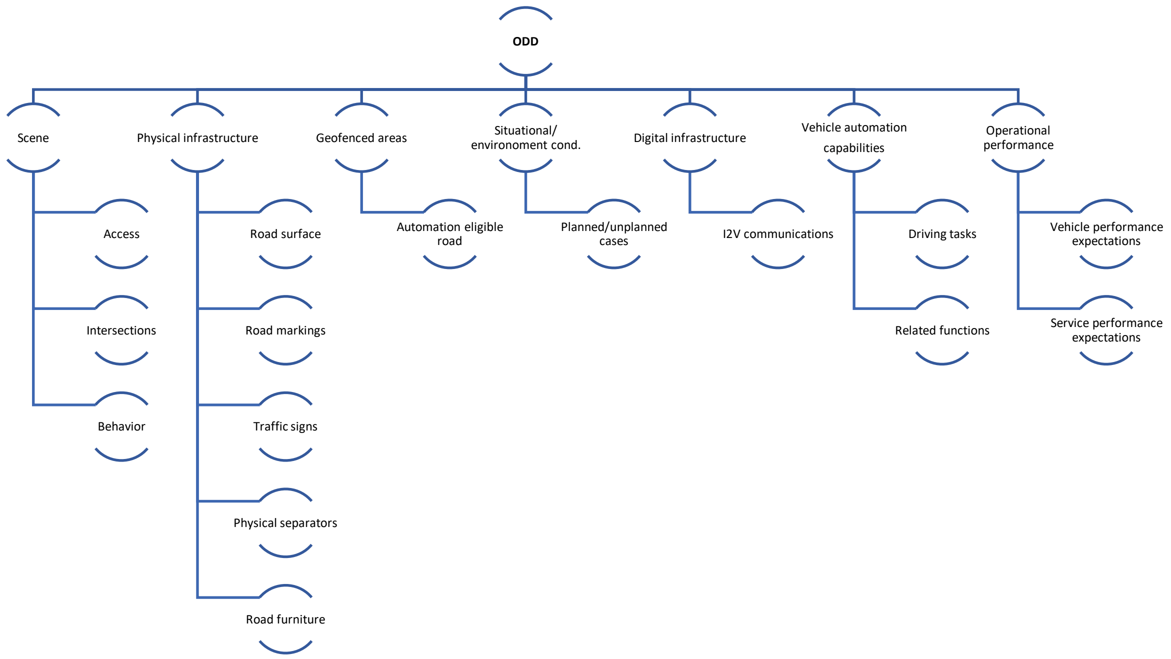

Figure 8: Synthetic view of the ODD described in [8]

Table 10: Reading template for Document [9]

<table>
<tr><td>Reference Paper</td><td colspan="2">Operational Design Domain for Automated Driving Systems - Taxonomy of Basic Terms. Czarnecki Krzysztof, 2018. [9]</td></tr>
<tr><td>Category</td><td colspan="2">Academic (Technical Report)</td></tr>
<tr><td>Definition (ODD)</td><td colspan="2">SAE-J3016</td></tr>
<tr><td>Metrics</td><td colspan="2">-The risk level of a scene is based on
▪ exposure measures
▪ severity measures
▪ controllability measures

-Crash situations and scenarios have associated
▪ crash severity,
▪ the five-level Abbreviated Injury Scale (AIS)
▪ Maximum AIS (MAIS) or Injury Severity Index (ISI)
▪ Crash statistics. For example:
o the Delta-V metric : allows estimating the occupant injury severity in frontal crashes
o probability of occurrence of injuries at levels AIS
▪ impact point and impact angle.

-Near-crash situations and scenarios may be identified using surrogate safety measures :
▪ time-to-collision (TTC)
▪ post-encroachment time (PET),
▪ time gap,
▪ required deceleration rate (RDR)
-For near-crash scenarios, summary measures are used :
▪ Minimum TTC
▪ Time Integrated TTC (TITTC)
-Rollovers situations and scenarios have associated
▪ the number of roof impacts,
▪ impact with fixed objects prior rollover,
▪ rollovers stopped by an impact with a fixed object….</td></tr>
<tr><td>Key words</td><td colspan="2">Automated Driving System (ADS), Operational Design Domain (ODD), Operational world models, Driving automation</td></tr>
<tr><td>Related terms</td><td colspan="2">• Operational road environment model (OREM) :

An operational road environment model (OREM) is a representation of the relevant assumptions about the road environment in which an ADS will operate the ADS-equipped vehicle
• Operational World Model (OWM)

An operational world model (OWM) is a composition of an OREM with one or more subject vehicle models, each coupled with a model of a subject ADS or an actual subject ADS, that is, an ADS under development
• Restricted Operational Domain

The Restricted Operational Domain (ROD) is the specific conditions under which a given driving automation system or feature thereof is currently able to function</td></tr>
<tr><td>Components</td><td>Sub Categories</td><td>Elements</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Road environment	Types of roads	Urban, rural, or freeways
	Specific elements	Roundabouts, tunnels
	Temporary structures	Construction zones, work area, etc.
	Traffic volumes	Low, high, etc.
	Weather and visibility conditions	Weather, visibility
	Specific limitations	Geographical area, season, etc.
Behavior of the ADS-equipped subject vehicle	Speed limitations	Specific speed
	Maneuvers limitations	Reversing, etc.
State of the vehicle	Specific limitations	Trailer (possible or not), loading limitations, minimum tire inflation level, etc.

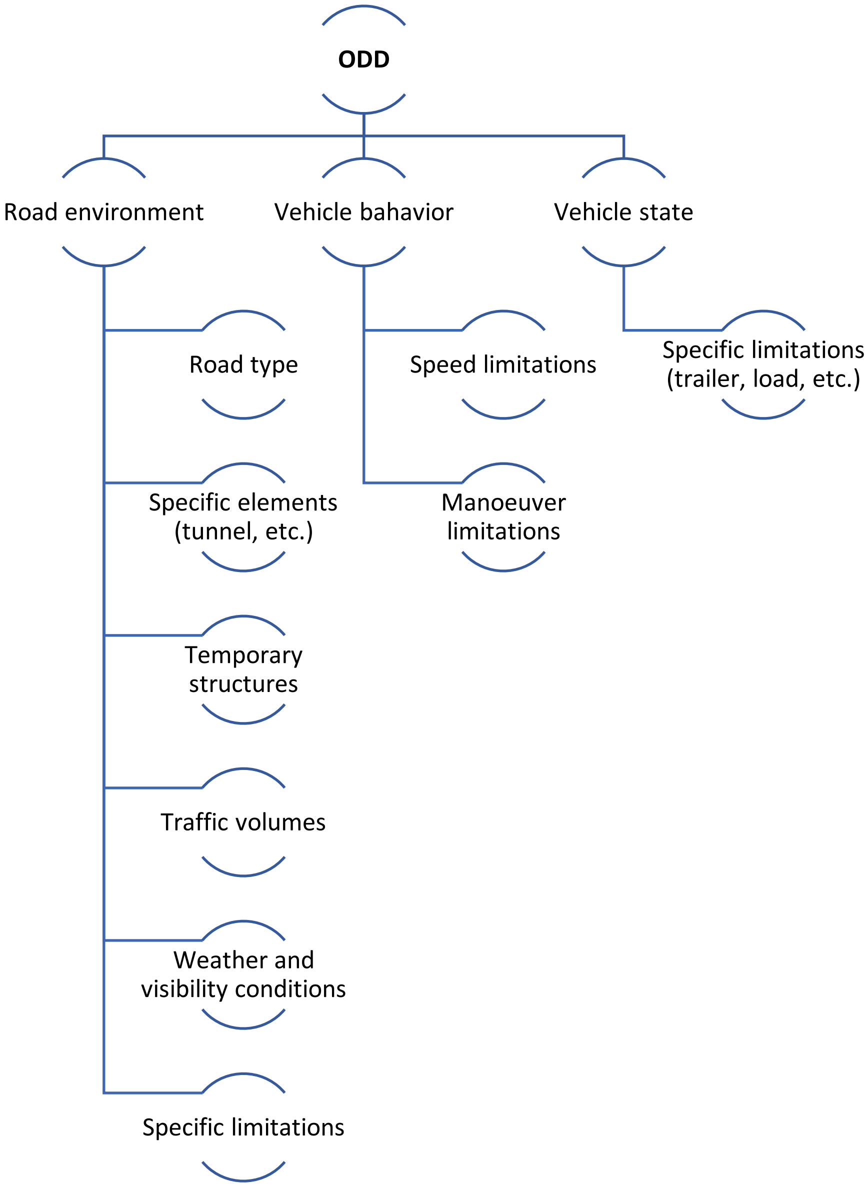

Figure 9: Synthetic view of the ODD described in [9]

3.5 Bibliographic Review - WG related Documents

Table 11: Reading template for Document [10]

Reference Paper	Best practice for designing an operational design domain: conceptual framework and lexicon. Automated Vehicle Safety Consortium (AVSC), 2020. [10]	
Category	WG International (industry program)	
Definition (ODD)	SAE-J3016	
Metrics (Safety)	Not defined in this document	
Key words	Conceptual framework, Lexicon, ODD Construction	
Related terms	ADS: Automated Driving Systems. The ODD should describe the specific conditions under which a given ADS or feature is intended to function. ADS-DV: ADS-dedicated vehicles	
Components	Sub Categories	Elements
Weather-related environmental conditions	Weather / Atmospheric and lighting conditions	Temperature, precipitation types (rain, rainfall rates, drizzle, mist, fog, snow, snow intensity, sleet, freezing rain, hail), haze, sky condition, illuminance, sun angle, wind
Physical Infrastructure	Roadway Alignment / Roadway infrastructure	Road/route network (Human) Sight distance Roadway grade Superelevation Vertical Curvature Horizontal Curvature Ramps Intersections Weaving sections Design elements (lane, Shoulder, curb, design and posted speed, buffer between curb and pedestrian facility, pedestrian facility, landscaping) Berms, guard rails, gutters, ditches Bridges Tunnels Roadside furniture Traffic control devices On-street parking
	Roadway Surfaces and Conditions	State of repair (cracking, rutting, ravelling, pothole, alligator cracking) Quality of road markings Road surface obscurants Transient roadway obstacles
Operational constraints	Zones	Fixed, i.e school, hospital, loading, etc Dynamic
Road User and Traffic	Road users (vehicles)	Automobile, bicycle, pedestrian, transit, trucks, motorcycles/scooters, micromobility, wheelchairs, emergency vehicles, other

	Road users behavior	Road user norms Traffic patterns Rush hour / intended operational times
	Time-of-day restrictions	
Non-static roadside objects		Objects that are not permanently fixed in place, but also not necessarily dynamic in nature
Connectivity / digital characteristics	Fleet management Obstructions	GNSS, Cellular, Infrastructure communication Obstruction from fixed infrastructure

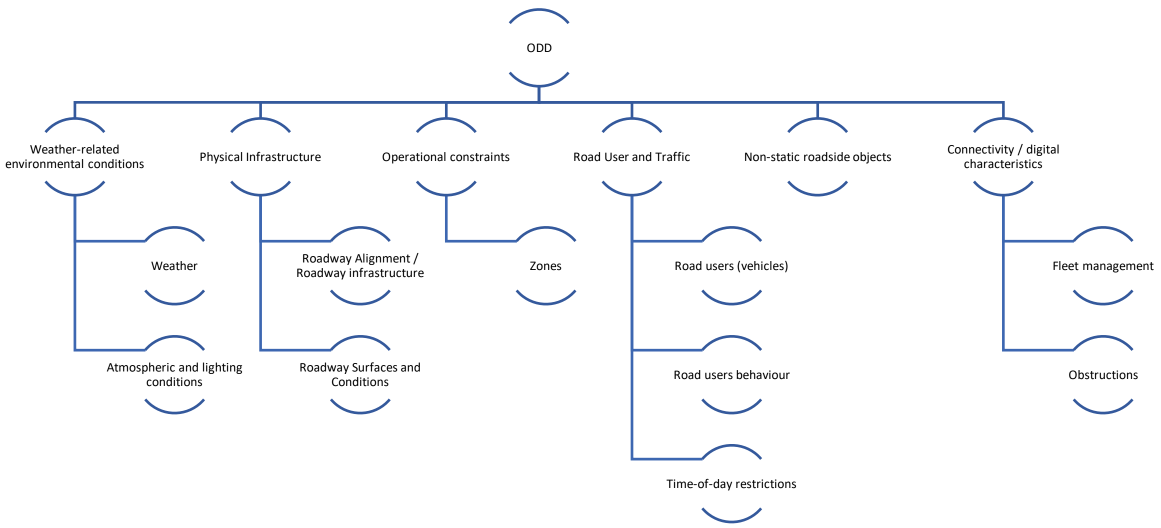

Figure 10: Synthetic view of the ODD described in [10]

4 REVIEW PROCESS – RESULTS ANALYSIS

4.1 Commonalities

J3016 defines an ODD as ‘‘operating conditions under which an ADS is designed to function, including (but not limited to) environmental, geographical, and time-of-day restrictions, and / or the requisite presence or absence of certain traffic or roadway characteristics.’’ All the documents presented in the previous sections consider this ODD definition as a starting point. Therefore, the taxonomies defined in these documents present some common features:

- **Physical Road infrastructure**

It is sometimes divided into two components (Physical road infrastructure and scenery). It usually consists of:
  - Roadway surface, roadway edge, roadway type, roadway geometry, roadway lane specification;
  - Drivable area signs, solid barriers, temporary line markers;
  - Permanent road structures, temporary road structures, special structures.

- **Environnemental conditions**

It usually consists of:
  - Weather, climate characteristics and weather-induced roadway conditions;
  - Illumination/Lighting;
  - Particulate Matter.

Environmental conditions have an important impact on ADS. Indeed, they can impact all ADS functions from perception and planning to actuation control, as they might impact visibility, sensor fidelity, vehicle maneuverability (changing road surface conditions), and communication systems.

- **Traffic conditions**

It usually consists of:
  - Traffic conditions (traffic speed and density);
  - Current speed limits;
  - Road operations.

4.2 Divergence

Limitations related to physical road infrastructure, environmental conditions or traffic conditions are elements included in all the proposed ODD taxonomies. However, an ODD could potentially include other elements present in some of the existing taxonomies:

- **Subject Vehicle**

The subject vehicle can be an additional ODD component. When the subject vehicle is considered in the ODD definition, it generally consists of:
  - the use of pre-defined routes for this vehicle;
  - the capabilities of this vehicle (theoretical or in real time)
    - Maneuvers that this vehicle can perform autonomously;

- Vehicle speed range;
- Maximum load supported by this vehicle;
- Minimum tires inflation;
- Etc.

- **Connectivity**

Connectivity refers to the ability of a vehicle to exchange information with different elements around it. The use of connectivity may provide the subject vehicle with information that will allow it to expand its ODD. It can be sorted into different categories:

- Traffic density informations ;
- V2V communications ;
- Remote fleet management systems ;
- Infrastructure sensors ;
- Positioning.

- **Other users**

Other entities that may be traveling on the road could also be included in the ODD definitions as they modify the vehicle environment. This would allow an assessment of the vehicle's ability to deal with these different users. These users are usually grouped into two categories:

- Roadway users (vehicles, pedestrians, cyclists, etc.);
- Non-roadway Users (animals, shopping carts, etc.).

- **Geo-fenced areas**

The ODD of vehicles can be defined for Geo-fenced or non-Geo-fenced areas. In the automotive field, some manufacturers, like Ford and Lyft, have limited the road networks to routes eligible for automation. The main challenge is that the unforeseen factors of the scene, the situation and the environment can never be completely excluded. It is therefore difficult to limit the automation capabilities of the vehicle to a geographic area, unless the automaker can safely handle any scenario in that area. Geo-fencing therefore does not guarantee that the vehicle will always be able to drive on the predefined sections.

5 ADDITIONAL REVIEW - IMPLEMENTATION OF AN ODD

5.1 Introduction

The characterization of the ODD, through a taxonomy, is a first step that has been considered in this document (see Section 2). The use of this taxonomy, in real conditions, to ensure the proper functioning of the automated and connected vehicle, is a second step that is addressed in this section. Thus, the works related to this topic, available in the literature, are presented in this section.

Similarly to the process presented in Section 2, different types of articles, focusing on the implementation of the ODD, have been considered. These are essentially research and institutional articles since no standardization or working group documents seem to propose results related to the implementation of the ODD. It should be noted that some documents proposing an ODD taxonomy, in particular institutional documents (NHTSA, Korean Institute), also include relevant information related to the implementation of the ODD and are also presented in this section.

Figure 11 provides a synthetic view of the directions that have been considered by studies related to the ODD implementation. It can be seen that three main ideas have been considered so far:

- ODD modeling: the main idea here is to think about the best solution to use the ODD taxonomy in real time. In other words, the research efforts in this direction focus on a minimalist definition of the ODD to allow the autonomous driving system to check in real time that it is still within the scope of its ODD;

- ODD adaptation to vehicle or sensors malfunction: the main idea here is to define mechanisms to adapt the ODD of a vehicle to real-world conditions. In other words, the research efforts in this direction focus on the implementation of solutions that will allow to manage the failure or the reduction of the capacity of one or several sensors of the vehicle. Indeed, the reduction of the perception capacity of the autonomous vehicle will necessarily imply an adaptation of its behavior: speed, authorized road type, etc.

- Expansion of ODD limits: the main idea here is to propose solutions to expand the ODD of automated and connected vehicle. To enable this, the proposed solutions are primarily based on the use of roadside infrastructure and the establishment of communications between this infrastructure and the vehicles. In other words, the idea is to use what is now called Cooperative Intelligent Transport Systems (C-ITS) to overcome the limitations of the vehicles sensors through the transmission of different pieces of information: presence of other road users, changing weather conditions, intersection management, etc. The expanded ODD can be seen has the ODD of a system consisting of the vehicles, the road infrastructure, and the related communications.

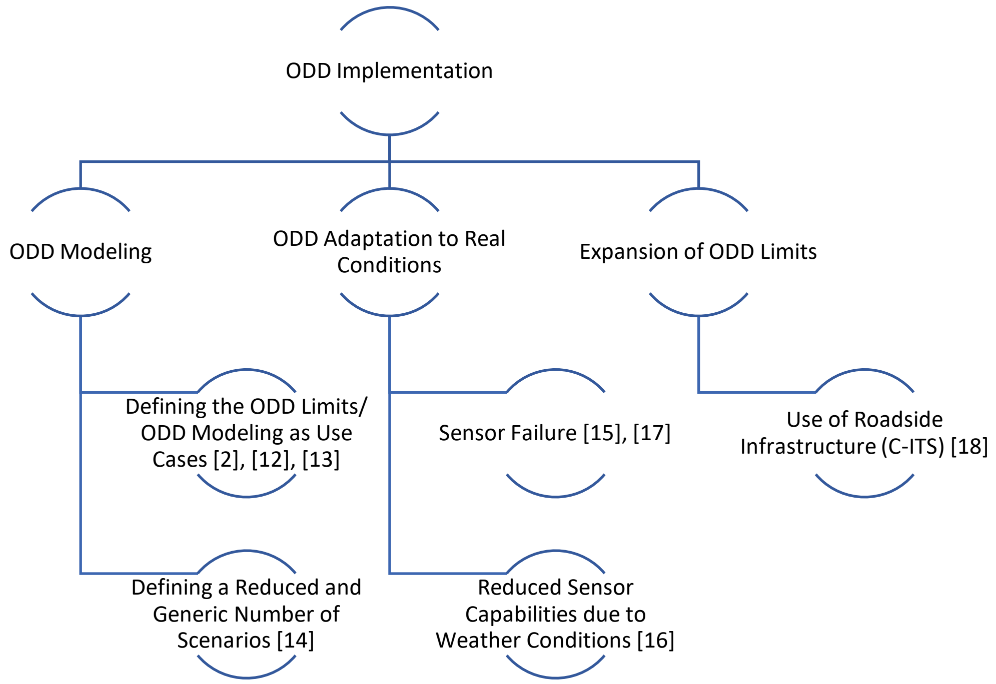

Figure 11: State-of-the-art solutions related to ODD implementation

Related to this figure, Table 12 provides the list of documents identified in this section and the type of issue addressed by these documents.

Table 12: List of documents related to the Implementation of an ODD

Issue considered	Document	Type
ODD Modeling Defining the ODD Limits/ODD Modeling as Use Case	[2]	Institutional
	[12]	Research
	[13]	Research
ODD Modeling Defining a reduced and generic number of scenarios	[14]	Research
ODD Adaptation to Real Conditions Sensor Failure	[15]	Research
	[16]	Research
ODD Adaptation to Real Conditions Reduced Sensor Capabilities due to Weather Conditions	[17]	Research
Expansion of ODD Limits Use of roadside infrastructure	[18]	Research

5.2 Modeling the ODD

ODD modeling is a first issue considered by the research studies focusing on the ODD implementation. The idea behind ODD modeling is to think about the use of the ODD taxonomy in a real environment/to integrate this ODD within vehicles. Existing work focuses on two ideas, 1) a direct application of this taxonomy and 2) the optimization/minimization of this taxonomy. Different technical terms can be associated with ODD modeling:

- Object and Event Detection and Response (OEDR) Subtasks of the Dynamic Driving Task that include monitoring the driving environment (detecting, recognizing, and classifying objects and events and preparing to respond as needed) and executing an appropriate response to such objects and events;

- Operating Conditions (OC): a set of conditions for operating a particular system or process.

These two terms are directly related to the idea of ODD implementation and aim to interconnect ODD to real situations (OC) or to the operation of the automated vehicle (OEDR).

5.2.1. Review – Document "Defining the ODD Limits/ODD Modeling as User Cases"

So far, three papers have specifically focused on this question [2], [12], [13].

The authors of [13] tried to propose an efficient and optimal modeling of the ODD intended to enable the automated and connected vehicle to check, in real-time, if it is still within the boundaries of its ODD. To do so, they proposed the definition of Operating Conditions (Dynamic Elements, Scenery, Connectivity, Actions and events, Goals and values, Functional range) that could be used to represent both Use Cases (UC) and ODD. Thus, by quantitatively representing ODD and UC thanks to the OC, it becomes possible to define the operating perimeter of the vehicle (set of UCs included in the ODD) and to ensure in real time that the OCs fall within this perimeter (OC are associated to UC that must be included in the vehicle ODD).

The method proposed in [2] is similar but much more simplistic. This institutional paper introduces a definition of the ODD taxonomy (cf. Section 2) and then proposes to directly apply this ODD taxonomy to road sections. Thus, depending on the type of road (surface), the type of zone (specific limitations, school, etc.) and the type of users, the authors determine in which sections an autonomous vehicle should or should not be allowed to circulate. Consequently, the ODD modeling therefore remains theoretical here (prior to the deployment of the vehicle) and not adaptive.

The objective of the authors of [12] is quite different of the authors of the two previous papers. For them the question is not only to model the ODD according to the taxonomy previously established but also to take into account the driver of the vehicle in this modeling. Indeed, these drivers could potentially be required to take control of the vehicle in complex situations. Therefore, it is necessary for them to be aware of the vehicle's ODD limits in order to know when these situations might occur. Thus, this study conducted in a Tesla Model S allowed these authors to observe that there is a real difference between the ODD specified by the Original Equipment Manufacturer (OEM) and the ODD felt by the driver. The interest of this study is therefore twofold, 1) it offers a methodology to compare the defined and perceived ODD 2) it demonstrates the importance of taking into account the drivers in the definition of the ODD for partially automated vehicles.

5.2.2. Review – Document "Defining a Reduced and Generic Number of Scenarios"

So far, this idea has only been considered in a single paper [14]. These authors start from the idea that defining, at the vehicle level, the ODD as the set of use cases managed by the ODD of this vehicle, as it is done in [13], is an unrealistic idea. Indeed, since the objective is to be able to check in real time that the vehicle is well within the limits of its ODD, the ODD must be defined in a minimalist way at the vehicle level. That is why, in this thesis manuscript, a new method is introduced. This method aims at defining a minimal set of use cases that could be used to describe all the scenarios that are covered by the ODD of this vehicle. Thus, the framework used to define these scenarios is presented and its benefits are highlighted. The main interest is to be able to speed up the verification at the vehicle level: to ensure that it is within its ODD it first compares the current Operating Conditions to this subset of scenarios and, if this is insufficient, it will combine some of them to determine whether or not it is within its ODD. Therefore, in most simple cases, this approach will limit the verification time. However, this solution is still in its infancy and many improvements are still needed before it can be applied: learning, efficient interfaces, safety, etc.

5.3 Adapting the ODD to Real Conditions

ODD adaptation to real conditions is a second issue considered by the research studies focusing on the ODD implementation. In this direction, two main ideas are considered, 1) sensor failure management and 2) reduced sensor capabilities management (due to weather conditions). Thus, the existing works, described in the sections (III.c.i, III.c.ii), propose responses to these two situations.
Different technical terms can be associated with this adaptation to real conditions:

- Minimal Risk Condition (MRC): Stable and stopped condition to which a user or an ADS brings a vehicle after performing DDT fallback, in order to reduce the risk of a crash when a given trip cannot be continued;

- Minimum Risk Maneuver (MRM): Tactical or operational maneuver triggered and executed by the user or the ADS to achieve the MRC;

- Transition of Control (TOC): Handover between automated a non-automated driving state;

- Restricted Operational Domain (ROD): Restricted version of the ODD in which ADS can still operate safety during changing system capabilities or faults (degraded mode);

- Degraded Operation Mode (DOM): A sub-optimal functional operating mode of a system or subsystem;

- Operational Design Conditions (ODC): a concept including driver status requirements (health, stress, etc.) in the ODD definition.

These different terms are therefore related to the real-time management of the vehicle's ODD. Four of these terms (MRC, MRM, TOC, ODC) are related to the management of a situation in which the vehicle no longer meets its ODD: mechanisms will then be used to stop the vehicle automatically and safely or to transfer the control of the vehicle to the driver. The last terms (ROD, DOM) are related to the adaptation of the vehicle's behavior (and of its ODD) to its real time capabilities (breakdown/failure of a sensor).

5.3.1. Review – Document "Sensor Failure"

Sensor failure is usually associated with the idea of ROD and, so far, two paper, written and published by same authors, have focused on this idea [15], [17].
In these papers, these authors aimed to propose a runtime representation of the ODD based on current system capabilities. In other words, they defined a solution to enable an automated and connected vehicle to keep operating within a safe domain and monitor the boundaries of the safe domain during changing system capabilities and faults. To enable that, they introduced two main ideas, 1) the mapping between ODD elements and high-level subsystem requirements, that could be used to determine which maneuvers could actually be done by the automated driving system, 2) the definition and implementation of and architecture enabling the real time monitoring of the system and the ODD management (system supervisor, system health monitor, ROD manager). Moreover, a proof of concept is presented to demonstrate the viability of the proposed approach. Finally, the future steps to enable the deployment of such a system are: an efficient mapping between ODD and system requirements and between DOM and ROD elements as well as a pre-definition of several DOM for each subsystem to guarantee a safe operation of automated vehicles.

5.3.2. Review – Document "Reduced Sensor Capabilities due to Weather Conditions"

So far, a single paper has proposed solutions aiming to adapt the vehicle's ODD to the reduction in the capabilities of some of its sensors [16]. The authors of this paper conducted a field test study in the Netherlands focusing on two functionalities of automated vehicles: Lane Departure Warning (LDW) and Lane Keeping Systems (LKS). During this experiment, they aimed to demonstrate that weather conditions and lane width have an impact on the performance of automated vehicle. In particular, they showed that LKS performance is degraded in lanes with a width less than 2.5m and in low visibility conditions (fog, rain). They also estimated an optimal speed for high detection performance. This demonstrates that the ODD of the vehicle cannot be constant as subsystem performance will be affected by external conditions. That is why the authors proposed to define different levels of ODD (low, medium, high) depending on these external conditions. They also highlight the need to extend such studies to different types of sensors and vehicles to enhance road safety and better determine the ODD of each automated and connected vehicle.

5.4 Expanding the ODD Limits

ODD limits expansion is a third issue considered by the research studies focusing on the ODD implementation. The idea here is to use the roadside infrastructure to increase the vehicle's perception and thus enable automated and connected vehicles to operate in new situations: areas, weather conditions, etc.

The terms associated with this expansion of the vehicle ODD limits are terms commonly used in the context of the autonomous and connected vehicles:

- Cooperative-Intelligent Transport Systems (C-ITS): C-ITS aims at increasing the level of safety and traffic flow using Infrastructure to Vehicles (I2V), Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications. It standardizes the protocol stack and the exchanges required for these communications;

- On-Board Unit (OBU)/RoadSide Unit (RSU): Basic building blocks of the C-ITS architecture, communication equipment deployed along roads (RSU) or within vehicles/mobile equipment (OBU) and which must allow the exchange of information between these entities;

- Traffic Management Centre (TMC): a roadside infrastructure collecting and combining information collected from vehicles and other operational and control data. This data processing is used to produce traveler information and to improve road safety.

So far, only one paper focused on the use of a roadside infrastructure to extend ODD validity/reduce ODD limitations [18]. This paper theoretically analyzes the impact that the use of a Traffic Management Centre could have in the context of the autonomous and connected vehicle. More specifically, through a case study, the authors demonstrate how in severe weather conditions (snow, fog, etc.) communications could allow the vehicle to be aware of its environment (other vehicles in traffic) and thus allow lane changes/overtaking/return to a minimal risk situation without requiring driver intervention. This paper also highlights the fact that even with the use of communications, equipment failure (non-transmission of information, latency, etc.) necessarily leads to risks that the authors propose to analyze in future work.

6 CONCLUSION

This paper presents a state of the art of the ODD with a focus on two main points, the ODD taxonomy and the implementation of the ODD. The work carried out in this study led to two main results: 1) the proposal of an ODD taxonomy 2) the proposal of an ODD implementation process.

6.1 Proposed ODD taxonomy

The proposed ODD taxonomy, resulting from the conducted study, is presented in Figure 12. This taxonomy is composed of six main elements:

1. Physical infrastructure: includes all the information related to the state of the physical infrastructure (Roadway type, roadway surface, roadway edge, roadway geometry, junctions, temporary structures, fixed surrounding structures, special structures, signage);
2. Scenery: includes all the information related to the scene, going beyond the physical infrastructure (specific zones, region/states, interference zones, geo-fencing);
3. Environmental conditions: includes all information related to weather conditions: precipitations, particulates, illumination, temperature, weather-induced roadway conditions - slippery road for example -);
4. Traffic conditions: includes all information related to traffic conditions (traffic density, road users – type, speed -, road users' behavior – accidents -);
5. Digital infrastructure: includes all information related to digital infrastructure and connectivity (type of information, radio access technology);
6. Vehicle capabilities: includes all information related to vehicle capabilities (maximal/authorized speed, maneuvers, vehicle dimensions).

This taxonomy includes elements that are not present in all the state-of-the-art taxonomies (see Section 4.2). This includes information relating to 1) other road users, 2) the digital infrastructure and 3) the vehicle itself. It seems necessary to take these parameters into account in the taxonomy. Indeed, any autonomous vehicle will not necessarily be able to operate under all types of traffic (types of vehicles, speed, non-motorized users, etc.), so it is necessary to consider the other road users (1). Similarly, the digital infrastructure could provide the vehicle with information that could extend its ODD (information on traffic, presence of pedestrians, etc.), so it is necessary to consider the information that can be provided by this digital infrastructure (2). Finally, on a given route, it may be required that the vehicle performs specific maneuvers. It might also face physical limitations (height, width, speed, etc.), so it is necessary to consider the subject vehicle (3).

It should be noted that a short description of the different terms used in this taxonomy is provided in the annex to this document (cf. section 8.1).

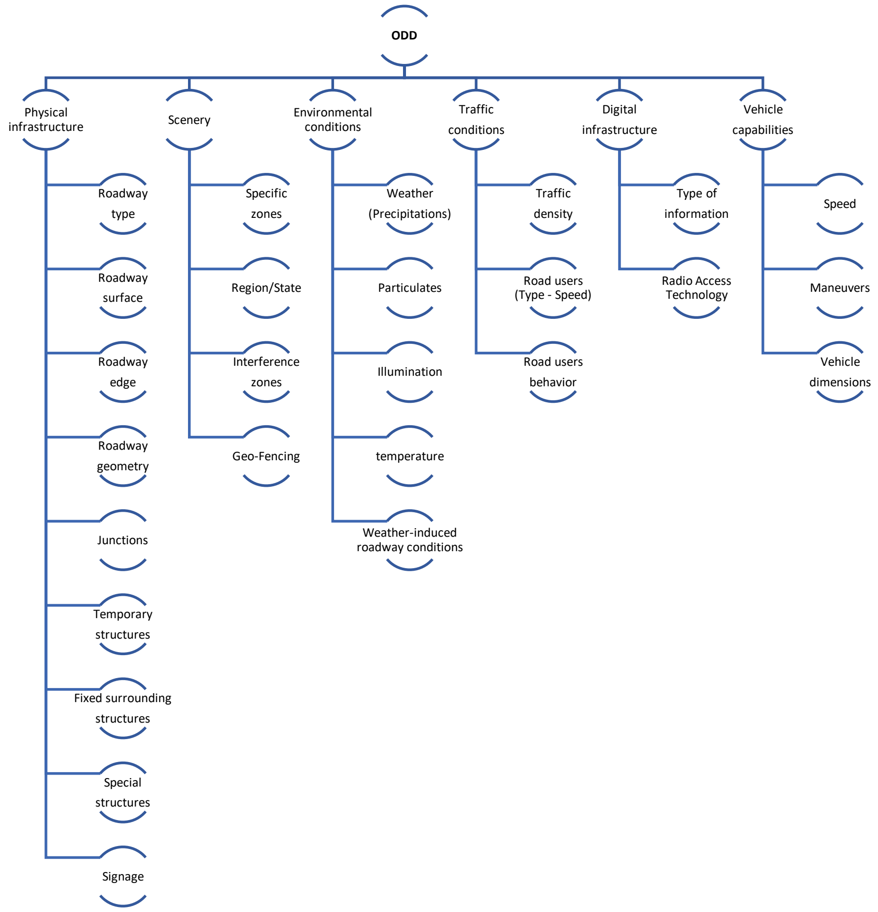

Figure 12 : Proposed ODD Taxonomy

6.2 Proposed solution for ODD implementation

Case of a pre-defined route:

The implementation of the taxonomy proposed in section 6.1 aims to determine the operating perimeter of a vehicle. To achieve this, three stages appear to be necessary:

1. First, the defined taxonomy can be used to identify the features of a pre-defined route. This stage could lead to the definition of a "sub-tree" of the proposed ODD taxonomy. This sub-tree would include the specific elements of that route, including the type of physical infrastructure, the scene, the possible weather conditions, the possible traffic conditions, the existing digital infrastructure and the required vehicle capacities.
2. Then, the defined taxonomy could be used to define the ODD of the system (vehicle). This would aim in particular at defining the limits of the vehicle, for example, the possible maneuvers, the type of intersections the system can handle or the type of traffic supported (type of users, speed, etc.).
3. Finally, the last stage would consist in comparing the ODD of the system and the pre-defined route ODD. Thus, the objective would be to determine whether the vehicle could drive on this predefined route and whether facilities would be required to make it possible (connectivity, physical infrastructure, etc.).

It should be noted that the taxonomy proposed in section 6.1 is intended to be generic. This means that the terms used in this taxonomy may evolve depending on the intended implementation. For example, if this taxonomy is used to define the features of a pre-defined route, the environmental restrictions will be defined. Therefore, regarding vehicle capacities, maximum dimensions and a set of necessary maneuvers will be defined. Thus, in this case, we could use the term of minimum vehicle capabilities. This could also be applied to other taxonomy elements: potential weather conditions, existing digital infrastructure, etc. On the contrary, if this taxonomy is used to define a system's ODD, the limits of this system will be defined. In this case, we could use the terms of maximum vehicle capabilities, supported weather conditions, required digital infrastructure.

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8 ANNEXES

8.1 Definition of the elements included in the proposed taxonomy

Below is proposed a short description of all the elements mentioned in the ODD taxonomy defined in section 6.1. (these descriptions will have to be completed during the next steps of the current work):

- Physical infrastructure: includes all the information related to the state of the physical infrastructure (Roadway type, roadway surface, roadway edge, roadway geometry, junctions, temporary structures, fixed surrounding structures, special structures, signage);
  - Roadway type: corresponds to the type of road that exists in the area/where the vehicle is able to travel (divided/undivided motorway, national road, emergency lane, etc.)
  - Roadway surface: corresponds to the type of surface that exists in the area/where the vehicle is able to travel (asphalt, gravel, etc.)
  - Roadway edge: corresponds to the type of edge that exists in the area/that can be handled by the vehicle (line markers, shoulder, concrete barriers, etc.)
  - Roadway geometry: corresponds to the roadway geometry that exists in the area/that can be handled by the vehicle (width, inclination - lateral/horizontal -, etc.)
  - Junctions: corresponds to the type of junctions that may be encountered in the area/that may be supported by the vehicle (roundabout - signalized/unsignalized -, lane junction, etc.)

  - Temporary Structures: corresponds to the type of temporary structures that may be encountered in the area/that can be supported by the vehicle (constructions, works, etc.)
  - Fixed surrounding structures: corresponds to the type of surrounding structures that may be encountered in the area/that may impact the vehicle (buildings, vegetation, advertising, etc.)
  - Special structures: corresponds to the type of structures that may be encountered in the area/that may impact the vehicle (pedestrian crossing, toll gate, train track crossing, etc.)
  - Signage: corresponds to the type of signage that may be encountered in the area/that can be supported by the vehicle (traffic signs, traffic lights, etc.)
- Scenery: includes all the information related to the scene, going beyond the physical infrastructure (specific zones, region/states, interference zones, geo-fencing)
  - Specific zones: corresponds to areas that may have specific speed or mobility restrictions (school, hospital, etc.)
  - Region/State: corresponds to constraints that may be related to the region/department/state in which the vehicle is travelling (speed, traffic lane, etc.)
  - Interference zones: corresponds to areas where interference may occur (tunnels, garages/parking, etc.)
  - Geo-fencing: potentially corresponds to a limitation of the areas in which the travel of automated and connected vehicles is allowed
- Environmental conditions: Environmental conditions: includes all information related to weather conditions: precipitations, particulates, illumination, temperature, weather-induced roadway conditions - slippery road for example -)
  - Weather: corresponds to the type of weather (precipitation level) that may be encountered in an area/supported by the vehicle (rain, snow, etc.)
  - Particulates: corresponds to the type of particulates that may be encountered in an area/supported by the vehicle (smoke, fog, sand, etc.)
  - Illumination: corresponds to the type of light that may be experienced in an area/supported by the vehicle (sun - elevation, brightness -, clouds - partial, total, etc. -, night, artificial lighting, etc.)
  - Temperature: corresponds to the temperature range that may be experienced in an area/supported by the vehicle
  - Weather-induced roadway conditions: corresponds to traffic conditions that may be experienced in an area/supported by the vehicle (slippery road - rain, ice, snow -, snowy road, submerged road, etc.)
- Traffic conditions: includes all information related to traffic conditions (traffic density, road users – type, speed -, road users' behavior – accidents -)
  - Traffic density: corresponds to the level of traffic density that the vehicle can support/that can be experienced in that area (potentially LOS A-F)
  - Road users (Type – Speed): corresponds to the type of users that may be present in that area/that the vehicle can support. These may be motorized (car, bus, etc.) or non-motorized (pedestrian, cyclist, etc.) users or other types (animal, debris, etc.)

  - Road users' behavior: corresponds to area-specific mobility patterns or area-specific accident levels
- Digital infrastructure: includes all information related to digital infrastructure and connectivity (type of information, radio access technology)
  - Type of information: corresponds to the type of information that can be provided to the vehicle/required for its operation (GPS, 3D High Definition Maps, Weather conditions, etc.)
  - Radio Access Technology: corresponds to the type of access network that the vehicle can use to retrieve this information (cellular – 4G, 5G-, ITS-G5, etc.)
- Vehicle capabilities: includes all information related to vehicle capabilities (maximal/authorized speed, maneuvers, vehicle dimensions
  - Speed: corresponds to the maximum speed required/permitted by the considered vehicle
  - Maneuvers: corresponds to all the maneuvers that could/should be performed by the considered vehicle (U-turn, sudden braking, etc.)
  - Vehicle dimensions: corresponds to the actual/tolerated maximum dimensions of the considered vehicle (length, width, height, etc.)