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AVSC Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon

Rationale

This document provides a conceptual framework and the parameters of interest, along with operational definitions, that manufacturers and developers can use to describe an Automated Driving System (ADS) Operational Design Domain (ODD). The document seeks to establish commonly defined terms and a framework in which to apply them. Where applicable, labels, definitions, and measurement ranges are provided to promote consistent communication and help ensure that users' ADS expectations are aligned with capabilities.

Preface

The Automated Vehicle Safety Consortium™ (AVSC) is an industry program of SAE Industry Technologies Consortia (SAE ITC®) working to quickly publish best practices that will inform and lead to industry-wide standards advancing the safe deployment of automated driving systems (ADSs). The members of this consortium have decades of accumulated experience focused on safe, reliable and high-quality transportation. They are committed to applying those principles to SAE level 4 and level 5 automated vehicles so that communities, government entities and the public can be confident that these vehicles will be deployed safely.

The Consortium recognizes the need to establish best practices for the safe operation of ADS-dedicated vehicles (ADS-DVs). These technology-neutral practices are key considerations for safely deploying ADS-DVs on public roads. Members of the AVSC intend to support the published principles and best practices in an effort to establish a suggested level for other industry participants to meet. These best practices will serve as a basis to enhance and expedite the formal industry standards development process through SAE International and other global standards development bodies. Effectively implementing these principles can help inform the development of sound and effective ADS regulations and safety assurance testing protocols that will engender public confidence in the efficacy of ADS-DVs.

Comment and open discussion on the topics are welcome in appropriate industry forums. As discussion unfolds, AVSC documents will be revised as significant information and/or new approaches come to light that would increase public trust.

Introduction

In 2016, the National Highway Traffic Safety Administration (NHTSA) published *Accelerating the Next Revolution in Roadway Safety*, [1] the first published U.S. document pertaining to automated vehicle guidance. This guidance was amended in 2017 establishing a structure for voluntary safety self-assessments (VSSAs) for automated vehicles, suggesting that developers "demonstrate to the public (particularly States and consumers) that entities are: (1) considering the safety aspects of ADSs; (2) communicating and collaborating with DOT; (3) encouraging the self-establishment of industry safety norms for ADSs; and (4) building public trust, acceptance, and confidence through transparent testing and deployment of ADSs. It also allows companies an opportunity to showcase their approach to safety, without needing to reveal proprietary intellectual property" [2, p. 16].

NHTSA guidance further suggests the "ODD should describe the specific conditions under which a given ADS or feature is intended to function." [2, p. 6]. The conceptual framework presented herein establishes a consistent lexicon that can be used by ADS developers and manufacturers responsible for defining their ADS ODD. A common framework and lexicon will reduce confusion, align expectations, and therefore build public trust, acceptance, and confidence.

Research is ongoing in other various organizations and across multiple projects to define and organize ODD elements into taxonomies and other relational constructs that developers might use to define their ODDs. Some examples of earlier and ongoing efforts include NHTSA's "A Framework for Automated Driving System Testable Cases and Scenarios" [3], Project Pegasus [4], and TNO StreetWise [5]. A common conceptual framework and lexicon that provides a balanced approach between level of granularity (abstraction) and usability are important. Guidance is needed on that level of granularity given that current regulations and standards assume human control of vehicles at all times, and therefore do not comprehend the concept of a limited ODD. Future standards should consider the ADS ODD capabilities and limitations.

Moreover, ADS ODD forms the foundation for the development of relevant tests that manufacturers and developers can apply consistently. This consistency, in turn, will lead to appropriate performance expectations on the part of the public regarding the locations and conditions in which ADS-operated vehicles will be designed to operate. It is important to acknowledge, however, that the manner in which ODD variables are perceived by ADS will vary from developer to developer and that ADS perception systems and the fusion algorithms that combine those inputs vary significantly from human capabilities. An ODD narrative helps stakeholders understand and relate to the operational conditions for which the ADS-DV was designed.

An ADS-operated vehicle's ODD is defined by the manufacturer based on numerous factors. For example, the technical capabilities of an ADS and its subsystems could be dependent on a particular technology, use case, or business model. Among other aspects that could influence ODD design directly or indirectly are complexity and risk management associated with the deployed system. As such, the ODD is part and parcel of a product's overall design and does not lend itself to external specification except in terms of specific limits imposed by regulatory authorities (e.g., local ordinances prohibiting driverless operation of ADS in certain zones at certain times). Moreover, and for the same reasons, it is also not possible to determine an ADS-operated vehicle's complete ODD through testing by a third party. Therefore, it is incumbent upon ADS manufacturers to describe their products' ODD with enough specificity to not only satisfy customer expectations, but also the needs of regulators and road operators.

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1. Scope

This Automated Vehicle Safety Consortium (AVSC) *Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon* (AVSC00002202004) **addresses a conceptual framework and lexicon manufacturers and developers can use in describing the ODD for their ADS-operated vehicles and communicating this with users and the public**. To that end, this document also provides an initial detailed list of *potential* variables with definitions that manufacturers and developers can use in describing the ODDs of their ADS-operated vehicles. The objective is to provide common terms across the industry. This lexicon is expected to grow as needed to accommodate changes in technology and the legitimate needs of stakeholders.

The document was developed with fleet-managed, SAE level 4 ADS-operated vehicles in mind[1]. SAE level 5 ADS is outside the scope of this discussion. This document is not a comprehensive list of all possible elements that may constitute an ODD. The ODD is a design element in ADS development which may vary according to specific product concerns that are not reflected in this document. ADS planning and vehicle behaviors based on elements within an ODD are not within the scope of this document.

Where appropriate, references are made to existing technical documentation, standards, or other commonly understood practices. This includes references that may not normally be used by the automotive sector such as technical descriptions of weather and pavement roughness. Common definitions in a conceptual framework lend themselves to future performance standards and tests. These tests are outside the scope of this document.

1.1 Purpose

This best practice provides a way to frame discussions around ODD for SAE level 4, fleet-managed, ADS-operated vehicles. This document describes how ODD is defined for public understanding during the development, testing, and deployment of SAE level 4 ADS. The document provides a conceptual framework and descriptive lexicon of available terms in order to facilitate discussions where understanding a given ADS ODD might be beneficial. It is the intention that this document serves as the foundation for the open standards process to accelerate the development of relevant industry standards.

The guidance provided in this document is intended for the technical community (e.g. developers, manufacturers, testers), as well as states, infrastructure owner-operators (IOOs), and the public. Individual developers should tailor programs and documentation to augment their ODD definitions where appropriate. States, municipalities, and IOOs

[1] NOTE: While the AVSC intends to advance the safe deployment of both SAE level 4 *and* SAE level 5 systems, level 5 as defined in SAE J3016_2018-06, is not limited by operational design domain; therefore, discussion of ODD does not apply to SAE level 5.

can utilize this document as a template for questions to pose to developers and technology companies wanting to operate in their jurisdictions. Constructing a conceptual ODD framework entails:

1. Identifying the road/route network;
2. Characterizing the fixed-route network and infrastructure;
3. Identifying operational constraints within the road/route network; and
4. Formulating a descriptive narrative.

2. References

2.1 Applicable Documents

The following publications were referenced during development of this document. Where appropriate documents are cited.

2.1.1 SAE Publications

Unless otherwise indicated, the latest issue of SAE publications apply. Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J3016_201806 Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles

SAE J3018_201909 Safety-Relevant Guidance for On-Road Testing of SAE Level 3, 4, and 5 Prototype Automated Driving System (ADS)-Operated Vehicles

SAE J2980_201804 Considerations for ISO 26262 ASIL Hazard Classification

SAE J3194_201911 Taxonomy and Classification of Powered Micromobility Vehicles

2.1.2 Other Documents

1. NHTSA, “Federal Automated Vehicle Policy: Accelerating the next revolution in roadway safety,” National Highway Traffic Safety Administration (NHTSA), Washington, D.C., 2016.
2. NHTSA, “Automated Driving Systems 2.0: A vision for safety,” National Highway Traffic Safety Administration (NHTSA), Washington, D.C., 2017.
3. Thorn E., Kimmel S. and Chaka M., “A Framework for Automated Driving Systems Testable Cases and Scenarios,” U.S. Department of Transportation National Highway Traffic Safety Administration, Washington, D.C., 2018.
4. “Project Pegasus,” [Online]. Available: https://www.pegasusprojekt.de/en/about-PEGASUS.
5. “TNO StreetWise,” [Online]. Available: https://www.tno.nl/en/focus-areas/traffic-transport/expertise-groups/research-on-integrated-vehicle-safety/scenario-based-safety-validation-for-connected-and-automated-driving/.
6. Singapore Standards Council, “Technical Reference: Autonomous Vehicles - Part 3: Cybersecurity principles and assessment framework,” Enterprise Singapore, Singapore, 2019.
7. Fores G., “Urban Roadway Classification: Before the design begins,” in *Urban Street Symposium Conference Proceedings*, Dallas, TX, 1999.
8. Federal Highway Administration, “Manual on Uniform Traffic Control Devices,” U.S. Department of Transportation, Washington, D.C., 2009.
9. American Assoication of State Highway and Transportation Officials, *A Policy on Geometric Design of Highways and Streets: 7th Ed.* (Washington, D.C.: AASHTO, 2018).
10. Bagschik, G., Menzel, T., and Maurer, M., *Ontology Based Scene Creation for the Development of Automated Vehicles* (Braunschweig, Germany: Technische Universitat Braunschweig, 2017).
11. “Naval Oceanography Portal,” [Online]. Available: https://www.usno.navy.mil/. [Accessed 2019].
12. Fraade-Blanar L., Blumenthal M.S., Anderson J.M. and Kalra N., “Measuring Automated Vehicle Safety: Forging a framework,” RAND Corporation, Santa Monica, CA, 2018.
13. Linde, C., “Narrative and Tacit Social Knowledge,” *Journal of Knowledge Management, Special Issue on Tacit Knowledge Exchange* 3(5), 2001.

14. American Meteorological Society, "Glossary of Meteorology," [Online]. Available: http://glossary.ametsoc.org/wiki. [Accessed 16 April 2019].
15. North Carolina Climate Office, "Education," North Carolina State University, [Online]. Available: https://climate.ncsu.edu/edu/home. [Accessed 15 April 2019].
16. American Meteorological Society, "Rain," American Meteorological Society, 25 April 2012. [Online]. Available: http://glossary.ametsoc.org/wiki/Rain. [Accessed 20 May 2019].
17. American Meteorological Society, "Meteorology Glossary," [Online]. Available: http://glossary.ametsoc.org/wiki/Mist. [Accessed 17 February 2020].
18. Encyclopaedia Britannica, "Rime - Weather," Encyclopaedia Britannica, 1998. [Online]. Available: https://www.britannica.com/science/rime-weather. [Accessed 22 October 2019].
19. San Joajuin Valley, Weather Forecast Office, "HNX Experimental Fog Severity Index," US Dept of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, [Online]. Available: https://www.weather.gov/hnx/HNXFogSI.html. [Accessed 22 October 2019].
20. American Meteorological Society, "Glossary of Meteorology," AMETSOC, 23 July 2013. [Online]. Available: http://glossary.ametsoc.org/wiki/Snow. [Accessed 21 May 2019].
21. Meteorological Office (UK), "What is the difference between mist, fog and haze?," [Online]. Available: https://www.metoffice.gov.uk/weather/learn-about/weather/types-of-weather/fog/difference-mist-and-fog. [Accessed 17 February 2020].
22. Byram G.M. and Jemison G.M., "Some Principles of Visibility and their Application to Forest Fire Detection," U.S. Department of Agriculture, 1948.
23. National Weather Service, "Forecast Terms," [Online]. Available: https://www.weather.gov/bgm/forecast_terms. [Accessed 15 April 2019].
24. Georgia State University, "Hyperphysics," Nave, 2015. [Online]. Available: http://hyperphysics.phy-astr.gsu.edu/hbase/vision/lumpow.html#c1. [Accessed 15 October 2019].
25. U.S. Naval Observatory, "Rise, Set, and Twilight Definitions," Astronomical Applications Department, [Online]. Available: https://aa.usno.navy.mil/faq/docs/RST_defs.php. [Accessed 20 May 2019].
26. National Oceanic and Atmospheric Administration, "Beaufort Wind Scale," National Weather Service Storm Prediction Center, [Online]. Available: https://www.spc.noaa.gov/faq/tornado/beaufort.html. [Accessed 22 May 2019].
27. PIARC - World Road Association, "Road Dictionary," PIARC, 2019. [Online]. Available: https://www.piarc.org/en/activities/Road-Dictionary-Terminology-Road-Transport/term-sheet/93216-en-surface+condition?search=%7B%22q%22%3A%22condition%22%2C%22s%22%3A%22en%22%2C%22scope%22%3A%22term%22%7D. [Accessed 29 November 2019].
28. City of Eugene, Oregon, City Manager's Office, "Street Repair Terminology," City of Eugene, Oregon, City Manager's Office, [Online]. Available: https://www.eugene-or.gov/1650/Street-Repair-Terminology. [Accessed 19 November 2019].
29. Oxford, "Oxford English Dictionary," Oxford, [Online]. Available: https://en.oxforddictionaries.com/definition/pothole. [Accessed 23 April 2019].
30. Lavin, P., *Asphalt Pavements: A Practical Guide to Design, Production, and Maintenance for Engineers and Architects* (CRC Press, 2003).
31. Forbes G. and Robinson J., "The Safety Impact of Vehicle-Related Road Debris," AAA Foundation for Traffic Safety, 2004.
32. Project Management & Engineering Department, "Chapter 1: Streets," . In: *Design Criteria Manual.* (Municipality of Anchorage, Anchorage, AK, 2007).
33. Khoso A.K., "How to Better Enforce the Dedicated Lanes Use?," in *Proceedings of the 25th World Road Congress - Seoul 2015: Roads and Mobility - Creating New Value from Transport*, Seoul, ROK, 2015.
34. Lefler Nancy, "Model Inventory of Roadway Elements - MIRE 2.0," Federal Highway Administration, Washington, DC, 2017.
35. U.S. Department of Transportation, "Beyond Traffic: 2045 Final Report," USDOT, Washington, D.C., 2017.
36. Google Maps, "Map of Detroit, Michigan," [Online]. Available: https://www.google.com/maps/place/Detroit,+MI/@42.3523699,-83.169275,12z/data=!4m5!3m4!1s0x8824ca0110cb1d75:0x5776864e35b9c4d2!8m2!3d42.331427!4d-83.0457538. [Accessed 15 January 2020].

37. Federal Highway Administration, "Highway Functional Classification Concepts, Criteria and Procedures," U.S. Department of Transportation, Washington, D.C., 2013.
38. Federal Highway Administration, "Traffic Control Device Conspicuity," FHWA, Washington, D.C., 2013.
39. National Optical Astronomy Observatory (NOAO), "Recommended Light Levels (illuminance) for Outdoor and Indoor Venues," Association of Universities for Research in Astronomy (AURA), [Online]. Available: https://www.noao.edu/education/QLTkit/ACTIVITY_Documents/Safety/LightLevels_outdoor+indoor.pdf. [Accessed 20 May 2019].
40. City of Boulder, "Pavement Condition Index," City of Boulder, CO, 2019. [Online]. Available: https://bouldercolorado.gov/boulder-measures/pavement-condition-index. [Accessed 29 November 2019].
41. Pierce L.M., McGovern G. and Zimmerman K.A., "Practical Guide for Quality Management of Pavement Condition Data Collection," Federal Highway Administration, Washington, DC, 2013.
42. Dingus Thomas A., "Enhanced Night Visibility Series," Federal Highway Administration, McLean, VA, 2005.
43. ASTM International, "Standard Practice for Computing International Roughness Index of Roads from Longitudinal Profile Measurements," ASTM International, West Conshohocken, PA, 2003.

3. Definitions

INTENDED USE: "A description of how the AV shall be deployed, including the ODD and any risk mitigations employed in the deployment …." [6, p. 18].

OPERATIONAL DESIGN DOMAIN (ODD) (SAE J3016_201806): Operating conditions under which a given driving automation system or feature thereof is specifically 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.

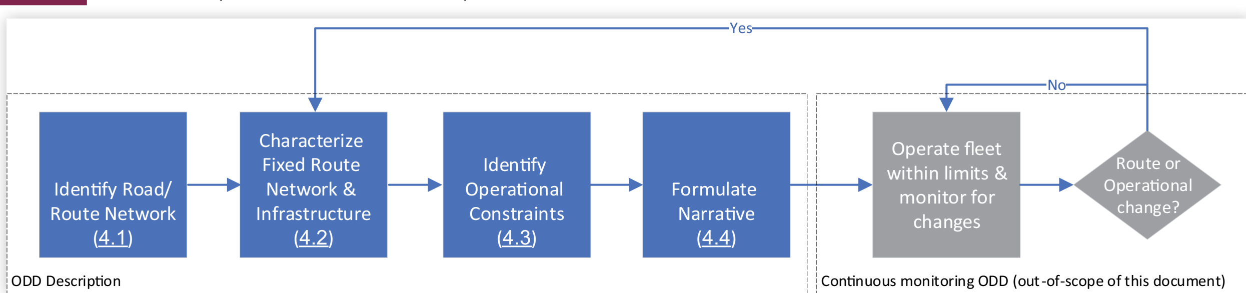
4. Operational Design Domain – Conceptual Framework

For the near term, ADSs will have defined ODDs. In conceptual terms, once a developer conceives of a service or use case, identifies a population to serve, and begins technical development, the road network appropriate for that use case must be identified and characterized. There are, then, generally two options for defining a conceptual framework for an ODD- a top-down or a bottom-up approach.

Describing the ODD can be done using a *top-down* approach based on general, functional classifications of roadways (e.g., the vehicle operates on minor arterials and collector roads). The top-down approach is complicated due to the subjective and inconsistent application of functional classifications for roadways [7]. A *bottom-up* approach leverages specific, mapped routes and makes the challenge of identifying objects and scenarios more tractable.

This best practice recommends the bottom-up approach outlined in this section and depicted in Figure 1. It enables a better understanding of (local) environmental conditions, roadway geometries, physical infrastructure, zones, and the behaviors of other road users. This recommendation and approach may be modified as technology advances and more knowledge and experiences are gained.

FIGURE 1 ODD Conceptual Framework Description



Level 4 ADS-DVs are confined to geo-fenced locations. They also typically have other ODD constraints such as inclement weather and/or time-of-day restrictions. With respect to geo-fence ODD parameters, an ADS-DV will not exit its geo-fence while engaged under normal operating conditions. While the bottom-up approach is useful for manufacturers defining their ODD, the level of detail communicated will vary depending on the stakeholder (audience). Generalized descriptions will help manufacturers communicate with the public and other stakeholders.

Colloquially, ODDs are described in terms related to their general operational setting (e.g. highway, urban, campus) and broad descriptions of the elements associated with the setting. The example conditions described in the SAE J3016 definition such as "weather" can be further decomposed into elements and parameters. For example, a *condition* associated with a manufacturer's ODD such as *weather* may include *elements* such as *rainfall rate* or *fog* which may be further parameterized in terms of *light rain, moderate rate, or heavy rain* and fog *severity index 1 thru 5*. Parameters can be used to provide quantitative values (or ranges of values) to the labels more familiar to the public. The following sections provide more details on how this concept can be applied within the framework.

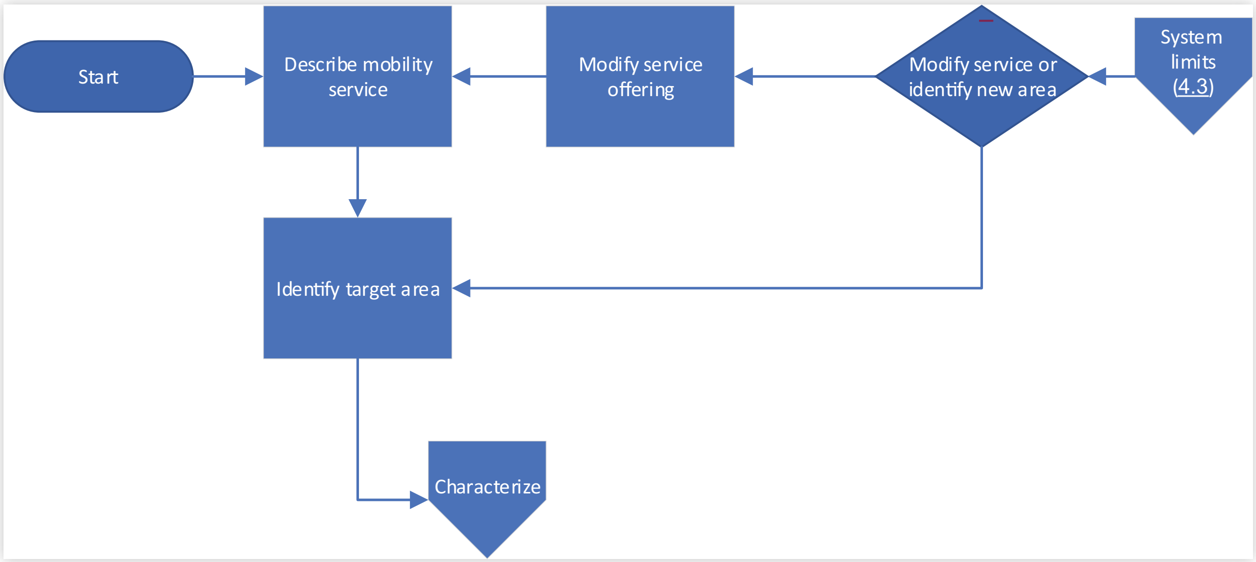
4.1 Identify the Road/Route Network

The first step in describing an ODD for ADS-operated vehicles, following the bottom-up approach, is to identify and map the road network on which the ADS-operated vehicle will be deployed. Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) provide guidance on the geometric design of various types of roadways which are significant elements of the physical infrastructure [8] [9]. Labeling roadways as arterials, collectors, or local roads, however, is a subjective process with sub-categories and qualifiers that complicate labels. This limits the practical use of functional classifications for ADS-operated vehicles ODD descriptions. Using the conceptual framework and definitions for variables provided in this document eliminates this labeling problem by identifying specific roadways (routes) or specific areas (route networks) versus naming a functional class of roadway.[2]

Identify a route, set of routes, or road network (geographic area) to match the intended use case for the ADS-operated vehicle. Mapping or obtaining and validating an existing map may also be included at this stage. Bounding the domain geographically limits the expected interactions and will more easily allow developers to identify the most relevant test cases. It also creates boundaries around the environmental conditions that can be expected (e.g. snow, rain, wind). As the system evolves, limitations to allowable routes may change creating a feedback loop within the framework for describing an ODD.

Figure 2 provides a detailed view of this part of the conceptual framework. Examples are presented in Appendix B.

FIGURE 2 Identify the Road / Route Network



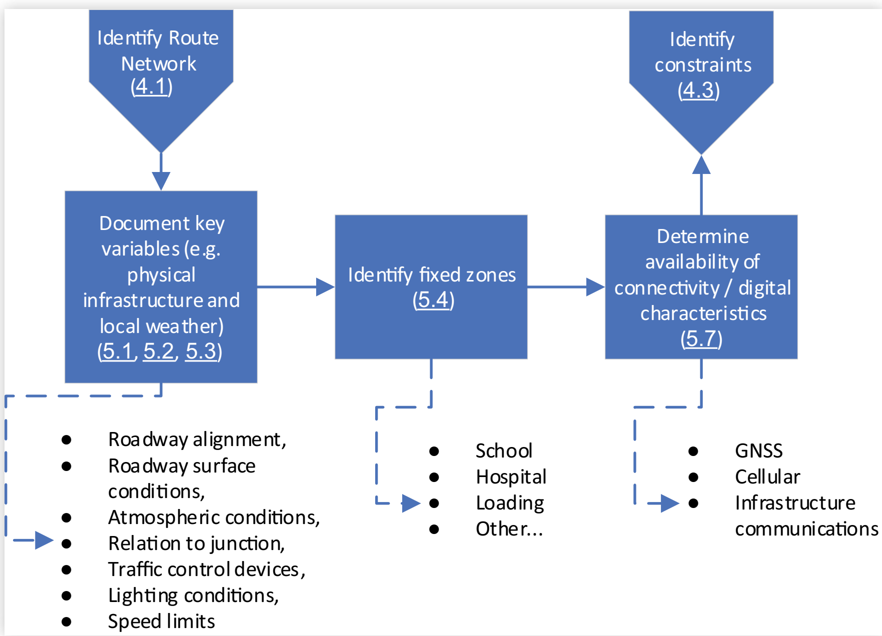
[2] Defining an ODD by the type of road is impractical because of the myriad road-specific variables that must be taken into account but are not comprehended by a functional description of a road type. The FHWA classifies roadways into eight types of functional types: urban/rural principle arterial; urban/rural minor arterial; urban/rural collector; and urban/rural local [37]

4.2 Characterize the Fixed Route Network and Infrastructure

Defining an ODD using mapped routes or route networks establishes knowable boundaries and reduces the number of challenges associated with characterizing an ODD compared to more general descriptions based on functional classifications. A fixed route network (or fixed route, if the ADS is limited to a single route) constitutes the foundation of the ODD description. The characteristics of the fixed network and infrastructure add a layer of detail to the road/route network already identified. These characteristics describe elements of the ODD relevant to the operation of an ADS [10]. Documented characteristics allow manufacturers and developers to focus on specific local road/route features and conditions (such as *local* weather, *local* customs, and anomalies) making the deployment of an effective ADS and the description of its ODD tractable.

Characteristics can include specialized zones described by NHTSA [3], required infrastructural elements, and/or areas that pose operational challenges to the specific ADS-operated vehicles (e.g., blind turns, roundabouts, tunnels). These may be clearly delineated and fixed (e.g. school zones), clearly delineated and dynamic (e.g. work zones), or areas that lack physical markers but become known over time through their physical characteristics (e.g. areas prone to flooding). Certain environmental conditions can be characterized for specific geographies and specific times and are knowable in advance. For example, the angle of the sun is measured by the U.S. Naval Observatory [11] and is knowable for given locations throughout the day. Figure 3 shows recommended attributes associated with route network characterization. While the level of detail under each step in the framework may vary or have no information (e.g. a route or route network may include no fixed zones), each of these steps should be addressed. The definitions provided in the lexicon (Section 5) are provided as the foundation for a common reference. Manufacturers will determine which characteristics are included in their ODD narrative.

FIGURE 3 Characterize the Fixed Route Network and Infrastructure

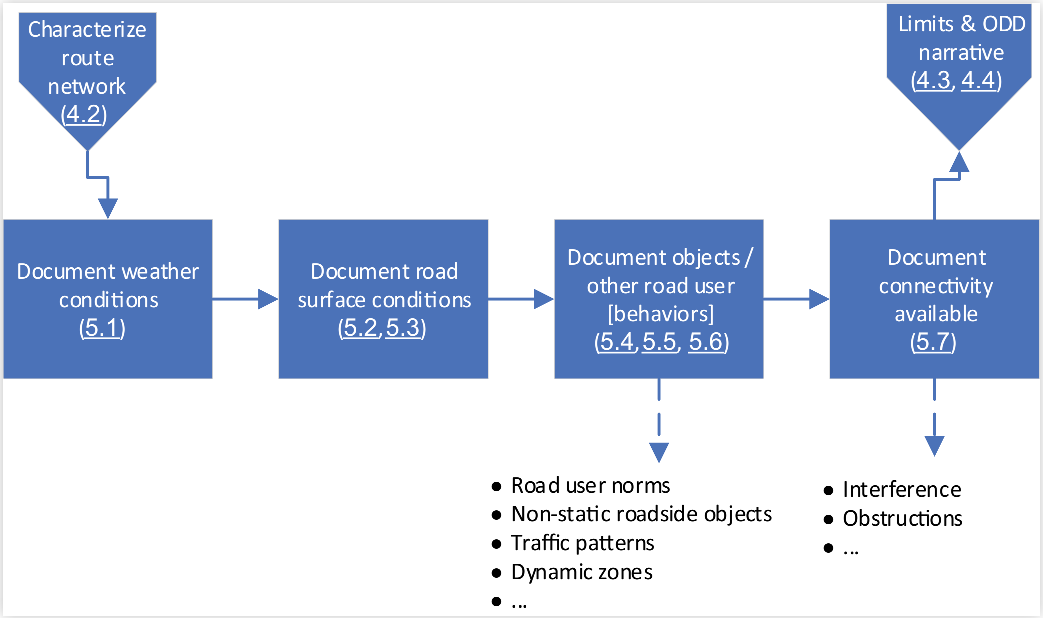


4.3 Identify Operational Constraints within the Road/Route Network

Identifying operational constraints is when ADS developers apply the capabilities and limitations of their ADS to their understanding of the route network characteristics described earlier. SAE level 4 ADS-DVs are responsible for keeping within their ODD. Because of this the ODD definition must be defined in terms identifiable or inferable by the ADS [12]. For fleet-operated vehicles this may include communications from the fleet operations center or other sources of ODD-relevant data.

Identification of operational constraints involves testing the ADS on the subject road/route network in order to identify objects, zones, conditions, events, etc. that the ADS-operated vehicle will be designed to avoid (see Figure 4). This supports the concept of a system that is safe by design because the ADS operation is only allowed in areas that are understood and appropriate to its capabilities.

FIGURE 4 Identify Operational Constraints within the Road/Route Network



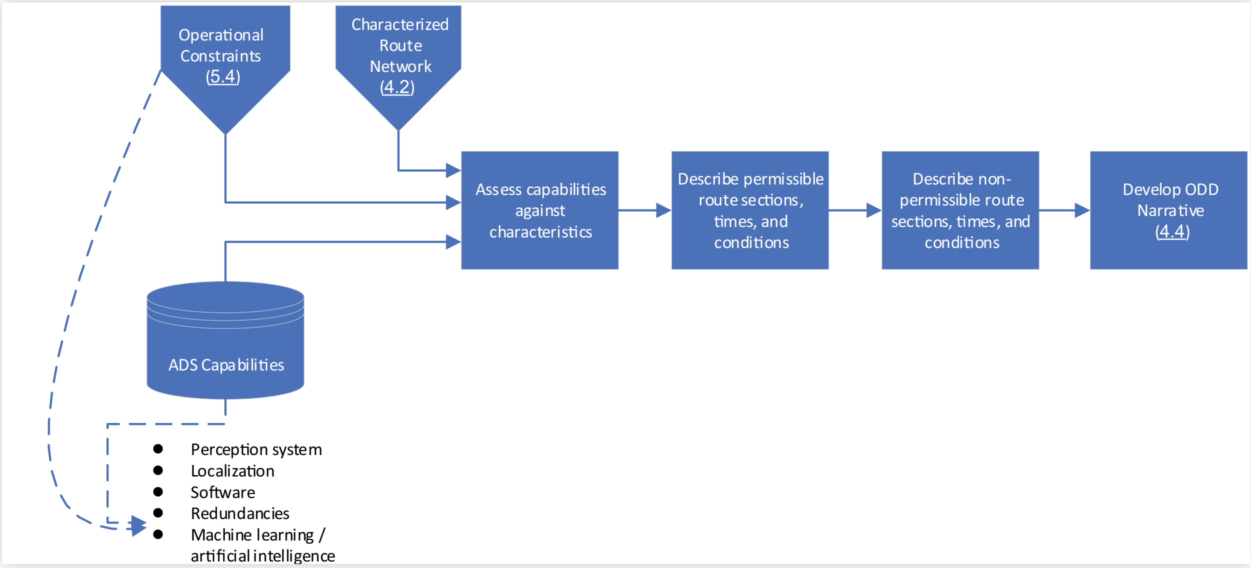
Weather conditions are likely to be most easily described in terms of constraints, but this may not always be the case and the permissive set of weather-related environmental conditions may be simpler to describe. SAE level 4 ADS-operated vehicles can identify and accommodate hazards within their ODD. Changes to the ODD, such as long-term work zones on or along a route/route network, that alter previously characterized routes may warrant an update of the ODD description. This will depend on the extent and duration of the change to the route/route network and also the type of narrative used by the manufacturer (see examples in Appendix B).

4.4 Formulate Narrative

Narratives convey both direct and implied information [13]. When a manufacturer/developer describes the ODD for their ADS-operated vehicle, they are creating a narrative to communicate with ADS-DV users, IOOs, and other road users about the system and its capabilities.

This part of the framework compares ADS capabilities to the route network characterization and the operational constraints completed earlier. Descriptions are framed in terms of permissive and non-permissive elements (see Figure 5). Routes (including intersections and other physical infrastructure), route characteristics (e.g. environmental conditions), and operational conditions that accommodate the ADS are considered permissive. Route sections and conditions beyond the ADS's ability to reliably handle are non-permissive. Permissive and non-permissive criteria are specific to each ADS and each route network (see examples in Appendix B).

FIGURE 5 Formulate Narrative



Increased consistency through publication and adherence to this framework will increase public awareness of the myriad considerations involved in safely deploying ADS-operated vehicles. This awareness will hold developers to a high standard and encourage detail and clarity in the definition of ODDs. It can also serve as part of the foundation for future discussions on ADS safety assurance.

5. Lexicon

This section provides some terminology manufacturers and developers can use in describing their ODD. Where possible, labels, semantic descriptions, and descriptions using ranges of values are provided. This facilitates brief ODD narratives using terms with which many stakeholders are familiar while also possibly providing testable values during development of the technology. These terms define environmental variables related to the road network, perception limitations, surface conditions which may affect ADS-DV performance, and expected road users. Definitions are consolidated from many sources such as AASHTO; the National Weather Service (NWS); and the National Oceanic and Atmospheric Administration (NOAA), among others. Elements associated with ODD conditions are defined and parameters are included, where available. The use of commonly agreed semantic categories and labels for identifying objects and conditions of an ODD support public acceptance, as well as transportation management goals. Common definitions for fixed aspects of the infrastructure and parameters (data ranges) for these variables can also inform standardized testing protocols.

For clarity, relevant industry standard terms and definitions are reproduced here. Where noted, definitions have been modified to be more appropriate to ADS deployment. This lexicon is not intended to be comprehensive but is provided as an exemplar for a common lexicon from which developers can select or derive terms to describe ODDs in terms that are permissive and/or non-permissive.

The use of these terms in the description of a product's ODD does not necessarily mean the ADS uses those elements or parameters to make operational decisions with regard to DDT or fallback performance. Many of the variables included in this document (e.g., weather, road surface conditions) are described using terms developers can use to be understood by humans. It should be noted that an ADS will not perceive many of these variables the same way humans do, so they may not be suitable for an ex post analysis for how an ADS should have behaved in any given scenario.[3] For example, a permissible element in an ODD description might include 'moderate rain'. This doesn't mean that the ADS will monitor rainfall in real time. The label describes a proxy for the amount of occlusion in the perception system and the impact of that occlusion combined with other variables on overall system performance. In this example, developers may include the semantic label 'moderate rain' in an ODD description so humans can create a reasonable (not exact) expectation of system availability.

[3] See SAE standards related to event data recording and logging at www.sae.org.

5.1 Weather-Related Environmental Conditions

Weather conditions are qualifiers that may impact an ADS's performance in a physical domain that has otherwise been characterized.

5.1.1 Temperature

Operating temperatures (upper and lower limits) may be included in a manufacturer's ODD description. If used, temperature should be described in terms of ambient air temperature.

5.1.2 Precipitation Types

The American Meteorological Society (AMS) [14] provides common-language descriptions of precipitation that can be useful to developers for describing their ODD.[4]

5.1.2.1 Rain. Water droplets of 0.5mm or greater [14]. In air below 0° F, raindrops may start as snow or ice crystals but melt when they fall into warmer air [15].

5.1.2.2 Rainfall Rates. Rainfall rate (see Table 1) is the intensity of rainfall calculated over a given interval assuming constant rainfall intensity over the interval [14].

TABLE 1 Rainfall Rates [16]

Description	Inches per Hour	Centimeters per Hour
Light rain	0.01 (trace)-0.10	< 0.25
Moderate rain	0.11 - 0.30	0.26 - 0.76
Heavy rain	>0.3	> 0.76

5.1.2.3 Drizzle. Water droplets falling through the atmosphere smaller than half a millimeter [14]. Human drivers are likely to distinguish drizzle from rain in that drizzle accumulating on a dirty windshield will smear when the wipers are engaged; rain will clear away the soil.

5.1.2.4 Mist. Mist is a "suspension in the air consisting of microscopic water droplets or wet hygroscopic particles, reducing the visibility at Earth's surface to not less than 1 km or 0.62 mi. The term mist is used in weather reports when there is such obscurity, and the corresponding relative humidity is 95% or more, but is generally lower than 100%" [17].

5.1.2.5 Fog. Fog is water droplets suspended in the atmosphere in the vicinity the earth's surface. Fog reduces visibility below 1 km (0.62 miles) [14]. Fog is most likely to occur when the temperature and dewpoint of the air are similar (within 4°F). Fog rime is an opaque deposit that occurs when the water droplet is below freezing and comes in contact with an object also below freezing [18]. Table 2 is based on the NWS experimental fog severity index and provides a good reference for the relative impact of fog on visibility [19].

TABLE 2 Fog Severity (adapted from NWS Experimental Fog Severity Index) [19]

Fog Severity	Visibility in Feet (Meters)
5	200 (61)–0
4	800 (244)–200 (61)
3	2,640 (805)–800 (244)
2	5,280 (1609) (mist) -2,640 (805)
1	>5,280 (1609) (mist)

[4] Precipitation (and other environmental variables) can be monitored in a variety of ways to ensure ADS operate within their ODD (e.g., secondary measurements may be calculated or inferred based on other data directly available to the ADS, data or instructions based on environmental data could be communicated between vehicles or from fleet operations, systems may be equipped to directly measure some of the variables and infer others).

5.1.2.6 Snow. Precipitation composed of white or translucent ice crystals, chiefly in complex branch hexagonal form and often agglomerated into snowflakes [14].

5.1.2.7 Snow Intensity. Snow intensity is characterized by the visibility of light over a distance (see Table 3).

TABLE 3 Snow Intensity [20]

Description	Associated Visibility
Light snow	1km (5/8 statute mile) or more
Moderate snow	< 1km > 0.5km (5/16 statue mile)
Heavy snow	< 0.5km

5.1.2.8 Sleet. Pellets of ice that form when snow falls into a warm layer and melts into rain. The rain then falls into a freezing layer of air that is deep enough to refreeze the raindrops into pellets. Sometimes the snow does not completely melt, and the partially melted snowflakes refreeze into snow pellets [15].

5.1.2.9 Freezing Rain. Rain that falls in liquid form but freezes upon impact to form a coating of glaze upon the ground and on exposed objects [14]. Freezing rain occurs when snow falls into a warm layer and melts, but the freezing layer is very shallow, so the liquid water falls onto surfaces that are below freezing and solidifies, resulting in an even coating of ice on streets, trees, cars, and power lines [15].

Freezing rain can be exceptionally hazardous. This is because the ambient air temperature may be above freezing, but as the AMS points out, "Freezing rain can sometimes occur on surfaces exposed to the air (such as tree limbs) with air temperatures slightly above freezing in strong winds. Local evaporational cooling may result in freezing." [14].

5.1.2.10 Hail. Precipitation in the form of balls or irregular lumps of ice, always produced by convective clouds, nearly always cumulonimbus. Hailstones have a diameter of 5 mm or more. Smaller particles of similar origin are either ice pellets or snow pellets [14].

5.1.3 Haze

Haze is "a suspension of extremely small, dry particles in the air, not water droplets. These particles are invisible to the naked eye, but sufficient to give the air an opalescent appearance" [21]. Haze can obscure or distort images at a distance through the "scattering, refraction, and reflection of light" [22, p. 4]. Some of this distortion can be corrected with filters [22].

5.1.4 Sky Condition

"Sky condition describes the predominant/average sky cover based on percent of the sky covered by opaque (not transparent) clouds" [23]. Table 4 below provides descriptions for observable cloud cover.

TABLE 4 Sky Condition [14]

Sky Condition (Day)	Sky Condition (Night)	Opaque Cloud Cover
Sunny	Clear	1/8 or less (0 to 12.5%)
Mostly sunny	Mostly clear	1/8 to 3/8 (12.5 to 37.5%)
Partly sunny	Partly cloudy	3/8 to 5/8 (37.5 to 62.5%)
Mostly cloudy	Mostly cloudy	5/8 to 7/8 (62.5 to 87.5%)
Cloudy	Cloudy	7/8 or more (87.5 to 100%)

5.1.5 Illuminance (Lux)

A measure of the intensity of visible light (luminous flux) over a given area (illuminance) [24]. Some common outdoor light levels from the National Optical Astronomy Observatory (NOAO) are provided in Table 5.

TABLE 5 Common Outdoor Light Levels [25]

Condition	Illumination (Lux)
Sunlight	107,527
Full Daylight	10,752
Overcast day	1,075
Very Dark Day	107
Twilight	10.8
Deep Twilight	1.08
Full Moon	.108
Quarter Moon	.0108
Starlight	.0011
Overcast Night	.0001

5.1.6 Sun Angle

The angle of the sun's rays relative to the travelled surface. Twilight and the apparent sunrise/sunset are examples of common descriptors for the general angle of the sun at the beginning and end of the day and can be easily understood by the general public. General light conditions will vary depending on local weather and the atmosphere. Artificial lighting may also be considered but is likely to be inconsistent [25]. Angles of light from the sun and artificial sources can create inconsistent shadows conditions.

Twilight is the time between daytime and nighttime when the sun is below the horizon and sunlight is reflected to the Earth's surface by the atmosphere. Table 6 includes common descriptions of twilight.

TABLE 6 Twilight Categories [14]

Condition	Description
Astronomical twilight	The time in the morning or evening when the sun is 18-degrees below the horizon
Nautical twilight	The time in the morning or evening when the sun is 12-degrees below the horizon
Civil twilight	The time in the morning or evening when the sun is 6-degrees below the horizon

The apparent sunrise/sunset is when light rays of the sun below the horizon bent through Earth's atmosphere to appear as if the sun were above the horizon. [14].

5.1.7 Wind

Wind is described in terms of the prevailing direction from which it is blowing with speeds in miles per hour [23]. Table 7 provides descriptive terms and related ranges for wind speed [26].

TABLE 7 Beaufort Wind Scale (Including World Meteorological Organization (WMO) Classification) [26]

Force	Wind (Knots)	Wind (mph)	WMO Classification	Appearance of Wind Effects on Land
0	Less than 1	Less than 1	Calm	Calm, smoke rises vertically
1	1-3	1-3	Light air	Smoke drift indicates wind direction, still wind vanes
2	4-6	5-7	Light breeze	Wind felt on face, leaves rustle, vanes begin to move
3	7-10	8-12	Gentle breeze	Leaves and small twigs constantly moving, light flags extended
4	11-16	13-18	Moderate breeze	Dust, leaves, and loose paper lifted, small tree branches move
5	17-21	20-24	Fresh breeze	Small trees in leaf begin to sway
6	22-27	25-31	Strong breeze	Larger tree branches moving, whistling in wires
7	28-33	32-38	Near gale	Whole trees moving, resistance felt walking against wind
8	34-40	39-46	Gale	Twigs breaking off trees, generally impedes progress
9	41-47	47-54	Strong gale	Slight structural damage occurs, slate blows off roofs
10	48-55	55-63	Storm	Seldom experienced on land, trees broken or uprooted, considerable structural damage
11	56-63	64-72	Violent storm	N.A.
12	64+	74+	Hurricane	N.A.

NOTE: Probability Forecast

The probability forecast is not a component of the ODD. It is included here so that, if used, it may help align stakeholder expectations for ADS-DV availability based on weather factors that may be relevant to a specific ADS ODD (if precipitation is a factor). Probability forecast information is readily available from local news outlets and on the web.

Looking ahead to the operational use of ADS-DV fleets providing Mobility as a Service (MaaS) and consumer/public expectations, this document includes a definition and parameters for the *forecast* element. Table 8 from the National Weather Service lists percent likelihood for precipitation events with commonly understood descriptions [23].

TABLE 8 Probability of Precipitation [23]

Probability of Precipitation	Expression of Uncertainty	Equivalent Areal Qualifier
10 percent	(none used)	Isolated/ Few
20 percent	Slight Chance	Widely Scattered
30, 40, & 50 percent	Chance	Scattered
60 & 70 percent	Likely	Numerous (or none used)
80, 90, & 100 percent	(None used)	Occasional, periods of, or none used

5.2 Road Surface Conditions

Road surface condition is an assessment of road surface state-of-repair, visibility of road markings, and the level to which the road surface is obscured. The following definitions are suggested as a first step in establishing a practical means of quantifying road surface conditions.

5.2.1 (Surface Condition) State of Repair

The World Road Association (PIARC) defines surface conditions with regard to the state of repair as a "combination of distresses or distress levels that describes the surface of the road using measured values or assigned categories"[27]. According to FHWA, both AASHTO and the American Society for Testing and Materials (ASTM) have been working since the 1980s to standardize data collection for pavement assessment, so variation across geographies is likely[5].

[5] The Pavement Condition Index (PCI) is one measure used by some state and city road management offices to label pavement condition for a network or section of roadway [41], [40]. The International Roughness Index (IRI) [43] assigns ratings of road surface smoothness based on cracking, rutting, raveling, potholes, and other measures.

5.2.1.1 Cracking. This condition is typically caused by surface compression due to vehicle weight and motion. Cracks allow water to penetrate the surface, leading to more significant deterioration [28].

5.2.1.2 Rutting. A type of road deformation, typically in asphalt surfaces and usually caused by higher weight vehicles such as trucks and buses, which deflect the pavement surface and can compress and distort the road base by "pumping" underlying materials creating subsurface voids [28].

5.2.1.3 Raveling. The first stage of street degradation, caused by weather (UV rays, oxidation, and expansion/contraction due to heating/cooling) and/or traffic (including wear from tires and studs). Fine particles are lost from the upper layer of asphaltic concrete, loose gravel may be present, and the surface appears rough [28].

5.2.1.4 Pothole. Holes or depressions in the road pavement surface with steep sides and sharp edges. Potholes are caused by wear or subsidence and usually have a diameter of 1m or less [29]. Potholes have both bowl- and irregular-shapes due to pavement surface failure as a result of some type of structural deficiency. Potholes grow in the presence of water [30]. Potholes can appear quickly in road surfaces creating challenges for ADS-operated vehicles in the form of detecting the pothole, causing unexpected behaviors in other road users, creating the need for mobile repair zones, and vehicle dynamic issues as a result of striking a pothole or a poorly repaired pothole.

5.2.1.5 "Alligator" Cracking. When longitudinal and transverse cracks intersect, an advanced state of multi-directional cracking, sometimes called block or alligator cracking occurs. This is a precursor to the formation of potholes [28].

5.2.2 Quality of Road Markings

Road markings degrade over time and are "…affected by material characteristics, traffic volumes, weather, and location" [8, p. 347]. In this context, road marking quality is relative to the ability of sensor systems to detect and interpret the meaning of the marking. In humans, this is visual detection based on eyes as the sole sensor system. ADS will often employ multiple sensor systems; therefore, what may appear to humans as poor quality may, or may not, be similarly poor quality to the ADS. Quality of road markings may relate to contrast, texture, fade, reflectivity, and retro-reflectivity among other factors. Because of the aforementioned variability used in perception systems, more experience is needed before quantitative values and ranges can be defined for road marking quality. For descriptive purposes, Table 9 is provided so, if used, manufacturers may more easily communicate this characteristic of their ODD.

TABLE 9 Road Marking Quality

Label	Definition
Good	Markings clearly visible under nominal conditions as defined by the ADS's ODD
Fair	Markings faded, but identifiable under most conditions as defined by the ADS's ODD
Poor	Faded markings with unreliable consistency in nominal conditions as defined by the ADS's ODD

5.2.3 Road Surface Obscurants

Visibility of road surfaces, edges, and road markings can be obscured by a variety of materials and conditions [8]. Obscurants may include a debris field on the roadway that covers all or a portion of the road surface. In addition to visibility, many of the obscurants included here may have a negative effect on traction. The list in Table 10 is not all-inclusive. Additional items or conditions may be added as more experience is gained and shared by manufacturers.

TABLE 10 Types of Road Surface Obscurants

Type	Description
Dry	No moisture on the road surface. No precipitation or dew is on the road surface. This state is assumed to be the steady state and condition of the roadway with no impact or obscuration of the surface.
Damp	Some surface darkening indicating the presence of moisture. May result from mist, morning dew, or following precipitation as surface transitions from wet to dry. Damp conditions may create glare and reduce traction on the road surface as well as create spray from other vehicles which may occlude some sensor systems.
Wet	Complete surface darkening; possible standing water or puddles in low areas and potholes; runoff across road surface during heavy or moderate rain events. Wet conditions may create glare and reduce traction on the road surface as well as create spray from other vehicles which may occlude some sensor systems.
Snow-covered	Road surface obscured by snow; masks cracks, lines, and potentially road edges. Snowy conditions may reduce traction on the road surface as well as occlude some sensor systems from accumulated snow kicked up from other vehicles.
Icy	Freezing temperatures causing water or moisture on the road surface to freeze. May be the result of freezing rain, packed snow, or surface moisture (e.g., dew) that has frozen. Icy conditions may be visible as sheets of ice, ice crystals, or packed snow. Black ice may not be visible or easily distinguished by the human eye or ADS vision systems. Icy surface conditions may create glare, obscure markings, and significantly reduce traction.
Sand and gravel	Encroaching sand or gravel may cover road markings and edges. Sand may be transported in dry conditions by the wind or wet conditions through moving water or floods. Sand on the roadway can also affect traction.
Leaves	Leaves may cover road markings and edges especially following storms and during the autumn season. Leaves on the roadway can also affect traction.

5.2.4 Transient Roadway Obstacles

Transient obstacles include objects that are foreign to the normal roadway environment. Obstacles may be produced by vehicular or non-vehicular sources [31]. These non-fixed objects pose a safety impact such as physical damage to ADS or harm to its occupants [3]. Obstacles may be difficult to classify because of the irregularity of shape (e.g. trash), unexpected locations (e.g. furniture in a roadway), unexpected motion (e.g. object falling off a truck or moving at an odd angle to the roadway), or other complicating factors.

5.3 Roadway Infrastructure

"Physical infrastructure is typically characterized by technical structures" [3, p. 32] Roadway infrastructure that may be relevant to ODD definitions includes, but is not limited to the presence or absence of surface crowning, curbs, shoulders, berms, guard rails, gutters, ditches, bridges, tunnels, roadside furniture such as traffic control devices and support structures, telephone poles, telecommunications, electrical infrastructure, etc. Once identified, roadway infrastructure may be described in an ODD narrative in a permissive or non-permissive manner.

5.3.1 Road Network

All of the interconnected roads in a referenced area. Route networks are subsets of the overall road network.

5.3.2 Route Network

A designated or select set of roadways and length of roadways on which a given ADS-operated vehicle may be designed to operate. The route network is a subset of the road network and can be thought of as a map of permissible roadways for a given ADS-operated vehicle. SAE level 4 ADS-operated vehicles may have their ODD geography based on a set route network. Route networks are subsets of a larger road network and may be subsets within a geofenced area.

5.3.3 (Roadway) Sight Distance

The distance allowed in roadway design for human drivers to receive information, decide on a course of action, and execute the appropriate control response. Sight distance is a design feature in roadway design and can be further broken down into stopping sight distance, decision sight distance, and passing sight distance [9].

5.3.4 (Roadway) Grade

The incline (+) or decline (-) of a roadway as a measure of percent change from horizontal (0). The grade of a roadway is a design feature in roadway design and can impact other design considerations[6] such as design speed, superelevation, signage, and lane markings [9].

[6] Steep downgrades (≥4%) with minimum radii may cause rollover in some vehicles if simultaneously braking and changing lanes; "Stay-in-lane" signage may be used in these instances. [9]

5.3.5 (Roadway) Superelevation

Angle of elevation measured from the horizontal (0) of the outside edge of a roadway on a horizontal curve. Superelevation is a design feature in roadway design. If vehicles are traveling more slowly than the original design speed for a high superelevation, lateral forces can pull the vehicle downslope creating a need for the ADS (and human drivers) to counter by steering upslope [9].

5.3.6 (Road) Vertical Curvature

Crests or sags between tangent grades in roadways (i.e., hills or dips). Vertical curvature is a design feature in roadway design [9].

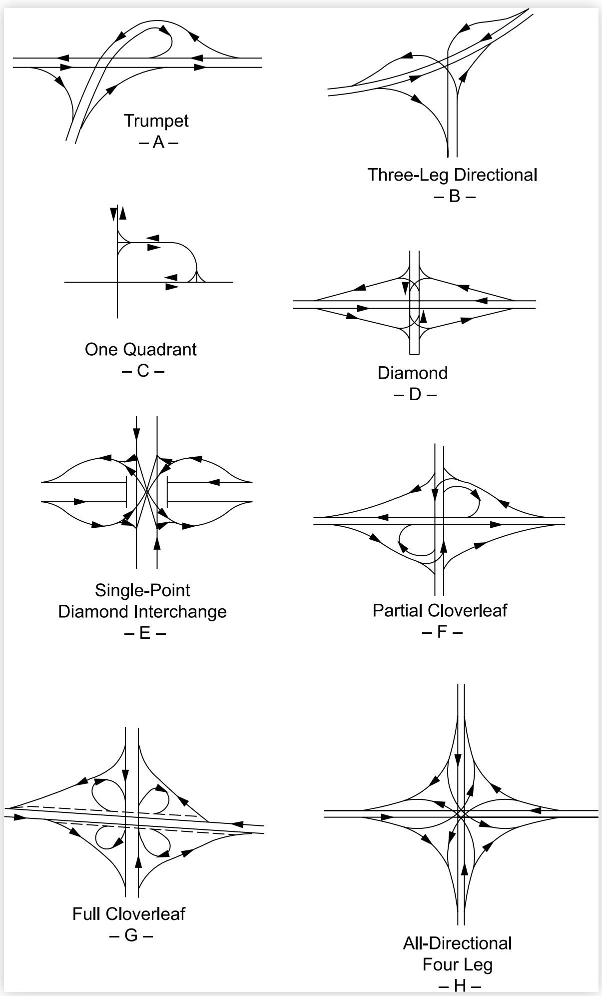
5.3.7 (Road) Horizontal Curvature

Features connecting tangent horizontal (e.g., map view) roadways. Horizontal curvature (a.k.a., curves) is described by their radius and superelevation in roadway design. According to AASHTO [9], curves have varying geometric design considerations for rural and urban environments, functional roadway classification, and expected usage among others.

5.3.8 Ramps

Ramps connect two roadways and are characterized by curvature and grade. AASHTO [9], identifies multiple types of ramps including diagonal, one-quadrant, loop-and-semi-direct, outer, and direct connections. Traffic generally flows uni-directionally on ramps. Ramps are typically envisioned in freeway applications, but can also be found in urban environments on secondary streets.

FIGURE 6 Interchange configurations (AASHTO) [9, p. 10-3]



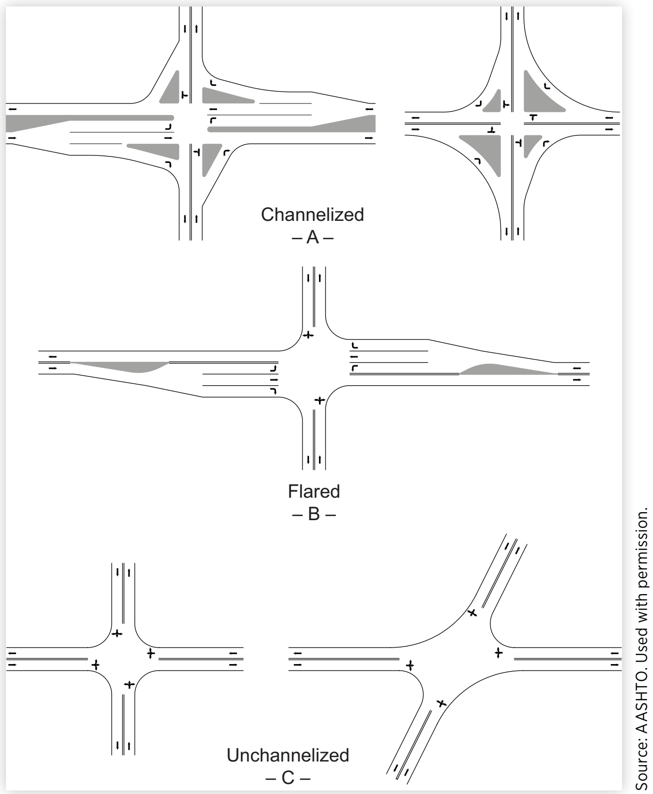
Source: AASHTO. Used with permission.

NOTE: The geographic area and route network may also require other types of ramps such as emergency escape ramps. These are common in highway applications in mountainous areas.

5.3.9 Intersections

Intersections are "the general area where two or more roadways join or cross, including the roadway and roadside facilities for traffic movement in the area." [9, p. 9-1]. Intersections are where most traffic conflict occurs.

FIGURE 7 General types of intersections (AASHTO) [9, p. 9-12]



5.3.10 Geofenced Area

An area defined by a perimeter within which ADS may be designed to operated. Typically, and when operating properly, ADS-operated vehicles will not operate outside a geofenced area, but, possibly with specific exceptions, may operate on any roadways within the geofenced area. SAE level 4 ADS-operated vehicles may have their ODD geography based on specific geofenced areas.

5.3.11 Traffic Control Devices

Traffic control devices (TCDs), such as traffic signals, signs and crosswalks, are used to promote "safety and efficiency by providing for the orderly movement of all road users on streets, highways, bikeways, and private roads open to public travel… Traffic control devices notify[7] road users of regulations and provide warning and guidance needed for the uniform and efficient operation of all elements of the traffic stream in a manner intended to minimize the occurrences of crashes." [8, p. 1]

[7] Conspicuity of TCDs is a measure of how visible the device is to human drivers. Factors include legibility, placement (e.g., distance from road edge, angle, and height), clutter, and background contrast [38]. Conspicuity may be relevant to ADS-operated vehicles in mixed traffic situations where the messages communicated by the TCD (e.g., speed limit, school zone, stop, go.) are not communicated using vehicle to infrastructure (V2I). In these instances, the ADS must be able to detect and recognize the regulation, warnings, or guidance provided in a manner consistent with other road users. According to FHWA, there is no standard or generally accepted measure for TCD conspicuity; however, FHWA identified five key performance indicators (KPIs) in their research [42] comparing headlamps and visibility of TCDs which may inform future best practices for TCD conspicuity.

5.3.12 Design Elements

According to the Municipality of Anchorage Project Management and Engineering Department [32], there are seven design elements (plus a 'general' category) that infrastructure designers use in their urban landscape. Common reference to these elements in ADS developers' ODD definitions can help in creating a common lexicon between ADS-operators/developers and infrastructure owner/operators (IOOs). The seven elements are:

1. Lane
2. Shoulder
3. Curb
4. Design and posted speed
5. Buffer (the separation between the curb and pedestrian facilities)
6. Pedestrian facilities (e.g., sidewalks, pedestrian islands, crosswalks)
7. Landscaping

5.3.13 Lane

Lanes are the traveled way width on a roadway designed for a single row of vehicle movement. Lanes may vary in width, use, and marking method. Manufacturers may choose to describe the number of lanes, directionality, or lane usage in the description of their ODD.

5.3.13.1 Dedicated Lane. Dedicated lanes are lanes reserved for a specific type of traffic or road user [33]. Some examples of dedicated lanes include those dedicated to automated vehicles, transit vehicles, high-occupancy vehicles, bicycles.

5.3.13.2 Managed Lane. "A highway lane or set of lanes, or a highway facility, for which variable operational strategies such as direction of travel, tolling, pricing, and/or vehicle type or occupancy requirements are implemented and managed in real-time in response to changing conditions. Managed lanes are typically buffer- or barrier-separated lanes parallel to the general-purpose lanes of a highway in which access is restricted to designated locations. There are also some highways on which all lanes are managed" [8, p. 16].

5.3.13.3 Mixed Use. Roadways intended for use by more than one type of vehicle and road user. In the context of an ODD description, mixed use means the roadway may be used by ADS-operated vehicles and traditionally operated vehicles; ADS-operated vehicles and VRUs; or ADS-operated vehicles, traditionally operated vehicles, and VRUs. The ratio of ADS-operated vehicle to traditionally operated vehicle is not considered in this definition.

5.3.13.4 Lane Width. "The lane width of a roadway influences the comfort of driving, operational characteristics, and, in some situations, the likelihood of crashes. Lane widths of 9 to 12 ft [2.7 to 3.6 m] are generally used [in the U.S.], with a 12 ft [3.6 m] lane predominant on most high-speed, high-volume highways." [9, p. 4-9]

5.3.14 Shoulder

The shoulder is "the portion of the roadway contiguous with the traveled way that accommodates stopped vehicles, emergency use, and lateral support of subbase, base, and surface courses [of the roadway structure]. In some cases, the shoulder can accommodate bicyclists." [9, p. 4-10]

5.3.15 Curb

Curbs are a raised or vertical element along a roadway. Curbs can influence the operation and traffic flow of a roadway because of their effect on (human) driver behaviour. Curbs help control drainage, define the edges of roadways, reduce roadway maintenance, define vulnerable road user (VRU) pathways, and assist in the development of roadside areas (e.g. drop-off/pick-up points). [9, p. 4-19]

5.3.16 Weaving Section

Section of roadway where two streams of one-way traffic merge and diverge. Sections with large volumes of human-driven vehicles performing weaving movement usually result in congestion and reduced speeds [9].

5.3.17 On-Street Parking

The presence of street parking can occlude objects around parked vehicles. It also introduces new considerations to ADS operation such as humans opening doors or pulling out of spaces. If allowed within the ODD, there are six types of street parking [34]:

1. Head-in/back-out angle parking on one side
2. Head-in/back-out angle parking on both sides
3. Back-in/head-out angle parking on one side
4. Back-in/head-out angle parking on both sides
5. Parallel parking on one side
6. Parallel parking on both sides

5.4 Operational Constraints

Operational constraints are elements within the operating environment not related to weather and atmospheric conditions that alter some characteristic of the operating environment [3]. Operational constraints describe the *non-permissive* elements of the ODD description.

5.4.1 Rush Hour

Rush hour is a description for regular periods of high traffic density on roadways often resulting in lower than posted speeds and stop-and-go conditions. Rush hours vary among geographic areas in terms of timing and relative density/ speed reduction. The U.S. Department of Transportation (USDOT) defines rush hour as peak travel times, between 7 a.m. and 9 a.m. and between 4 p.m. and 6 p.m., that correspond with commuting to and from work during what are colloquially referred to as “normal business hours.” USDOT also points out that “people are much more likely to travel alone when they are commuting [during rush hour] than when they are traveling to run errands and for social and recreational purposes” [35, p. 132]. A given ADS product may be designed to exclude operation, or avoid certain roads/routes, during such peak demand times, or conversely, to operate exclusively during them.

5.4.2 Intended Operational Times

The intended operational times are the planned days and hours for when MaaS (or delivery) will be provided. Many considerations may be captured in the operational time description, including but not limited to, traffic density, sun angle, zone-specific times (e.g., school zone), etc.

5.4.3 Zones

Zones are areas with boundaries where some element of the broader operational domain changes.

5.4.3.1 Fixed Zones. Zones with geographic boundaries (e.g., hospital zone) or geographic and temporal boundaries (e.g., school zone) [3]. Fixed zones are described as a part of the route network but may not be explicitly called out in the description of a route network[8].

5.4.3.2 Dynamic Zones. Zones with boundaries that are not permanent or may not be clearly delineated on maps (e.g., mobile work zone) [3]). Dynamic zones may or may not be marked by signage (e.g., low-lying area prone to flooding or standing water during rain events). A characteristic of work zones may be removing or otherwise obscuring extant roadway markings (e.g., cover with tape, sandblast). These methods may result in new gauges or the appearance of markings of different colors.

5.5 Road Users

AASHTO lists five categories of road user [9] (listed 1 to 5 below). Because of the unique characteristics associated with them, this document adds motorcycles, micromobility vehicles, wheelchairs, emergency vehicles, and other vehicles to this list of road user categories. Categories are included in this document for consideration by manufacturers as the ODD is characterized. While behaviors associated with other road users should be considered in an

[8] For example, an ADS with a school, multiple loading zones, and a hospital zone in its ODD may not explicitly describe each zone. It is understood that by including the route, the zone and its operational considerations can be accommodated.

ADS manufacturer's safety case, it is outside the scope of this document and what could be considered a reasonable description of an ODD. Road user categories include:

1. Automobile (passenger-carrying motor vehicle other than bus or heavy truck)
2. Bicyclist
3. Pedestrian
4. Transit (buses are most common, but also include "streetcars, trolleys, or other vehicles that may share the traveled way with autos [including light rail]"
5. Trucks (heavy trucks, such as classes 6, 7, and 8)
6. Motorcycles and scooters
7. Micromobility vehicles (e.g., e-scooters, e-bikes, and motorized skateboards) as defined by SAE J3194_201911
8. Wheelchairs/wheeled mobility assistance devices (manually-operated and motorized)
9. Emergency vehicles (e.g., fire, police, ambulance, wrecker/tow vehicles, etc.)
10. Other vehicles (e.g., golf-carts, garbage trucks, postal vehicles, street sweepers, etc.)

5.6 Non-Static Roadside Objects

Non-static roadside objects are things in the driving environment that are not permanently (or semi-permanently) fixed in place, but also not (necessarily) dynamic in nature. Trashcans are examples of non-static objects; they cannot be considered roadside furniture but are not dynamic in the sense of a bouncing ball or dynamic in the sense of a running animal, yet they (mostly) appear regularly at the side of roads in certain areas with varying outlines that can make them difficult to include in a static world model.

5.7 Connectivity

Connectivity is an ADS ability to communicate with other vehicles, other road users, and infrastructure including a fleet operations center. It can be through cellular connections or other radio communications including line-of-sight or using satellites as with Global Navigation Satellite System (GNSS).

5.7.1 Fleet Management

Fleet management is the coordinated operation and oversight of multiple ADS-operated vehicles in one or more ODDs. Fleet management is included here because it implies connectivity with the fleet operations center which may be an element of the ADS ODD if this connectivity is required for certain functions (e.g. communications with the fleet operations center).

NOTE: Fleet management is not to be confused with performance of the DDT fallback or bringing an ADS-DV to a minimal risk condition (MRC). SAE L4/5 ADS-DV perform these functions independently of external oversight.

5.7.2 Obstructions

Obstructions are signal blockages of communications or perception systems. Obstructions can take the form of infrastructure *shadows* (as in the ability to receive GNSS or cellular signals) created by objects such as tunnels, overhead wires, tall buildings, overpasses, etc. Obstructions can also be dynamic as the result of a work zone or large vehicle occluding a vision system or line of sight communication system. The earlier step in the framework which defines all routes (or areas) in developing an ODD should account for obstructions resulting from fixed infrastructure.

6. Summary

This document provides a recommended conceptual framework for ADS developers to define their operational design domain (ODD). An initial lexicon of recommended terms and definitions for variables that may be considered in crafting a narrative to describe the ODD to stakeholders (e.g. users of the ADS-operated vehicle, infrastructure owner-operators, other road users) is also provided. These elements combined in a narrative help to create common understanding of where, when, and under what conditions SAE level 4 ADS-operated vehicles can and cannot operate. Follow-on research and additional discussion in an open forum can expand the lexicon begun in this document.

7. About Automated Vehicle Safety Consortium™

The objective of the Automated Vehicle Safety Consortium™ is to provide a safety framework around which automated vehicle technology can responsibly evolve in advance of the broad use of commercialized vehicles. The consortium will leverage the expertise of its current and future members and engage government and industry groups to establish safety principles and best practices. These technology-neutral principles are key considerations for deploying SAE level 4 and level 5 automated vehicles on public roads.

AVSC Vision:
Public acceptance of SAE level 4 and level 5 automated driving systems as a safe and beneficial component of transportation through industry consensus.

AVSC Mission:
The mission of the Automated Vehicle Safety Consortium™ (AVSC) is to quickly establish safety principles, common terminology, and best safety practices, leading to standards to engender public confidence in the safe operation of SAE level 4 and level 5 light-duty passenger and cargo on-road vehicles ahead of their widespread deployment.

The AVSC will:

- Develop and prioritize a roadmap of pre-competitive topics;
- Establish working groups to address each of the topics;
- Engage the expertise of external stakeholders;
- Share output/information with the global community;
- Initially focus on fleet service applications.

8. Contact Information

To learn more about the Automated Vehicle Safety Consortium™, please visit https://avsc.sae-itc.org.

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9. Abbreviations

AASHTO - American Association of State Highway and Transportation Officials

ADS - Automated Driving System

ADS-DV - Automated Driving System-dedicated vehicles

AMS - American Meteorological Society

ASTM - American Society for Testing and Materials

AURA - Association of Universities for Research in Astronomy

AV - Automated Vehicle

AVSC - Automated Vehicle Safety Consortium

DOT - Department of Transportation

FHWA - Federal Highway Administration

ft - foot

GNSS - Global Navigation Satellite System

IRI - International Roughness Index

IOO - Infrastructure Owner-Operator

km - kilometer

KPI - Key Performance Indicator

MaaS - Mobility As A Service
mi - mile
mph - miles per hour
MRC - Minimal Risk Condition
NHTSA - National Highway Traffic Safety Administration
NOAA - National Oceanic and Atmospheric Administration
NOAO - National Optical Astronomy Observatory
NWS - National Weather Service
ODD - Operational Design Domain
PCI - Pavement Condition Index
PIARC - World Road Association
TCDs - Traffic Control Devices
USDOT - U.S. Department of Transportation
V2I - Vehicle to Infrastructure
WMO - World Meteorological Organization

10. Acknowledgements

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Appendix A. AVSC Best Practice Quick Look

Describing an Operational Design Domain: Conceptual Framework and Lexicon

Operational Design Domain (ODD) Conceptual Framework (4.0). A bottom-up approach that enables realistic understanding of (local) environmental conditions, roadway geometries, physical infrastructure, zones, and the behaviors of other road users.

- **Identify the Road/Route Network (4.1).** Identify the road network on which the ADS-operated vehicle will be deployed.
- **Characterize the Fixed Route Network and Infrastructure (4.2).** Identify and describe the conditions and elements of the environment relevant for operation of the ADS.
- **Identify Operational Constraints within the Road/Route Network (4.3).** Identify objects, zones, conditions, events, etc. in the designated road/route network that the ADS-operated vehicle will avoid.
- **Formulate Narrative (4.4).** Describe the ODD in terms of permissive and non-permissive characteristics, elements, and parameters.

ODD Lexicon (5.0). Provides some terminology manufacturers and developers can use in describing their ODD.

- **Weather-Related Environmental Conditions (5.1).** Weather conditions that may impact an ADS's performance in a physical domain.
- **Road Surface Conditions (5.2).** Definitions to quantifying road surface conditions.
- **Roadway Infrastructure (5.3).** Types of physical roadway infrastructure.
- **Operational Constraints (5.4).** Elements within the operating environment not related to weather and atmospheric conditions.
- **Road Users (5.5).** Categories of road users.
- **Non-static Roadside Objects (5.6).** Non-static roadside objects are things in the driving environment that are not permanently (or semi-permanently) fixed in place.
- **Connectivity (5.7).** Communication with other vehicles, other road users, and infrastructure including fleet operations center.

Appendix B. Example Format - ODD Narratives

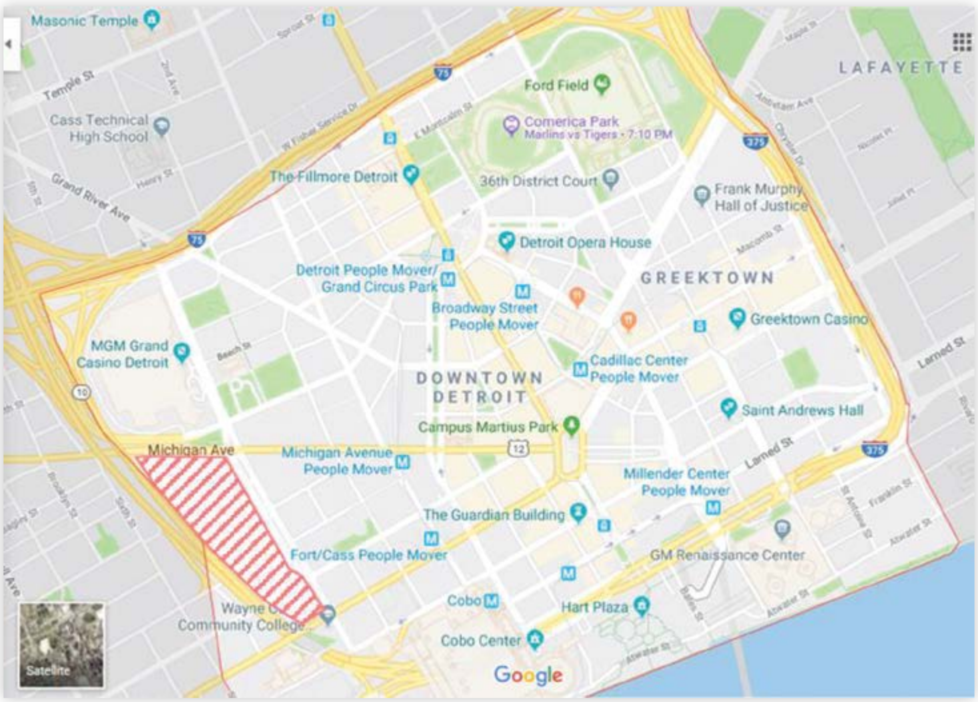
Below are examples developed following the high-level framework and definitions from this document. It is important to note that the items/categories listed are not all-inclusive. This is one way to represent the location and conditions in which an ADS-operated vehicle is designed to operate.

ODD Narrative (Example 1)

Summary: The ODD is the urban center of Detroit, Michigan, during daylight hours in fair weather.

Geofenced area:

FIGURE 8 Example Route network boundaries [36]



ODD Description Table:

ODD Category	Explicitly within ODD	Explicitly Outside ODD
Route network	Downtown Detroit, Michigan see map boundaries	Area around Detroit Police Department and Department of Public Safety see map boundaries (red hatch marks)
Sun Angle	Apparent sunrise/sunset (sun at or above the horizon)	
Precipitation	Light rain and light snow (*provided road surface conditions are not exceeded)*	Mist, Fog (severity 5)
Operating speed	$\leq$35mph	
Wind	Up to strong breeze (31 mph)	
Lane width	$\geq$12ft	
Road surface conditions	Wet or dry	No standing water; not snow covered
Connectivity	Cellular connection required	
Rush hour	Yes	

NOTE: The described numerical values are based on the developer's ability to measure them. Any margin for error in the ADS' ability to measure should be accommodated in the ODD description.

ODD Narrative (Example 2)

The system is designed to operate on the road network in the urban center of Detroit, Michigan on all streets with a speed limit of 35mph or less. Its boundary is constrained by I-75 to the north; I-375 to the east; M-10 to the west; and Atwater Street along the Detroit River to the south. The areas around the Detroit Police Department and Department of Public Safety are excluded from this ODD. The system is capable of operating during daylight hours when the sun is at or above the horizon. It can operate in fair weather, includng wind gusts up to 35 mph, light rain, and light snow, provided the road surface is not covered by snow. It recognizes and understands all signage and traffic control devices inside this ODD. Work zones are coordinated with the local transportation department and excluded from the route network as needed.