A Scenario-Based Test Selection and Scoring Methodology for Inclusion Into a Safety Case Framework for Automated Vehicles

by

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ABSTRACT

The need for robust verification and validation of automated vehicles (AVs) to ensure driving safety grows more urgent as increasing numbers of AVs are allowed to operate on open roads. To address this need, AV developers can present a safety case to regulators and the public that provides an evidence-based justification of their assertion that an AV is safe to operate on open roads. This work aims to describe the development of a scenario-based testing methodology that contributes to this safety case. A high-level definition of this test selection and scoring methodology (TSSM) is first presented, along with an outline of its scope and key ideas. This is followed by a literature review that details the current state of the art in AV testing, including the driving performance metrics and equations that provide a basis for the TSSM. A chart-based method for quantifying an AV's operational design domain (ODD) and behavioral competency portfolio is then described that provides the foundation for a scenario generation and filtration process. After outlining a method for the AV to progress through increasingly robust test methods based on its current technology readiness level (TRL), the generation and filtration of two sets of scenarios by the TSSM is outlined: a standardized set that can be used to compare the performance of vehicles with identical ODD and behavioral competency portfolios, and a set containing high-relevance scenarios that is partially randomized to ensure test integrity. A related framework for incorporating testing on open roads is subsequently specified. An equation for an overall AV driving performance score is then defined that quantifies the aggregate performance of the AV across all generated scenarios. The TSSM continues according to an iterative process, which includes a method for exploring edge and corner scenarios, until a stopping condition is achieved. Two proofs of concept are provided: a demonstration of the ability of the TSSM to pare scenarios from a preexisting database, and an example ODD and behavioral competency portfolio specification form. Finally, this work concludes by evaluating the TSSM and its proofs of concept and outlining possible future work on the methodology.

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CHAPTER 1

INTRODUCTION

Statement of Purpose

The Science Foundation Arizona has enumerated an Automated Vehicle Test and Evaluation Process (AV-TEP) mission[1] that aims to develop a methodology for an automated vehicle (AV) developer to present a "safety case" - a "structured argument, supported by a body of evidence, that provides a compelling, comprehensible, and valid case that a product is safe for a given application in a given environment" (Wishart, "AV-TEP Mission Need" Slide Deck, 2022). The AV-TEP methodology visualizes this safety case as a "stool" supported by three legs: (1) Scenario-Based Testing, which demonstrates safe operation using specific temporal sequences of specified driving events in which the AV participates, referred to as "scenarios" (2) Design Methods, which outlines best practices for AV driving system design, and (3) Safety Management System (SMS) and Culture, which outlines best practices for creating a work culture that fosters safety-centered AV design (Wishart, "AV-TEP Mission Need" Slide Deck, 2022).

The objective of this thesis is to describe the development of a test specification and scoring methodology (TSSM) for testing the automated driving performance of AVs using scenarios. This thesis introduces the TSSM and its validation as a core component of the AV-TEP mission that informs the Scenario-Based Testing leg of the safety case.

The TSSM is an algorithmic structure that defines a universally applicable iterative verification and validation methodology for AVs by providing the following:

[1] https://www.azcommerce.com/science-foundation-arizona/av-tep/

1. Two sets of test scenarios conforming to the following specifications:
    a) A set of scenarios that are at least partially randomized based on their relevance to the vehicle operational design domain (ODD) and behavioral competency portfolio and are therefore impossible for the AV developer to anticipate;
    b) A set of scenarios that are the same across identical ODD and behavioral competency portfolios;
2. An opportunity for specification of the vehicle ODD and behavioral competency portfolio and ranges for each component of the ODD and behavioral competency portfolio by the AV developer;
3. An opportunity for specification of a mix of test methods and weights for each component of the ODD and behavioral competency portfolio by the implementer or the relevant regulatory body;
4. A method for generating a single numerical score for automated driving performance that represents the aggregate driving performance of the AV across a wide breadth and depth of scenarios and a diverse set of test methods.

Scope

The TSSM is an iterative AV verification and validation process, following the definition presented above, that is based on a preexisting set of driving assessment (DA) metrics initially published by the Institute for Automated Mobility (IAM) and further refined by SAE J3237 (Wishart, et al., 2020) (SAE). These metrics provide a quantification of the vehicle behaviors and maneuvers that constitute “safe” driving, as well as the complexity and relevance of the test scenario and fidelity of the test method. (Wishart, et al., 2020)

The TSSM will be applicable to AVs with all levels of driving automation, from SAE J3016 driving automation Level 1 (driver assistance) to Level 5 (fully automated) (SAE, 2019).

Full validation of the methodology presented in this thesis requires access to as many diverse testing opportunities as possible, whether via industry and governmental partnerships or by way of academic research channels. Such a validation of the TSSM is not readily available, and would be additionally constrained by the accessibility and safety concerns inherent in closed-course and open road testing; therefore, to provide evidence of the validity and usefulness of the outlined approach, this thesis includes the results of two adjacent proofs of concept and will present any significant conclusions arising from the data generated therein. Validation on a physical vehicle is left as future work.

Finally, this thesis will conclude with a discussion of possible future work so that other interested parties may identify opportunities to improve on the research presented in this document.

Ideas

There are six significant challenges in the field of AV testing that have stymied the introduction of a unified testing standard.

The first challenge is that the number of testable AV driving scenarios is, for all practical purposes, infinite. This means that determining which scenarios in the space of all possible scenarios are worth testing, while balancing this question with considerations of the cost of testing those scenarios, is extremely difficult; this is one aspect of what is referred to in industry as the "long-tail" problem (Liu & Feng, 2022).

The second challenge is that if a "standard" set of scenarios is known to the AV developer in advance, it becomes possible for that developer to test a vehicle or automated driving software suite that has *a priori* knowledge of these scenarios. Such a vehicle or suite would appear to score very highly in driving performance when tested using these scenarios; however, that vehicle would not actually be as safe as these results would indicate, as it was not tested with scenarios that were not known beforehand. The false confidence in the safety of an AV that would arise from such performance represents a significant safety risk and would heavily undermine the safety case.

The third challenge is the "curse of rarity", or the fact that potentially hazardous driving scenarios do not occur frequently during most driving events; this means that open road testing alone is a very inefficient method for discovering and testing these potentially hazardous scenarios, as the driven mileage required to encounter these scenarios frequently enough to gain usable data from them is intractably large (Liu & Feng, 2022). While testing on closed courses or tracks is often cited as an alternative to open road testing, creating complex and realistic scenarios in closed-course testing is challenging due to equipment and safety requirements. Similarly, while creating scenarios in simulation is relatively simple in concept, the question still remains of how to guarantee that a sufficient number of rare, but relevant, scenarios are generated and analyzed.

The fourth and final challenge relates to standardization. The curse of rarity problem has spurred research in the AV testing space that focuses on incorporating randomness into the AV testing process in order to stumble upon previously unknown potentially dangerous scenarios by random chance, as will be discussed in the following literature review. However, in order to benchmark AVs with the same ODD and behavioral competency portfolio against each other, not all the tested scenarios can be random – a standard set of scenarios for a given ODD and behavioral competency portfolio must exist so that the test results from these scenarios for different AVs can be meaningfully compared. At the time of writing, no publications exist to the best of the author's knowledge that propose a methodology for generating such a standard set.

Two additional challenges relate to edge and corner scenarios. The fifth challenge is that these scenarios, and problematic scenarios in general, are not the same between different AVs; AVs with even slightly different software, firmware, or hardware configurations may have significantly different sets of potentially unsafe scenarios. Finally, the sixth challenge is that no standardized way to quantify or describe edge and corner scenarios exists to the author's knowledge at the time of writing.

The TSSM seeks to address these issues. The TSSM generates a subset of scenarios for testing from the space of all possible scenarios in a given ODD and behavioral competency portfolio, thus addressing the first challenge by providing the individual or organization responsible for administering the TSSM process, referred to in this thesis as the "implementer", with a practical number of scenarios to test. These scenarios are randomized, which provides a solution to the second challenge by ensuring that an AV developer cannot know in advance which scenarios will be tested. The TSSM addresses the "curse of rarity" by both probing around edge and corner scenarios to discover additional problem scenarios and by ensuring that the set of randomly generated scenarios contains a subset with high relevance to the current ODD and behavioral competency portfolio. The TSSM also includes an algorithm, based on the 37 pre-crash scenarios published by the National Highway Traffic Safety Administration (NHTSA), that generates a standard test set for comparison across AVs operating in the same ODD and behavioral competency portfolio (National Highway Traffic Safety Administration, 2007).

Lastly, the TSSM incorporates a dedicated process for addressing edge and corner scenarios. The scenario generation process generates these scenarios naturally based on the ODD and behavioral competency portfolio of the AV, addressing the fifth challenge by ensuring that these scenarios are specific to the AV currently being tested. Finally, the TSSM provides a major improvement on the state of the art by providing an ODD and behavioral competency portfolio chart-based method for directly defining and quantifying edge and corner scenarios, as will be discussed in the following sections.

CHAPTER 2

LITERATURE REVIEW

There is a large body of preexisting work from both industry and academia in the field of AV testing. Because the scope of the AV testing problem is so large, researchers have attempted solutions that draw from and incorporate diverse approaches and academic disciplines. Some of the papers in the space are described below.

In 2020, Dr. Jeffrey Wishart; et al., working in their capacity as members of the Institute of Automated Mobility (IAM)[2], defined a set of driving safety assessment (DSA) metrics for AVs that “collectively, quantitatively describe the driving safety performance of an AV” for a single scenario (Wishart, et al., 2020). While the finalization of these metrics (which are now referred to as driving assessment (DA) metrics) has been taken up by the V&V Task Force under the SAE On-Road Automated Driving (ORAD) Committee and is still underway, their paper established a more comprehensive set of AV performance metrics than had been defined in any previous work. These metrics and their applications therefore form the foundation of this project.

The work presented by the AV-TEP group in this paper is built upon and extended by several later papers. One such paper details methods by which the severity of metrics violations can be quantified, while another presents a methodology by which the DA metrics were tested for robustness to parameter and measurement uncertainty (Como, Wishart, Elli, & Kidambi, 2022), (Kidambi, Wishart, Elli, & Como, 2022). Most importantly, the DA metrics were validated using both simulated and real-world data

[2] https://www.azcommerce.com/iam/

(Elli, Wishart, Como, Dhakshinamoorthy, & Weast, 2021), (Jammula, Wishart, & Yang, 2022).

Subsequent papers from the IAM address the topic of applying the DA metrics to existing real-world driving behaviors. To that end, infrastructure-based data capture systems designed to interface with and provide data for the DA metrics were discussed (Srinivasan, et al., 2022), (Altekar, et al., 2021). This includes CAROM, a framework for applying the DA metrics to real-world vehicles using either intersection camera data or data gathered from aerial photographs taken by drones (Lu, et al., 2021) (Lu, et al., 2023). The DA metrics are refined and elaborated on by Dr. Steven Como in his doctoral dissertation; the work presented in this thesis relies heavily on his equation for the "score" for AV automated driving performance in an individual scenario (Como, An Approach to Quantifying Automated Vehicle Safety, 2022).

Several institutions and teams unaffiliated with the AV-TEP mission have contributed work to this space. These works include a full AV safety validation methodology presented in a white paper by the AV validation company Foretellix, an "ABC" framework enumerated by the University of Michigan's MCity project that prioritizes accelerated evaluation, behavior competence, and corner cases, and a full testing methodology from Feng, et al. that incorporates statistics and augmented reality (Foretellix, 2023) (Peng & McCarthy, 2019), (Feng, Yan, Sun, Feng, & Liu, 2021), (Feng, et al., 2020). Further, Zhao, et al. outline a similar statistically-motivated accelerated lane-change evaluation scheme (Zhao, et al., 2016). More broadly, a survey of test methods for machine-learning based systems was released by Schwalbe, et al in 2020 (Schwalbe & Schels, 2020). A comparably rigorous mathematical approach is outlined by Weng, et al. (Weng, Capito, Ozguner, & Redmill, 2023). Lastly, a useful ontological tool for AV scenarios is offered in an expansion of the six-layer PEGASUS framework for urban environments by Scholtes, et al. (Scholtes, et al., 2021).

The team lead by Dr. Shuo Feng has generated several significant papers addressing the topic of AV verification and validation. One such paper details a methodology that provides a library of test scenarios for a given AV (Feng, Feng, Yu, Zhang, & Liu, 2021). The group's work in this paper defines a "criticality" metric for individual scenarios that takes into account "a combination of exposure frequency and maneuver challenge"; the paper also outlines a ϵ-greedy sampling method that combines random sampling of scenarios outside of the generated library with sampling of scenarios within the generated library. The group also provides a case-study based validation of this theoretical model in a separate paper (Feng, et al., 2022). The most recent work from Feng, et al. outlines a deep learning-based approach to AV testing that uses AI-generated and controlled agents to reduce the time required to efficiently test AVs (Feng, et al., 2023).

The task of meaningfully validating AVs is so large that several papers exist that deal solely with the size of AV testing problem, including one from Liu, et al., who provide an analysis of the "curse of rarity" for AV testing applications (Liu & Feng, 2022).

Within the context of the progress made so far in AV verification methodologies, the task of this thesis is to combine the spirit of these different AV testing approaches with the DA metrics currently under development by the AV-TEP group to produce a universally applicable V&V test methodology that is practical, efficient, and significant.

Thoughts and Arguments

As outlined in the Introduction section, the main idea being put forward by the AV-TEP group is that of the AV safety case, which has three legs – Scenario-Based Testing, Safety Management System (SMS) and Culture, and Design Methods. These three focus areas combine to add strength to an AV developer's case that their vehicle is safe to freely operate on open roads.

The DA metrics that the AV-TEP group has developed to support the Scenario-Based Testing leg of the safety case, mentioned in the preceding literature review, can be aggregated to produce a single score for the driving performance of an AV in a single scenario, as devised by Wishart, et al. and shown in Equation (1):

$$DA\ Score_S = (Complexity_S)(Relevance_S)(Fidelity_T)\left(1 - \sum_i \big((Metric_i)(Magnitude_i)\big)\right) \quad (1)$$

where $Complexity_S$ refers to the level of difficulty of the current scenario, $Relevance_S$ nominally refers to the relative frequency which the vehicle under test (VUT) will experience the navigated scenario in its ODD and behavioral competency portfolio over its lifetime, $Fidelity_T$ refers to the adherence of the current test method to reality, and i is an iterable over all the metrics tested. $Metric_i$ and $Magnitude_i$ together represent the value of the i^{th} DA metric for the AV for the given scenario, ranging from 0 (best) to 1 (worst) (Wishart, et al., 2020) (Como, An Approach to Quantifying Automated Vehicle Safety, 2022). This equation provides the foundation for this thesis, and is therefore adapted to provide a basis for a component of the overall TSSM score formula, as discussed in the "Execution and Analysis" section. Briefly, this overarching equation averages out the individual DA scores for each scenario on the basis of their generation schemes.

CHAPTER 3

METHODOLOGY

Quantifying ODD and Behavioral Competency Portfolio Size and Shape

Any non-trivial AV ODD and behavioral competency portfolio will be characterized by a possibility space defined by a large number of variables, including weather, objects in the environment, and type, number, and actions of road users (i.e., pedestrians and other vehicles). Each of these variables can take any value within a wide range of possible values; further, this range can either be discrete (e.g., number of cars on the road) or continuous (e.g., inches of rainfall). It follows that the set of all possible combinations of variable values that can possibly exist during even a very short scenario is intractably large.

The first step toward addressing this intractability and creating a scenario-based verification and validation scheme for AVs is to fully discretize the variables that make up the ODD and behavioral competency portfolio possibility space. To conceptualize the AV ODD and behavioral competency portfolio as a quantitative, not qualitative, entity allows for the application of mathematical approaches to the task of extracting the necessary information for AV performance testing.

Accordingly, this discretization process occurs in three steps. The first step in the process is to define all the variables that make up the ODD and behavioral competency portfolio possibility space. As mentioned previously, this task amounts to conceptualizing what can possibly occur in an arbitrary scenario and providing a precise definition for each of these entities, phenomena, or conditions, collectively referred to as scenario components. This conceptualization can be accomplished by a thorough literature review and by seeking expert opinion.

The second step is to assign a range to each variable in the possibility space. Each variable will have a range defined by a minimum and a maximum; as a default, these two values will be informed by the most extreme values of the entity, phenomenon, or condition that have ever been known to occur. For example, if the variable under consideration is rainfall level, the minimum will be zero (no rain at all) and the maximum will be the heaviest rainfall that has been known to occur on Earth since the beginning of record keeping. This ensures that any value of this variable that can possibly be encountered by an AV will fall between one of these two extremes. This range assignment can be accomplished by consulting expert sources (meteorological, legal, et cetera). Alternatively, the AV developer has the opportunity in the TSSM to specify a range for any component, given their intimate knowledge of the vehicle ODD and behavioral competency portfolio.

The third step in the discretization process is to discretize all the ODD and behavioral competency portfolio possibility space variables within their respective ranges. This step involves some engineering judgement, as the increments for each variable should represent the smallest changes in that variable that can have an effect on the AV under test while avoiding giving rise another problem of intractably large sets of possible options. This discretization will likely be informed by the accuracy of the sensors used by an AV; for example, if the most advanced commercially available LIDAR sensor has an accuracy of $\pm$ 10 m in fog, the increments for the fog variable will be in steps of 10 m. Outside of sensors, the ODD and behavioral competency portfolio variables might be discretized by way of expert sources, a literature review, or industry and government consensus.

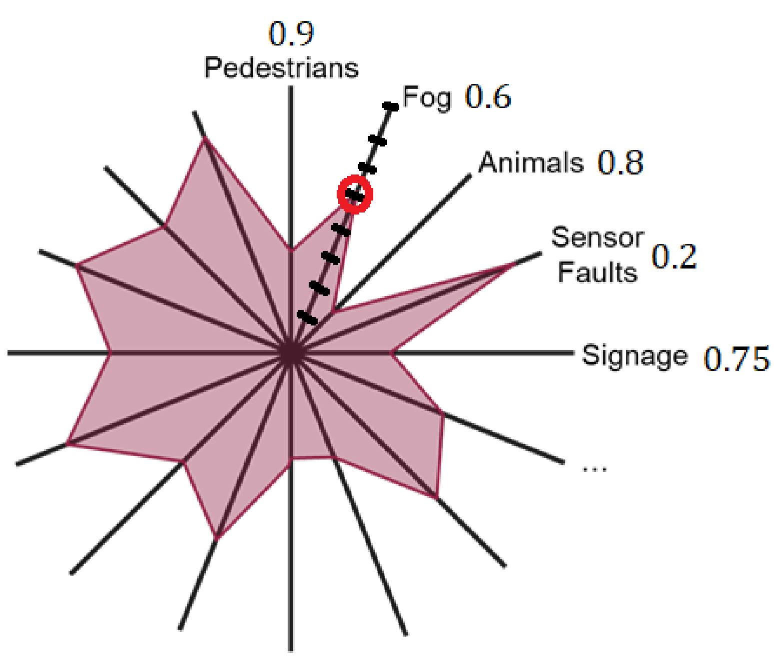
With these three steps completed, the ODD and behavioral competency portfolio of the VUT can be visualized as being made up of values provided by the AV developer that are located on a spider chart. A spider chart allows an arbitrary set of variables with independent ranges and possible values to be displayed in the same two-dimensional figure. The axes in this figure represent the possibility space variables defined in Step 1, and each of these axes has a range that is specified in Step 2. The axis tick marks represent the increments produced by the discretization of the ODD and behavioral competency portfolio variables in Step 3. It should be noted that the use of a spider chart to visualize these axes is not unique; the information contained in the chart might also be conveyed in a spreadsheet or in a bulleted list.

Each axis on the spider chart is assumed to be represented independently of the other axes. This means that, when the axes on the chart are said to represent the possibility space variables, the action of these variables on the AV as quantified by the tick marks on each axis is assumed to be quantified independently of the action of other components on the AV. As an example, while the action of rain on the AV may be different depending on the daytime condition in the scenario, the spider chart does not consider such a difference; instead, the rain axis is said to represent an “absolute” influence of rain on the AV. Future work may generalize the chart to account for the dependence of each axis on the influence of the other axes.

The “absolute” influence of each axis is quantified by one point placed on each axis of the ODD and behavioral competency portfolio chart by the AV developer. These points represent the boundary of the AV ODD and behavioral competency portfolio; that is, the maximum values of the scenario components that the AV is designed to be able to competently handle consistent with its ODD and behavioral competency portfolio, assuming that this competence is independent of the other scenario components. The farther from the origin of the chart a certain point is along an axis, the greater the expected competency of the vehicle when encountering the entity represented by that axis. A hypothetical example is shown in Figure 1; here, the ODD and behavioral competency portfolio boundary for the "Fog" axis is highlighted in a red circle. The vehicle having the ODD and behavioral competency portfolio in Figure 1 is robust to sensor faults, but does not perform well when encountering animals.

Figure 1

Example ODD and Behavioral Competency Portfolio Chart



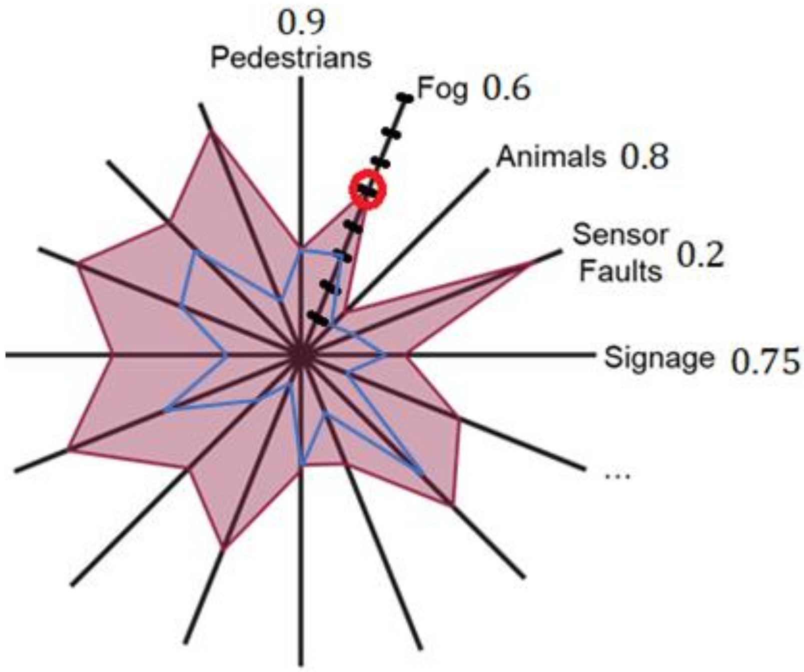
All of the axes on the ODD and behavioral competency portfolio chart are quantitative. This means that qualitative distinctions inherent to different scenario components (e.g., buses being either standard or articulated) are treated as separate axes listing the instances of those distinct entities in the scenario (e.g., one axis representing the number of articulated buses that appear in the scenario and another axis representing the number of standard buses). Additionally, some axes are binary, representing a yes/no condition for the inclusion of certain scenario components that are not adequately characterized by specifying a quantity to appear in the scenario (e.g., stop signs).

Each axis has a "weight" value between 0 and 1, as shown at the periphery of each axis in Figure 1. This weight represents the overall importance of the scenario component represented by that axis; for example, an axis detailing the number of vulnerable road users (VRUs) in the scenario will likely have a larger weight than the axis that quantifies the number of tumbleweeds in the scenario. While these weights will ultimately be decided by regulators or the implementer, the weights for all axes are initially set to 1 as a default until additional data is collected. The nature of the transition from this default to "true" weight values specified by regulators is detailed in the "Future Work" section.

Because scenarios can be derived from any ODD and behavioral competency portfolio chart, any scenario can be plotted on the same set of axes as the corresponding vehicle ODD and behavioral competency portfolio. An example scenario lying within the AV ODD and behavioral competency portfolio is shown as a blue outline in Figure 2:

Figure 2

Example ODD and Behavioral Competency Portfolio Chart with Scenario



The ODD and behavioral competency portfolio chart can be said to represent the set of all possible logical scenarios for the given ODD and behavioral competency portfolio. Logical scenarios are distinct from functional scenarios, which are high-level descriptions of scenarios that do not include specific scenario component values or ranges, and also from concrete scenarios, which are full scenario descriptions including scenario component values that can be immediately executed on the VUT (Jeffrey Wishart, personal communication, September 25, 2023). Thus, the chart can be used to generate any number of concrete scenarios, precisely because it represents the set of all possible logical scenarios.

Creating an ODD and behavioral competency portfolio chart in this way also offers other benefits. One such benefit is that an ODD and behavioral competency portfolio chart gives the implementer and the AV developer an easy way to identify potential problem areas for a given ODD and behavioral competency portfolio.

The information about the VUT ODD and behavioral competency portfolio necessary to construct a corresponding discretized chart is solicited from the AV developer via a specification form. While the overlap between the vehicle ODD and behavioral competency portfolio, behavioral competencies, and the components the VUT is expected to handle is very large, they are not all the same; thus, the specification form should include clarifying sections and solicitations that make sure to preserve the differences between these categorizations. To that end, an example specification form for a "representative" ODD and behavioral competency portfolio can be found in Appendix A as part of the proofs of concept outlined in the "Proofs of Concept" section. This specification form is adapted from the Automated Vehicle Safety Consortium (AVSC) best practices on ODD and behavioral competency frameworks, as well as ISO 21448 Annex F and other sources where noted.

A helpful taxonomy for classifying chart axes is provided by Scholtes, et al. who define six "layers" for entities, phenomena, and conditions occurring in a scenario (Scholtes, et al., 2021). These layers provide an improvement on the PEGASUS model that can be used for urban driving in addition to highway travel; consequently, they provide a complete scenario description that can be used to classify the axes of the chart. A full classification of the ODD and behavioral competency portfolio chart axes that may incorporate this taxonomy is left as future work.

Initialization

The first iteration of the TSSM begins by defining what test methods may be used for the VUT. Broadly, there are five different test methods available for AV validation: (1) pure simulation, (2) vehicle-in-the-loop/dynamometer simulation (which is not specifically considered in this thesis; both pure simulation and vehicle-in-the-loop/dynamometer simulation are referred to simply as "simulation"), (3) closed-course testing, (4) open road testing with a safety driver, and (5) open road testing without a safety driver. AVs are frequently tested using combinations of all five test methods, as each method offers unique benefits. Generally, testing in simulation is cheap and offers a guarantee of safety, closed-course testing splits a middle ground between safety and fidelity, and open road testing offers total fidelity to real-world conditions. Each test method also has corresponding disadvantages: simulation may not have the required degree of fidelity to ensure the rigor of any subsequent test results, closed-course testing may, as mentioned previously, be difficult to set up and execute, and open road testing always carries with it a safety risk to both the test driver (should one exist) and the VRUs in the immediate vicinity of the VUT.

Given that five different test methods may conceivably be used to test the VUT, the first step of the initialization phase is to specify a mix of test method percentages that will be used to guide the process by which generated scenarios are assigned to test methods in future iterations. To ensure the safety of both the implementer and the public, only simulation is "unlocked" by default for the first TSSM iteration; this means that no other test methods other than simulation are available to the implementer when starting the TSSM for the first time. Additional test methods are accessed using a tiered system of unlocks that tracks the technology relevance levels (TRLs) of the vehicle and checks for sufficient scenario coverage.

The TRL taxonomy was developed by NASA in the 1970s to “assess the maturity level of a particular technology” (NASA, 2021). A modified version of the TRL taxonomy, adapted to define the development phases for an AV, is shown in Table 1 in Appendix C; this modified version is the taxonomy that guides the unlocking of test methods with progressively higher fidelity for the VUT. (Andrew Smart, personal communication, August 11, 2023)

To advance from a given TRL to the next higher TRL, two conditions must be satisfied; first, the scenarios executed by the VUT up to the current time must provide sufficient coverage of the ODD and behavioral competency portfolio. To calculate the coverage of the ODD and behavioral competency portfolio by the scenarios generated and executed up to the current time, the TSSM draws on the ODD and behavioral competency portfolio chart as described above. The ODD and behavioral competency portfolio chart presented in Figure 1 has a “shape” indicated by the shaded purple areas in Figures 1 and 2; correspondingly, this shape can be thought of as having a “size” or “area” that is determined by the placement of the boundary points on the chart axes. This size is quantified by Equation (2):

$$\sum_{i=1}^{n_c} w_{c_i}\left(\frac{\text{tick mark \#}}{\text{\# of tick marks}}\right) \tag{2}$$

where n_c is the number of components or axes for the ODD and behavioral competency portfolio chart being used, w_{c_i} is the weight for the current axis, “tick mark #” represents the distance in tick marks of the ODD and behavioral competency portfolio boundary on the current axis from the origin, and "# of tick marks" is the total number of tick marks on the current axis.

A corresponding equation is necessary in order to equate the ODD and behavioral competency portfolio size as calculated in Equation 2 to the coverage of that portfolio provided by a given set of scenarios. Consequently, the total scenario information (TSI) yielded by any set of scenarios is given in Equation (3):

$$TSI = \sum_{j=1}^{n_s} F_j R_j C_j \left(\frac{\sum_{k=1}^{n_c} w_{c_k}}{2n_0} \right) \tag{3}$$

where n_s is the number of scenarios in the set, F_J is the fidelity for the test method assigned to scenario j, R_j is the relevance of scenario j, C_j is the complexity of scenario j, and n_0 is a tunable parameter representing a "standard" number of scenarios agreed upon by regulators and industry.

The parameter n_0 merits additional discussion. At the time of writing, little consensus exists on a standard number of scenarios, and different institutions either implicitly or explicitly offer recommended numbers of scenarios that can differ significantly between different groups. For example, a paper from Hauer, et al. that investigates the question of testing all relevant scenario types details scenario sets ranging in size from 1,000 to 50,000 (Hauer, Schmidt, Holzmuller, & Pretschner, 2020); if one takes preexisting scenario databases as a usable example, the scenario sets can range in size between approximately 100,000 to 250,000 (Deepen AI, 2022) (Waymo, 2023). As such, research into the "correct" value of n_0, and research into bolstering the formulation of the TSSM scenario coverage requirement in general, will be a key part of any future work done on the methodology.

With formulations in hand for the information yielded by any set of scenarios and for the size of the ODD and behavioral competency portfolio, the coverage by a set of scenarios of the ODD and behavioral competency portfolio can be calculated the ratio of the two quantities. Referring to Equation (2) as the minimum required scenario information (MRSI), we have an equation for this ratio as presented in Equation (4):

$$\frac{TSI}{MRSI} = \frac{\sum_{j=1}^{n_s} F_j R_j C_j \left(\frac{\sum_{k=1}^{n_c} w_{c_k}}{2n_0} \right)}{\sum_{i=1}^{n_c} w_{c_i} \left(\frac{\text{tick mark \#}}{\text{\# of tick marks}} \right)} \tag{4}$$

The ODD and behavioral competency portfolio coverage as determined by Equation (4) must be greater than a certain chosen threshold selected by the implementer. If the coverage up to the current time is less than the chosen threshold, the VUT cannot progress from one TRL to the next. In fact, if problem behaviors are sufficiently prevalent in any VUT, it may be possible for that VUT to regress from one TRL to a lower TRL.

The second condition on TRL progression is that the VUT must satisfy the definition of the current TRL before it can proceed to the next TRL. This satisfaction is determined by comparing two averages against corresponding thresholds: the average of the DA scores for scenarios executed using the current test method that are or were ever located in the RTS, and the average of the DA scores for scenarios executed using the current test method that were in the STS. These scores are equivalent to the overall TSSM scores for the RTS and STS that will be discussed in the Execution and Analysis section.

If both of these averages are greater than or equal to corresponding thresholds chosen by the implementer, the AV is said to have satisfied the definition of the current TRL and may proceed to the next TRL, pending its satisfaction of the coverage requirement. If either the RTS or the STS average scores are below their chosen thresholds, the AV must remain at the current TRL in the next TSSM iteration.

While the definitions provided in Appendix C are concise, the meanings of certain phrases and words as they relate to AV development will need clarification before the TRL taxonomy can be used to guide test method progression. Along with possible TRL backsliding by the VUT, both of these considerations are outside the scope of this thesis and are consequently left as future work.

If the performance of the AV up to the current iteration satisfies the two conditions outlined above, the VUT proceeds through the list of TRLs from TRL 5 to TRL 9. Specifically, when a sufficient level of safety and coverage has been demonstrated in simulation (corresponding to TRL 5), closed-course testing, as the next safest test method, is then "unlocked" (corresponding to TRL 6) and may be employed in the next TSSM iteration. Likewise, when the closed-course testing results demonstrate satisfactory performance and coverage, open road testing with a fallback test driver (TRL 7) becomes available in the iteration after that. Finally, if sufficiently competent performance and good coverage has been demonstrated in all other test methods, open road testing without a fallback test driver (TRL 8) is unlocked, eventually leading to TRL 9 – full commercial deployment on open roads without fallback drivers. If the performance or coverage for any one test method is not sufficient in any one iteration, the less safe test method remains prohibited in the next iteration. This tiered system of test method unlocks ensures that the AV developer's safety case is strong for all possible test methods and prioritizes the safety of both the implementer and the public.

As simulation is available by default as a method for test scenario execution, the TSSM allows the implementer free choice between any test methods beyond simulation that have been unlocked. However, this chosen mix must satisfy minimum percentages for simulation, closed-course, and open road testing that will be specified by a regulatory body.

While the methods may be available, some simulators and closed courses may be unable to reliably reproduce certain components of a scenario, by way of either insufficient fidelity or insufficient test equipment. This inadequacy is accounted for in the scenario generation process: if the simulator or closed course to be used for testing are not capable of simulating all the axes of the "general" ODD and behavioral competency portfolio chart approved for use by regulators, an abridged version with fewer axes may be used for all test methods instead, again assuming regulatory approval.

As the transition from TRL 8 to TRL 9 is perhaps the most important transition that the AV will undergo, additional data may be required to support the safety case for that TRL and ensure that the choice to deploy the VUT on open roads without a safety driver is not made in error. Specifically, this data will need to provide a basis for comparison between human-driven vehicles (HDVs) and AVs; therefore, the data will likely be in the form of HDV fatality and injury statistics (Jeffrey Wishart, personal communication, September 24, 2023). However, introducing HDV data results in a resurrection of the third challenge – events resulting in fatalities or even minor injuries simply do not occur during most driving situations, so an AV must accumulate an intractably large driven mileage in order for that mileage to generate enough "problem" events to be comparable to similar data from HDVs (Feng, personal communication, September 24, 2023). As mentioned in the literature review, Feng, et al. have done significant work in addressing this problem with their AI-based approach (Feng, et al., 2023). A TSSM-based approach might run several TSSM simulation process *in parallel* on the same AV. Doing so would be attainable (because of the relatively low cost of simulation) and would generate a larger set than normal of partially randomized scenarios as described in the following sections; many of these scenarios would represent potentially hazardous conditions. It may then be possible to extrapolate or upsample from this set of scenarios to create a set large enough to be compared to HDV statistics. The exact implementation of this process is left as future work.

The next step of the initialization phase is to determine the minimum required scenario information (MRSI) necessary to provide sufficient testing coverage for the VUT ODD and behavioral competency portfolio. The minimum required scenario information is given by Equation (2); once this quantity is calculated, four test sets are then generated that are used to organize the scenarios executed by the TSSM: (1) the random test set (RTS), (2) the standard test set (STS), (3) the known unsafe test set (KUTS), and (4) the known safe test set (KSTS). The RTS consists of all the scenarios randomly generated by the TSSM; it is the most significant of the four test sets and, initially, the largest. The STS outlines a set of scenarios that is standardized between identical ODD and behavioral competency portfolios; that is, two AVs from different developers or that have different sensor layouts and characteristics will be tested on the same set of scenarios in the STS if they operate with identical ODD and behavioral competency portfolios. The KUTS consists of scenarios that are known to cause issues for the VUT, either from cases specified by the AV developer beforehand or from knowledge gained through repeated TSSM iterations. Finally, the KSTS contains any scenarios that the AV has been able to navigate successfully. An additional distinction is that the RTS and the STS always contain scenarios that are due to be executed in the current TSSM iteration; by contrast, the scenarios in the KUTS and KSTS have already been executed and are not executed again. Normally, as problem scenarios known beforehand to the developer are both known and unsafe, they would be placed in the KUTS; however, to ensure these scenarios are executed, they are instead placed in the RTS in the first TSSM iteration.

These test sets are structured to conform to the taxonomy provided by ISO 21448, as presented in Figure 3 (International Organization for Standardization, 2019). ISO 21448 provides a categorization scheme for AV test scenarios depending on if they are known to the developer beforehand and whether they are safe or unsafe. Specifically, in Figure 3, Area 1 represents the space of known safe scenarios; Area 2 represents the space of known unsafe scenarios, Area 3 represents the space of unknown unsafe scenarios, and Area 4 represents the space of unknown safe scenarios.

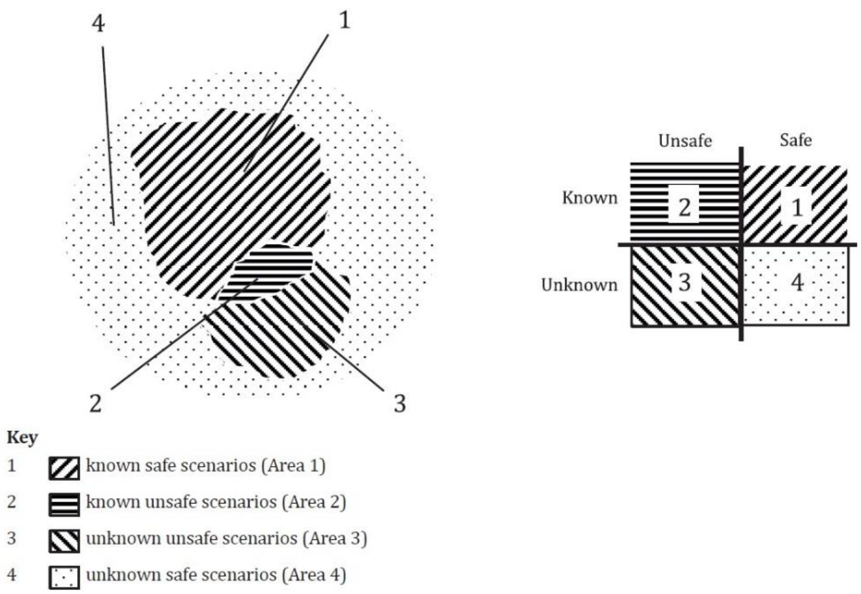
The KUTS, because it receives previously unknown unsafe scenarios as known unsafe scenarios from the RTS after execution, is a direct analogue for Area 2: both provide a measure of how many known, unsafe scenarios currently exist. As the number of scenarios added to the KUTS increases, so too does the size of Area 2; this also results in an (unquantifiable) decrease in the size of Area 3, which is the goal of ISO 21448.

Area 1 is accounted for by the KSTS; lastly, as the scenarios in Area 4 do not represent a safety issue, Area 4 is not explicitly accounted for by the TSSM.

Figure 3

Visualization of the Known/Unknown Safe/Unsafe Categories

(International Organization for Standardization, 2019)



The final step in the initialization phase is for the implementer or AV developer to specify any desired behavioral competencies to test, pursuant to the AVSC best practice on behavioral competencies (Automated Vehicle Safety Consortium, 2021). These behavioral competencies are revisited in a later step of the TSSM when open road testing becomes available.

STS Specification

The next phase of the TSSM after initialization is the specifying of scenarios with which to test the VUT in the given ODD and behavioral competency portfolio.

Accordingly, the first test set of the four test sets to be populated is the STS. This population process is accomplished through filtering, whereby a large set of scenarios are subjected to specific criteria and are allowed to proceed to the next stage of the process if they conform to those criteria. Correspondingly, scenarios that fail to meet any one of the specified criteria are either modified by changing one or more components until they conform or are rejected outright. Filtering is used in several stages of the TSSM to provide an overall set of scenarios that is both meaningful and small enough to be testable.

NHTSA has published a list of the 37 most common scenarios that occur prior to traffic collisions in the United States (National Highway Traffic Safety Administration, 2007). The STS is derived solely from this list. The STS is generated by first filtering all 37 scenarios on the list through the VUT ODD and behavioral competency portfolio; that is, those scenarios that can possibly occur within the VUT ODD and behavioral competency portfolio and can therefore pass through the filter go through to the generation stage, while those that do not pass are discarded. For example, if the ODD and behavioral competency portfolio of the VUT only entails driving down a single-lane highway, scenarios from the list of 37 pre-crash scenarios that involve lane changes will be discarded. Developing nominal and critical versions of the scenarios distilled from the list is an active area of research for the AV-TEP group.

The “generation” stage of the STS proceeds by considering the first scenario on the filtered list of 37 pre-crash scenarios. The ODD and behavioral competency portfolio chart will have a “Permissible Speeds” axis that quantifies the permissible speeds for both the VUT and any other vehicles in the current scenario. STS scenarios are generated by beginning at the lowest speed on the "Permissible Speeds" axis and iteratively assigning to the VUT and other vehicles all possible combinations of the speeds on that axis. Once all possible combinations of speeds have been exhausted for that scenario, the TSSM moves to the next scenario on the filtered list, and the generation process starts again. While the scenario actor speeds are varied, all other components for each scenario are held constant; future work may generalize this process of iterating values on a single axis to include any of the other axes on the ODD and behavioral competency portfolio chart.

A "solver" step is included at the end of the STS iteration process whereby scenarios that cannot exist are removed from the test set. For the purposes of this thesis, self-contradicting or impossible scenarios are removed manually; the exact details and automation of this process are left as future work.

Below are some example constant values:

- The generated scenario takes place on the most common road type in the ODD and behavioral competency portfolio area.
- Any other vehicles are of the most common vehicle type in the ODD and behavioral competency portfolio area.
- The weather during the scenario is typical for the ODD and behavioral competency portfolio area.
- The road type, markings, and contours are typical for the ODD and behavioral competency portfolio area.

These components are held constant to ensure that the STS is, indeed, standardized between identical ODD and behavioral competency portfolios.

RTS Specification

Once the STS has been generated, the TSSM moves on to generating the RTS. After the RTS is first populated with any scenarios that have been provided by the developers for testing, the RTS can be generated in one of two possible ways. The RTS may be generated by "overlaying" the TSSM onto a suitably large preexisting database of scenarios, making the TSSM suitable for use and compatible with any number of scenario databases from regulatory, industry, or academic bodies. Alternatively, the RTS can be generated from scratch, without the use of a preexisting database. The method of RTS generation therefore changes based on the availability of a suitable database.

If a scenario database is available, a scenario is randomly selected from the database and discretized according to the VUT ODD and behavioral competency portfolio chart currently in use. Each component of the selected scenario, as it is described in the database, is matched with the axis corresponding to it in the ODD and behavioral competency portfolio chart and quantized according to the tick marks on that axis. This process repeats until a fully discretized description of the database scenario is generated. An additional check is made to ensure that the scenario is within the VUT ODD and behavioral competency portfolio; if the scenario as discretized lies outside of the current portfolio, a different scenario that is inside the current portfolio is selected and discretized. An example execution of this process is outlined for scenarios in the database maintained by the UK-based SafetyPool initiative in the "Proof of Concept" section.

If a scenario database is not available, or if the decision is made by the implementer or developer not to use a preexisting scenario database, a set of n_c scenario components are generated by selecting a random tick mark on each axis of the VUT

ODD and behavioral competency portfolio chart, where n_c is the number of axes on the VUT ODD and behavioral competency portfolio chart in use. This selected tick mark is always within the given ODD and behavioral competency portfolio as defined by the boundary points on each axis (note that, in general, the ODD and behavioral competency portfolio boundary is not located at or equivalent to the global axis maximum for a given axis). Requiring that the tick marks are always selected within the boundaries of the ODD and behavioral competency portfolio ensures that the VUT is not tested under conditions in which it was not designed to operate.

The resulting scenario can be analyzed and manipulated on two different levels. The first level is the component level, whereby each component of the scenario, as specified by a value on an axis of the ODD and behavioral competency portfolio chart, can be considered individually and actions taken based on the values therein. The second level is, naturally, the scenario as a whole, which can be thought of as the sum of all of its constituent components; actions can then be taken that are based on the quantitative characteristics of the entire scenario. Further, each component comprising the generated scenario can be thought of as having a relevance of its own, separate from the overall scenario relevance. Likewise, the whole scenario, as mentioned previously, has some complexity and some relevance, and the test method supplies a fidelity value.

Once a complete scenario has been generated according to either of the two procedures outlined above, the scenario is then subjected to two filters. For the first filter, the implementer sets a numerical threshold for component-level relevance between 0 and 1. The TSSM then iterates through all of the generated components for the current scenario; if the relevance of the value of any single scenario component (as calculated in

Equation (8)) is less than the chosen threshold, the value of that scenario component only has a certain probability of being allowed to remain unchanged in the generated scenario. However, if the relevance of the component is equal to or greater than the chosen threshold, the value of that scenario component will be included in the overall scenario.

The equations used to implement this filtration algorithm are given in Equations (5) and (6):

$$R_{0,C} \leq R_C < 1.0\text{: included} \tag{5}$$

$$0 < R_C < R_{0,C}\text{: randomized} \tag{6}$$

where $R_{0,C}$ is the component-level relevance threshold selected by the implementer and R_C is the relevance of the value of the component currently being considered.

If the relevance of a component value is less than the chosen threshold, as described in Equation (6), the probability that it will be preserved in the overall scenario is as given in Equation (7):

$$P_C = \frac{R_C}{R_{0,C}} \tag{7}$$

where P_C is the probability of the preservation of the value of the current component in the overall scenario. If the value of the current component is not preserved in the overall scenario according to Equation (7), its value is simply changed at random and the process begins again with the new value.

Implementing a stochastic approach to component value preservation as described above balances considerations of testing efficiency with random discovery of potential problem scenarios. Further, constructing the probability of component value preservation as being proportional to the component relevance ensures that high-relevance component values are favored for preservation over low relevance values, but are nonetheless not guaranteed to be preserved.

The actual relevance of the scenario component is calculated using Equation (8):

$$R_C = \beta \cdot \max\left(w_C\left(\frac{\text{tick mark \#}}{\text{\# of tick marks}}\right),\ d_{PR}\left(\frac{\omega_{S_{PR}}}{n_{s_{PR}}}\right)\right) \tag{8}$$

where β is a normalizing term, w_C is the axis weight for the current component, d_{PR} is the total executed mileage of open road testing, $\omega_{S_{PR}}$ is the number of occurrences of the current component in the scenarios derived from open road test data, and $n_{s_{PR}}$ is the number of scenarios that have been derived from open road test data.

Equation (8) is structured to take the maximum of two different quantities to ensure that, if sufficient open road test data are available, the relevance value accurately reflects the frequency of that scenario component in the VUT ODD and behavioral competency portfolio. As the total mileage of open road testing grows, the open road term dominates and is eventually selected to represent the component relevance. However, if open road testing has not yet been conducted or has not yet been unlocked, there must still be a way to quantify component-level relevance, which is why an alternative, ODD and behavioral competency portfolio chart-based formulation is available. To that end, if no open road testing has been conducted previous to the current iteration, d_{PR} is zero, and Equation (8) collapses to Equation (9):

$$R_C = \beta w_C\left(\frac{\text{tick mark \#}}{\text{\# of tick marks}}\right) \tag{9}$$

The filtration cycle repeats as outlined above until a scenario is obtained whose components have all passed through the component-level relevance filter.

The ODD and behavioral competency portfolio specification form provided in Appendix B allows for the VUT developer to have the option of specifying relevance values on a per-component basis. This specified value may be used in place of the value calculated in Equations (8) or (9); however, safeguards will need to be put in place to ensure that the ability of the VUT developer to specify a relevance value is not abused to manipulate the results of the TSSM in favor of the VUT.

Once the component-level relevance condition is satisfied, an additional random filter is applied at the level of the whole scenario. The implementer selects another threshold for scenario-level relevance, which is not necessarily equal to the threshold selected for component-level relevance. If the relevance of the scenario taken as a whole is less than the chosen threshold, that scenario only has a certain probability of inclusion into the RTS. However, if the relevance of the scenario is greater than the chosen threshold, the scenario is immediately included in the RTS.

The scenario-level filtration algorithm is implemented as shown in Equations (10) and (11):

$$R_{0,S} \leq R_s < 1.0\text{: included} \tag{10}$$

$$0 < R_s < R_{0,S}\text{: randomized} \tag{11}$$

where $R_{0,S}$ is the scenario-level relevance threshold selected by the implementer and R_S is the relevance of the scenario taken as a whole.

If the relevance of the scenario falls below the threshold chosen by the implementer as described above, the probability that the scenario will be selected to be added to the RTS is as shown in Equation (12):

$$P_s = \frac{R_s}{R_{0,S}} \tag{12}$$

where P_S is the probability of the scenario's inclusion in the RTS.

The relevance of the whole scenario is calculated as the normalized sum of the relevance values of its constituent components, as shown in Equation (13):

$$R_s = \frac{1}{n_c}\sum_{i=1}^{n_c} R_{C_i} \tag{13}$$

The generation and filtration process described above iterates until the TSI of all the generated random scenarios is equal to the calculated size of the VUT ODD and behavioral competency portfolio.

Equations (5) through (13) collectively ensure that, on the whole, scenarios irrelevant to a given ODD and behavioral competency portfolio are excluded from the test suite and relevant cases are included, while a mechanism is in place to include possibly significant cases by way of random selection. Additionally, the dual randomness of the process ensures that the scenarios that will be used to test the VUT are not known to either the implementer or the AV developer beforehand, ensuring the integrity of the TSSM process.

To demonstrate that MRSI is satisfied as given in Equation (2), the complexity of the current scenario and the fidelity of the current test method must also be determined. An equation for scenario complexity is given in Equation (14):

$$\frac{1}{n_c}\sum_{i}^{n_c} w_{c_i}\left(\frac{\text{tick mark \#}}{\text{\# of tick marks}}\right) \tag{14}$$

This ODD and behavioral competency portfolio-chart based calculation of complexity, in concert with the scenario-level relevance equation given in Equation (13), provides an easy, integrated method for calculating scenario information. While complexity and relevance for the current scenario are well-quantified, research into methods for calculating the fidelity of a certain test method are ongoing; for the purposes of this thesis, placeholder values are used on a case-by-case basis for each test method. An equation for calculating test method fidelity is currently under development as part of the AV-TEP mission.

Optimizing the TSSM to balance test complexity, relevance and fidelity while still providing a practical and effective mix of scenarios is a very complex task. As stated in the Introduction section, the TSSM allows the implementer the choice of a mix of test methods (conforming to regulatory minimums) as they are most aware of the mix of tools available to them for AV testing and the benefits and drawbacks inherent to each.

To ensure that this mix is satisfied, newly generated scenarios are always assigned to simulation by default, regardless of which test set they are generated for. In later iterations of the TSSM, certain scenarios that have been previously executed in simulation are duplicated and reassigned to new test methods with higher fidelities. This provides a mechanism to both extract more information from scenarios of interest and to validate the testing tools being used by the AV developer – specifically the simulator and the closed course. This reassignment process is detailed in the “Further Iterations” section.

Open Road Testing

Unlike with simulation and closed-course testing, it is impossible to specify beforehand which scenarios to test on open roads, as such testing is unpredictable by its very nature. A separate, different testing structure is therefore in place in the TSSM to be able to glean useful information about the safety of an AV from testing on open roads.

As an overview, the core idea behind open road testing is that, after the execution of a prescribed open road test mileage, scenarios can be discretized from the raw open road test data. These scenarios are then added to the RTS and executed in simulation in the current iteration.

While the scenarios derived from open road testing are analyzed on their own, the TSSM also includes a method for checking behavioral competencies pursuant to the AVSC best practice on the matter (Automated Vehicle Safety Consortium, 2021). First, any behavioral competencies that the AV developer desires to test are specified by the developer at the outset of the TSSM process. These behavioral competencies are then checked for in the open road testing data for each iteration after open road testing has been unlocked; the resulting pass/fail values are then factored into the final scoring equation in the "Execution and Analysis" section.

Open road testing with a safety driver must first be unlocked by proving good results on a closed course. Once sufficient closed-course performance has been demonstrated, a prescribed mileage of open road testing d_{PR_0} is generated using Equation (15):

$$d_{PR_0} = \frac{C_{PR_{avg}} d_{ODD,tot} \left(\sum_{i=1}^{n_c} w_{c_i} \left(\frac{\text{tick mark \#}}{\text{\# of tick marks}}\right)\right)}{\varphi_{PR,avg}} \tag{15}$$

where $C_{PR_{avg}}$ is the average complexity of the scenarios that have been distilled from open road testing, $d_{ODD,tot}$ is the total mileage of all of the roads in the ODD and behavioral competency portfolio (estimated if the figure is not publicly available), and $\varphi_{PR,avg}$ is the average TSSM score for all of the scenarios that have been distilled from open road testing. If no open road test data is available (as would be the case for the first TSSM iteration that open road testing has been unlocked), then $C_{PR_{avg}}$ and $\varphi_{PR,avg}$ both have default values of 1, collapsing Equation (15) to Equation (16):

$$d_{PR_0} = d_{ODD,tot}\left(\sum_{i=1}^{n_c} w_{c_i}\left(\frac{\text{tick mark \#}}{\text{\# of tick marks}}\right)\right) \qquad (16)$$

The exact algorithm for derivation of workable scenarios from open road test data is outside the scope of this thesis and is left as future work.

The scenarios derived from open road testing will be informed by data gathered either using on-vehicle sensors or sensor arrays deployed on the infrastructure surrounding the scenario area. Data gathered using one modality will not be qualitatively different from data measuring the same phenomena gathered using the other modality (beyond the deviations attributable to the varying measurement uncertainties of the two modalities). However, each sensor modality will be able to gather certain types of data that the other modality may struggle or fail to record. For example, sensors mounted on the AV itself may be able to record forces applied to or generated by the vehicle directly, such as those that may be generated during a collision event or by the vehicle accelerating, respectively, while infrastructure-based sensors might struggle to infer force data based on kinematic calculations “from afar”. Likewise, infrastructure-based sensor systems will be able to record and analyze global traffic flow data that is not as easily captured by sensors mounted on a single vehicle. The derivation process for scenarios based on open road test data should account for the above considerations and should ideally incorporate data from both on-vehicle and infrastructure-based data capture systems; if only one can be used, the modality should be selected that is best able to record data relevant to the chosen behavioral competencies.

Execution and Analysis

The final step of any TSSM iteration is to execute all scenarios that have been provided and/or generated for the current iteration using their assigned test methods and to conduct any open road test mileage that has been prescribed. After execution, the TSSM will generate an overall score for AV performance. This score will be a single numerical rating that can be used to compare safety performance across AV brands or even between human-operated vehicles and AVs; as stated previously, this score numerically represents the aggregate driving performance of the AV across the wide breadth and depth of scenarios generated by the TSSM.

The TSSM score combines three separate measures of AV driving performance. The first measure involves averaging the DA metrics score formula (Equation (1)) over the n cases included in the test suite.

First, the scores for the individual executed scenarios undergo a modification to properly reflect their pass/fail statuses for the VUT. If the DA score for any individual scenario is below a certain threshold specified by regulators, and the VUT therefore fails in its execution of that scenario, that scenario score is treated as a zero in the overall TSSM scoring equation. Alternatively, if the implementer or AV developer wishes to take a qualitative approach to passing or failing individual scenarios, they may specify safety test objectives for each scenario as outlined by ISO 34502 (International Organization for Standardization, 2022). If this approach is taken, the scenario score will be treated as a zero in the overall TSSM scoring equation if the scenario does not meet its corresponding safety test objective; if the scenario does meet the objective, its numerical score is preserved. Regardless of which approach is taken, the scenario score retains its numerical value elsewhere.

Thus, using a shortened form of Equation (1), the TSSM score is as presented in Equation (17):

$$\varphi_{TSSM} = \varphi_{STS} + \varphi_{RTS} \tag{17}$$

where φ_{TSSM} is the overall TSSM score and φ_{STS} and φ_{RTS} are the average modified scores for the scenarios placed in the STS in the first TSSM iteration and all the scenarios placed in the RTS over all TSSM iterations. Note that, for the first iteration, cases provided by the developer and assigned to the RTS are not considered in φ_{RTS}.

φ_{STS} and φ_{RTS} are as shown in Equations (18) and (19):

$$\varphi_{STS} = \frac{1}{n_{STS}} \sum_{i=1}^{n_{STS}} \left(C_{s_i} R_{s_i} F_{T_i} \left(1 - \sum_j M_j S_j \right) \right) \tag{18}$$

$$\varphi_{RTS} = \frac{1}{n_{RTS}} \sum_{k=1}^{n_{RTS}} \left(C_{s_k} R_{s_k} F_{T_k} \left(1 - \sum_l M_l S_l \right) \right) \tag{19}$$

where $C_{s_i} R_{s_i} F_{T_i} \left(1 - \sum_j M_j S_j\right)$ and $C_{s_k} R_{s_k} F_{T_k} (1 - \sum_l M_l S_l)$ are the DA scores for a scenario in the STS and RTS, respectively, and n_{STS} and n_{RTS} are the number of STS and RTS scenarios, respectively. Breaking the overall TSSM score up into STS and RTS components allows regulatory bodies to prescribe score thresholds for both the RTS and STS scores (and, by extension, the total TSSM score).

The second part of the TSSM score reflects the knowledge gained from the KUTS. Any scenarios that appear in the KUTS should be addressed in the overall safety case; further, the growth of the KUTS over time, as is addressed by ISO 21448, must be considered in the overall TSSM score. To that end, we incorporate the term outlined in Equation (20) into the overall scoring equation as a condition that must be satisfied in order to achieve a nonzero score:

$$\frac{1}{n_i}\sum_{k=2}^{n_i}|KUTS|_k - |KUTS|_{k-1} \geq |KUTS|_0 \tag{20}$$

where n_i is the number of TSSM iterations in total, $|KUTS|_k$ and $|KUTS|_{k-1}$ are the numbers of scenarios in the KUTS for the k^{th} and $k-1^{\text{th}}$ iterations, respectively, and $|KUTS|_0$ is a threshold providing success criteria for the equation. Note that this equation begins from $k = 2$, as in the first iteration the KUTS will not contain any scenarios.

As with other equations underlying the TSSM, the quantity in Equation (20) is compared against a threshold selected by the implementer (in this case, $|KUTS|_0$). However, if the quantity on the left side of Equation (20) is less than this threshold and therefore fails to satisfy it, the quantity is replaced by a zero in the overall scoring equation, and the AV fails the TSSM.

The third part of the TSSM score incorporates the behavioral competencies checked for in the open road testing data. At least some percentage of behavioral competencies out of the total number of specified behavioral competencies must be satisfied, so we again compare the results against a threshold, as per Equation (21):

$$\frac{BC_{sat}}{BC_{tot}} \geq BC_0 \tag{21}$$

where BC_{sat} is the number of satisfied behavioral competencies over all iterations, BC_{tot} is the total number of specified behavioral competencies, and BC_0 is the threshold between 0 and 1 specified by the implementer.

Because the TSSM employs a rigorous scenario selection and generation process and is based on an equally rigorous set of DA metrics, the simple averages defined in Equations (18) and (19) convey a great deal of information about the general automated driving performance of the AV under test. However, the conditions on the growth of the KUTS and the satisfaction of any specified behavioral competencies add an additional measure of robustness; therefore, the final equation for the TSSM score is as shown in Equations (22) and (23).

If $\frac{1}{n_i}\sum_{k=2}^{n_i}|KUTS|_k - |KUTS|_{k-1} \geq |KUTS|_0$ and $\frac{BC_{sat}}{BC_{tot}} \geq BC_0$:

$$\varphi_{TSSM} = (\varphi_{STS} + \varphi_{RTS}) \tag{22}$$

Otherwise:

$$\varphi_{TSSM} = 0 \tag{23}$$

If no scenarios yet exist in the KUTS and open road testing has not yet been unlocked, no conditions are imposed on the scoring equation in Equation (22).

Once the TSSM score has been calculated for the given TSSM iteration, the scores for each test method (calculated as the TSSM score for the set of all scenarios executed in a given test method over all iterations) are analyzed. As stated previously, if the net score for all the scenarios executed using a given test method surpasses a specified minimum, the next test method is unlocked according to the provided TRL taxonomy: for example, if results in simulation are sufficiently robust, then closed-course testing is unlocked; if results for closed-course testing are satisfactory, then open road testing is unlocked, and so on. If the scores for all test methods, as well as φ_{STS}, φ_{RTS}, and φ_{TSSM}, surpass thresholds specified by regulators, then the AV is said to have "passed" the TSSM, and may undergo full commercial deployment on open roads in the specified ODD and behavioral competency portfolio without a safety driver.

Further Iterations

All iterations of the TSSM from the second iteration onward begin with a KUTS and a KSTS populated with scenarios from all previous iterations. Therefore, the TSSM has a slightly different structure for these iterations; the TSSM begins these iterations by selecting the scenario in the KUTS that has the largest product of relevance and complexity (denoted RC). Two conditions must be met here: the value of RC for the current scenario must be greater than a threshold set by the implementer, and the DA score for the current scenario must also be lower than a specified threshold (as the KUTS contains scenarios that have "failing" DA scores, and those scenarios with especially severe failures (i.e., low DA scores) are of particular interest). These two conditions are in place to ensure that the TSSM does not lean too heavily on closed-course testing.

If these two conditions are satisfied, a copy of the current scenario is made, and this copy is moved from simulation, to which the original was assigned by default, up a single test method to the test method with the next lowest fidelity. In the case of simulation, this next test method is closed-course testing. If the original scenario does not exceed the DA score threshold, it will still be bumped up to closed-course testing if a safety-critical situation or challenging situation for the VUT has been identified in the scenario by the implementer. The copy scenario will then be added to the RTS for the current iteration. The original scenario remains in the KUTS, which only ever contains scenarios that have already been executed and will not be executed again.

The TSSM continues to iterate through the scenarios in the KUTS in order of descending RC values until the KUTS has been exhausted of scenarios that meet the RC value threshold. It then checks if the test method mix specified by the implementer has been satisfied and meets regulatory requirements; if this is not the case, then the TSSM does one of two things depending on the current mix. If more scenarios need to be generated in simulation, the TSSM generates them according to the procedure outlined in the "RTS Specification" section until the test method mix is satisfied. If more scenarios need to be assigned to closed-course testing to satisfy the test method mix, then the TSSM decreases the RC threshold and redoes the assignment algorithm presented above using the new, lower threshold. The TSSM will continue to lower the RC threshold and rerun the assignment algorithm until a sufficient number of scenarios have been assigned to closed-course testing to satisfy the test method mix specified by the implementer. Once the test method mix is satisfied, the TSSM proceeds to the edge and corner scenario probing section as normal. The TSSM process past this point is identical to the first iteration.

A filter is put in place in the TSSM to ensure that, given the simulation and closed-course test configurations in use for the current TSSM cycle, any scenarios that are moved from simulation to closed-course testing can be handled and effectively reproduced on the closed course. Alternatively, if a certain scenario cannot be executed in whole on a closed course, that scenario can be executed using a hybridized approach using elements of both simulation and closed-course testing. In this case, those parts of the scenario that can be executed on a closed course are executed with that test method, while the parts of the scenario that cannot be executed on a closed course are instead simulated. In fact, it is possible to execute these components simultaneously on the same vehicle; such an approach is evidenced in the combination of simulation and closed-course testing being developed by Feng, et al. (Feng, Yan, Sun, Feng, & Liu, 2021), which uses an augmented reality (AR)-based approach that simulates those components that cannot be adequately addressed by closed-course testing. The vehicle used by Dr. Junfeng Zhao's BELIV lab is also intended to utilize a similar approach to combining simulation and closed-course testing. The fidelity value for such a "hybrid" scenario might be calculated as the average between the two test methods, weighted by the total relevance of the components addressed by each.

The above process with this filter in place allows for validation of the chosen simulator by using closed-course results for the same scenarios; a condition where a discrepancy is found triggers a stop to the entire TSSM process, as described below.

The TSSM will go through successive iterations as described above until one of five conditions are met. The first condition occurs when a discrepancy is found between any two otherwise identical result sets for scenarios that have been run using different test methods beyond that which may be indicated by the different fidelity values of the two methods. Such a discrepancy indicates that the fidelity value for one of the test methods is incorrect and must be revised; the TSSM will stop and advise the implementer to revisit the fidelity value of that method before beginning a new iteration.

The second condition is triggered when a safety-critical scenario is identified on a closed course. The TSSM cannot allow an AV to pass to open road testing that has had safety-critical scenarios identified in a real-world environment, so the current iteration stops at this point and directs the implementer to generate a new software or hardware version that addresses the safety-critical scenario and prevents it from reoccurring. The TSSM will then restart from the beginning with the new software or hardware build.

The third condition is similar, occurring when a safety-critical scenario is identified in open road testing. While the second stop condition ensures that an AV that experiences a safety-critical scenario on closed course testing will not be advanced to open road testing, the possibility remains that, even if an AV does not experience a safety-critical scenario on a closed course, the vehicle may still experience a safety-critical scenario on the open road. In this case, it is crucial to differentiate between whether the VUT initiated or simply responded to the safety-critical scenario. If the VUT is the initiator of the safety-critical condition, the stop condition is implemented, and as before, the current TSSM iteration stops and the implementer is directed to generate a new software or hardware version that prevents the AV behavior that gave rise to the safety-critical scenario. However, if the AV only responds to the safety-critical condition initiated by another vehicle, the stop condition is only put in place at the discretion of the implementer, depending on the severity of the resulting safety-critical condition and the corresponding DA score.

The fourth condition happens when any conditions are encountered during open road testing that cannot be accounted for by the ODD and behavioral competency portfolio chart currently in use (if that ODD and behavioral competency portfolio chart is abridged from the “general” ODD and behavioral competency portfolio chart). This demands a stop to the current iteration and the adoption of a more complex ODD and behavioral competency portfolio chart that can account for the conditions encountered during open road testing.

The fifth condition is as mentioned above – a “passing” condition in which all scores for the corresponding test suites and test methods are satisfactory as determined by regulators. In this case, the AV is allowed full commercial operation on open roads.

Edge and Corner Scenarios

Edge scenarios, like the name implies, are scenarios in which the VUT struggles or fails to properly execute the driving task because of a problem component (or components) which has a value (or values) on the edge of its ODD and behavioral competency portfolio. Corner scenarios are any scenarios that lead to insufficient or hazardous performance by the VUT as a result of the combined action of two or more scenario components that are not necessarily located on the edge of the ODD and behavioral competency portfolio. As mentioned previously, these definitions are made possible by the use of the TSSM’s ODD and behavioral competency portfolio chart-based approach.

The TSSM must include a method to probe around edge and corner scenarios because these scenarios represent potentially hazardous conditions for the VUT. As such, they have a high informational value, owing to the curse of rarity; testing efforts are better spent probing around edge and corner scenarios to potentially discover additional, related hazardous scenarios than if they were spent randomly generating scenarios otherwise.

Because edge and corner scenarios are already generated naturally by the TSSM, after the first iteration the TSSM iterates through the scenarios meeting the above definitions that have individual DA scores below the failing threshold. This is done in the same way the TSSM handles KUTS scenarios; the TSSM first selects the edge or corner scenario in the set of failing edge and corner scenarios with the highest RC value and iterates in the direction of decreasing RC until no edge or corner scenarios remain that meet or exceed a chosen RC value threshold. When an edge scenario is selected, the TSSM copies it and decrements the value of the edge component (or the value of one of the edge components, selected at random) in the copy scenario by one axis unit. This new scenario is also added to the RTS for execution in the next iteration. When a corner scenario is selected, the TSSM again copies it and decrements the value of one of the corner components (selected at random) by one axis unit. As before, the new scenario is placed in the RTS for execution in the next iteration.

Alternatively, instead of decrementing by one axis unit, a percentage decrement can be specified. For example, the implementer may specify that the TSSM, when performing the error probing algorithm for edge and corner scenarios, must decrement by 10% in each probing step. For an axis with 100 distinct tick marks, then, the TSSM would decrement by 10 tick marks for each probing step. This prevents the TSSM from making changes on axes that have many tick marks that are so small as to be insignificant. Another option is to decrement the value of a certain edge or corner component all the way to the ODD and behavioral competency chart origin. Decrementing in this fashion allows for more efficient probing, as decrementing a component all the way to zero will quickly demonstrate the effect of the lack of that component on AV driving performance.

Probing edge and corner scenarios as described above also conforms to the ISO 21448 taxonomy. Doing so results in an additional decrease in the size of Areas 3 and 4 (representing unknown safe and unsafe scenarios) with a corresponding growth in the size of Areas 1 and 2 (known safe and unsafe scenarios).

TSSM Expedition

The methodology presented in this paper also includes a reduced, expedited testing process that can be used when any change to the overall AV system that requires testing is too small to justify the costs associated with a full TSSM iteration. The exact threshold that determines whether a full or expedited TSSM is conducted is left as future work.

If the current TSSM iteration is expedited, closed-course testing is unlocked as a test method by default in the first iteration alongside simulation. The methodology passes straight to the "RTS Specification" section, and generates RTS scenarios in simulation until MRSI is satisfied per Equation (2). It then selects the scenario in the set of newly generated scenarios with the highest RC value and, iterating in the direction of decreasing RC values, reassigns each scenario to closed-course testing until there are no cases remaining in the RTS that are above the chosen RC threshold. It then checks if the test method mix specified by the implementer is satisfied; if not, the RC threshold is lowered and the reassignment process starts again until the mix is satisfied. The rest of the TSSM proceeds as normal, including for further iterations.

CHAPTER 4

PROOFS OF CONCEPT

ODD and Behavioral Competency Portfolio Specification Form

The TSSM is validated by way of two proofs of concept. The first proof of concept involves generating an ODD and behavioral competency portfolio "specification form". This specification form outlines all of the information contained in an ODD and behavioral competency portfolio chart that is suitable for testing and may be presented to an AV developer for solicitation of information about the VUT ODD and behavioral competency portfolio. The specification form prompts the AV developer to provide a range and boundary for each axis of the chart, seeking to place a point on the axis that represents boundary of the ODD and behavioral competency portfolio and, equivalently, the ability of the VUT to handle the entity, phenomena, or condition represented by that axis.

Specifically, the entries in the specification form for each axis of the ODD and behavioral competency portfolio is structured in the specification form as follows (as is also presented in Appendix A):

All entries share the same first six fields and section classification scheme, as shown below:

Axis Group (Example: Roadway Infrastructure)

(Section #) Axis name (Example: Roadway grade)

- Definition: a short definition that gives an explanation of the current component
- Source(s) (if applicable): The source of reference information from which information about the axis was drawn, if one exists. To save space and avoid

repetition, the source is only cited in this field; however, the source applies to both the axis name, the definition, and any provided diagrams.

- Metric: what the axis represents (e.g., roadway grade/slope)
- Units: the unit that the axis uses (e.g., percentage)
- Range: the maximum and minimum values on the axis, measured using the axis unit
- Increment: the distance between adjacent tick marks on the axis, measured using the axis unit

The entries differ in what questions they pose to the AV developer. For behavioral competency components that are not binary:

- Question 1: A question asking the AV developer to specify the boundary of the ODD and behavioral competency portfolio for the current component (e.g., Based on the information above, what is the maximum roadway grade that the VUT is expected to be able to handle?)
    - AV Developer Response: The developer’s answer to the information requested in Question 1
- Question 2: A question asking the AV developer about any possible limitations related to the current component (e.g., Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle roadway grades?)
    - AV Developer Response: The developer’s answer to the information requested in Question 2

- Question 3: A question asking the AV developer to specify the relevance for the current component (e.g., What is the relevance for this component in the VUT ODD and behavioral competency portfolio?)
    - AV Developer Response: The developer's answer to the information requested in Question 3

For behavioral competency components that are binary:

- Question 1: A question asking the AV developer if the AV is able to handle the current component (e.g., Based on the information above, is the VUT expected to be able to handle three-leg directional interchanges?)
    - AV Developer Response: The developer's answer to the information requested in Question 1
- Question 2: A question asking the AV developer about any possible limitations related to the current component, as above
    - AV Developer Response: The developer's answer to the information requested in Question 2
- Question 3: A question asking the AV developer to specify the relevance for the current component, as above
    - AV Developer Response: The developer's answer to the information requested in Question 3

Lastly, for ODD-specific components:

- Question 1: A question asking the AV developer to specify the boundary of the ODD and behavioral competency portfolio for the current component, as above
    - AV Developer Response: The developer's answer to the information requested in Question 1
- Question 2: A question asking the AV developer to specify the relevance for the current component, as above
    - AV Developer Response: The developer's answer to the information requested in Question 2

As mentioned previously, an example specification form is provided in Appendix A. The information in Appendix A can be presented to AV developers for them to be able to be able to specify the intended ODD and behavioral competency portfolio of the VUT in a way that can be taken as an input by the TSSM.

Scenario Selection from a Preexisting Scenario Database

The second proof of concept involves overlaying the TSSM onto scenarios from an existing database and filtering them using the filtration scheme outlined in this report. The database used for this thesis is SafetyPool, an access-restricted scenario database maintained by a public-private partnership headed by the University of Warwick[3]. Scenarios are added to the database by users in exchange for access to private libraries of scenarios; however, SafetyPool also maintains a few libraries of scenarios that are freely accessible to its user base regardless of scenario submission. The 5,544 scenarios

[3] https://live.safetypooldb.ai/index

downloaded and analyzed for this proof of concept are downloaded from those public scenario libraries.

The first step in paring down the space of scenarios from the SafetyPool database is to use a custom Python script to parse the JSON file that contains the information for each scenario into TSSM-compatible components. From there, the parsed components can be mapped to an ODD and behavioral competency portfolio chart coded into the same script and created specifically for the purpose from the possibility space of components that are represented in the database. Then, the script can apply the component-level and scenario-level filtering equations with specified, discrete thresholds. These thresholds can be varied to change both the number of scenarios that are pared from the set and how quickly this paring occurs. The output from this proof of concept is a set of plots showing the paring behavior of the filters for a given component relevance threshold as the overall scenario relevance threshold is varied in increments of 0.1 from 0 to 1. The full Python script written to execute this process is given in Appendix B.
The script collimates all of the possible scenario component values that it can handle in the database into a single list; those components are listed in Table 2 in Appendix D, as generated by the parser script and formatted for clarity.

For each scenario, the values of the above components are mapped to the custom ODD and behavioral competency portfolio chart developed for this proof of concept. The mapping is not even across the board; some components required additional code to be successfully mapped to the ODD and behavioral competency portfolio chart, as the data parsed from the scenario JSON files was not always immediately compatible with the axis format. Nonetheless, the mapping was successful and contains a mix of both binary components and components with a significant range.

Finally, with the components for each of the database scenarios mapped to a unique ODD and behavioral competency portfolio chart, the Python script filters the scenarios according to Equations (5) through (13). For each iteration of the script and resulting plot, a single component relevance threshold is chosen; ten iterations in total produce a range of component relevance threshold values in increments of 0.1 between 0 and 1. As stated above, for each component relevance threshold, the overall scenario relevance threshold is varied in increments of 0.01 from 0 to 1. This process produces the plots given in Figure 4 through Figure 12, showing the number of scenarios output by the process for a given component relevance threshold across a range of scenario relevance thresholds.

Figure 4

Scenario Preservation Over a Range of $R_{0,s}$ Values With $R_{0,c} = 0.1$

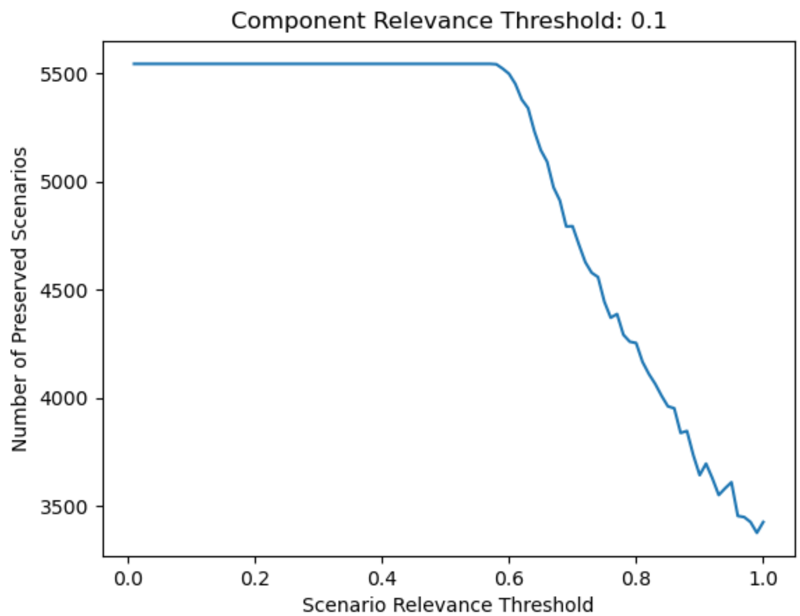


Figure 5

Scenario Preservation Over a Range of $R_{0,s}$ Values With $R_{0,c} = 0.2$

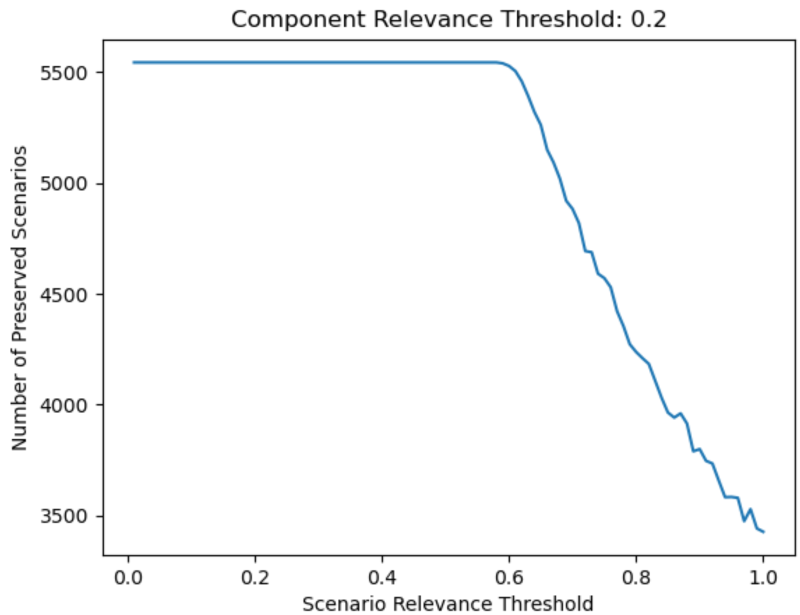


Figure 6

Scenario Preservation Over a Range of $R_{0,s}$ *Values With* $R_{0,c} = 0.3$

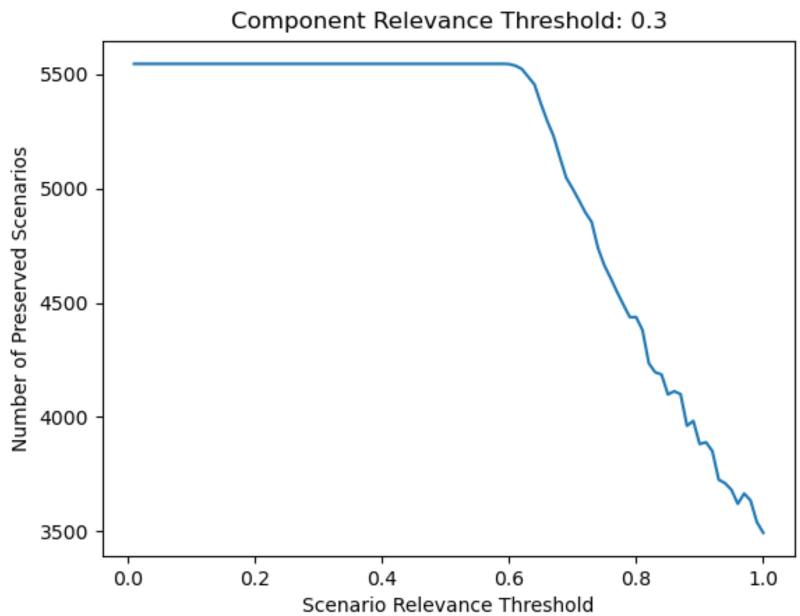


Figure 7

Scenario Preservation Over a Range of $R_{0,s}$ *Values With* $R_{0,c} = 0.4$

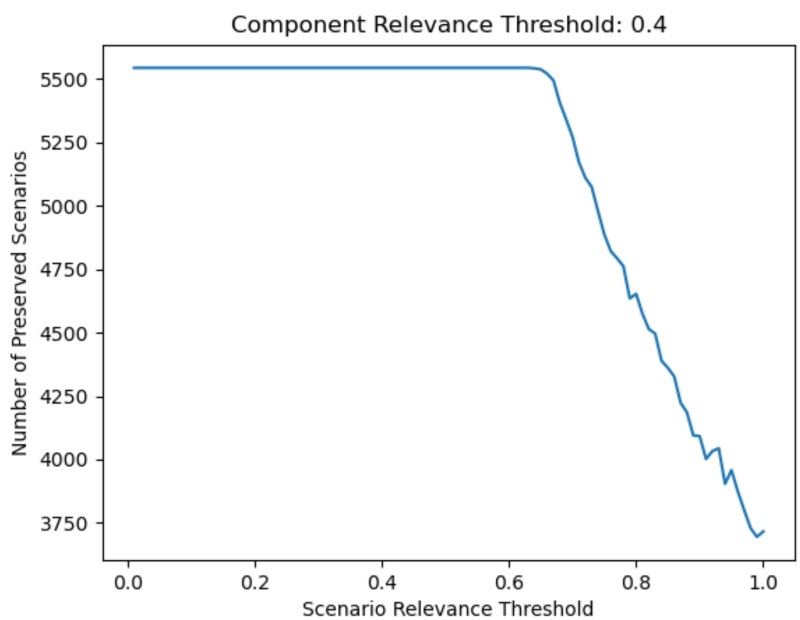


Figure 8

Scenario Preservation Over a Range of $R_{0,s}$ Values With $R_{0,c} = 0.5$

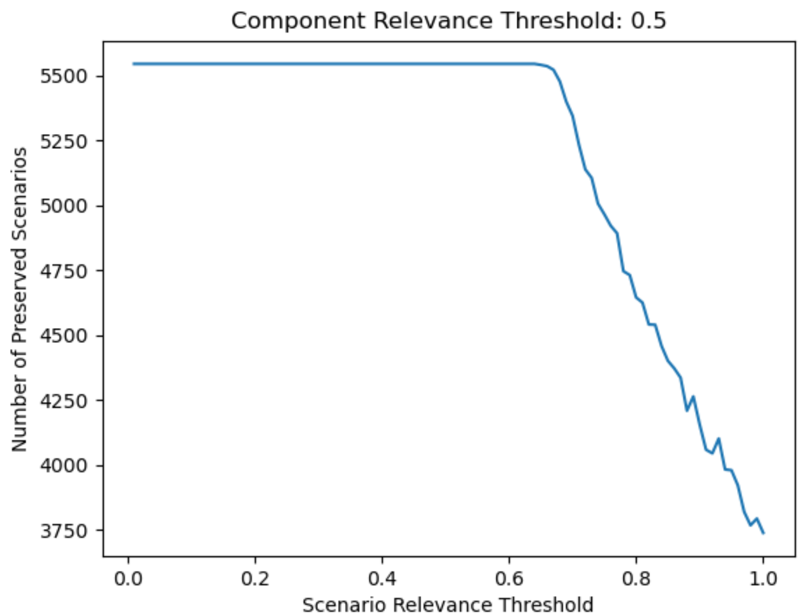


Figure 9

Scenario Preservation Over a Range of $R_{0,s}$ Values With $R_{0,c} = 0.6$

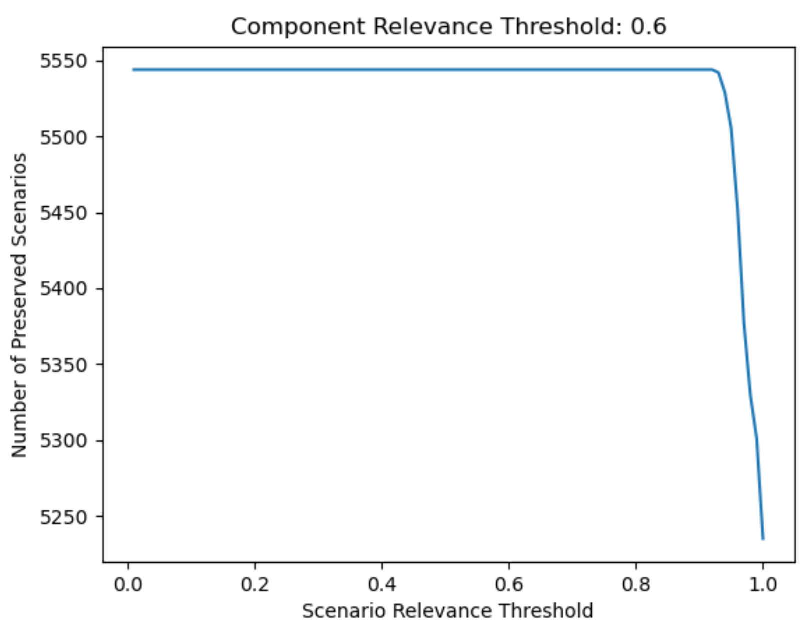


Figure 10

Scenario Preservation Over a Range of $R_{0,s}$ *Values With* $R_{0,c} = 0.7$

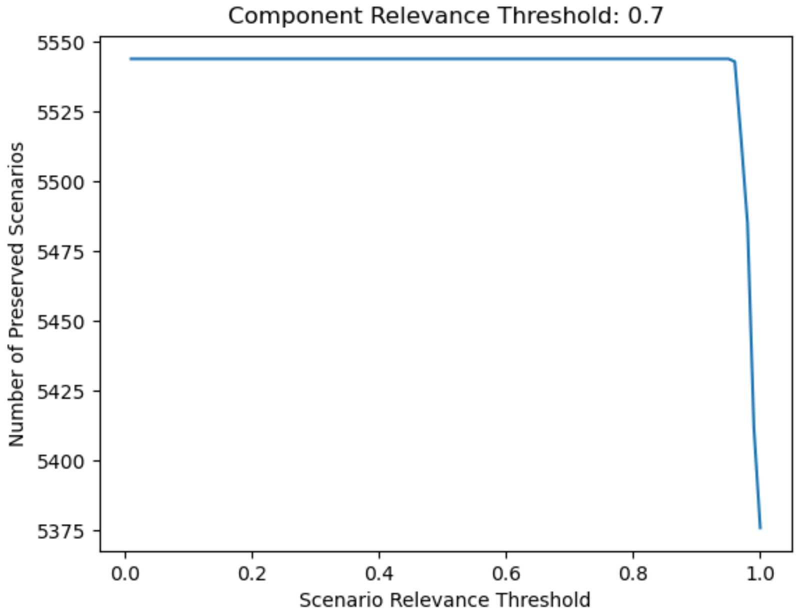


Figure 11.

Scenario Preservation Over a Range of $R_{0,s}$ *Values With* $R_{0,c} = 0.8$.

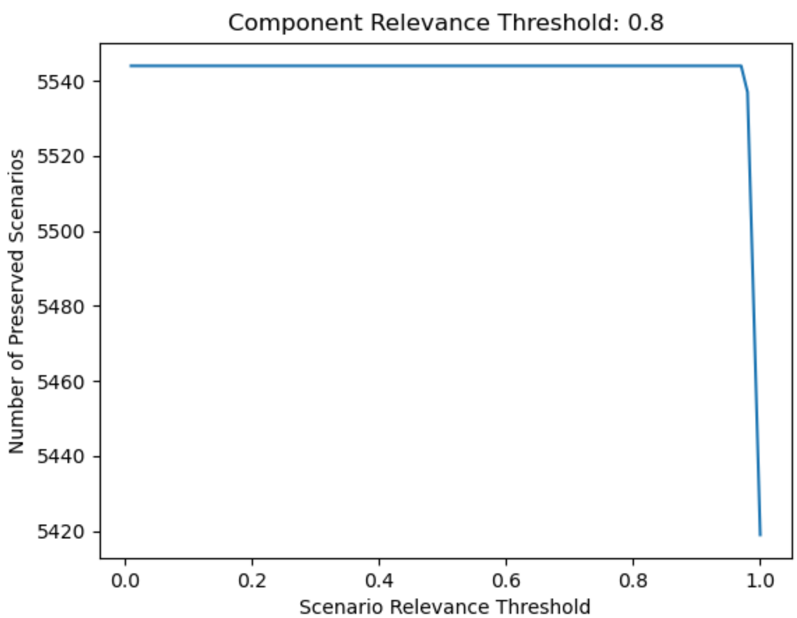
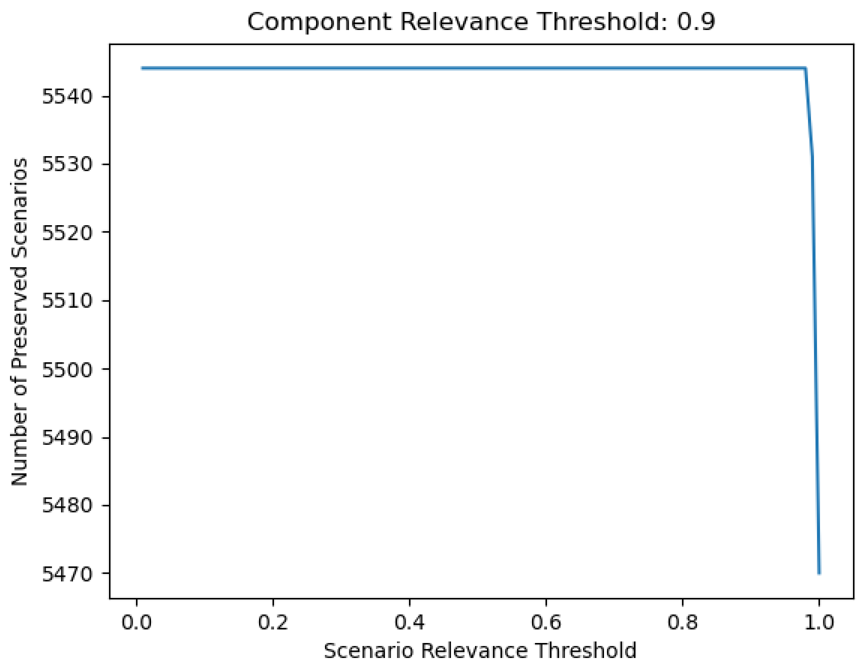


Figure 12.

Scenario Preservation Over a Range of $R_{0,s}$ *Values With* $R_{0,c} = 0.9$.



For values of $R_{0,c}$ between 0.1 and 0.5 inclusive, the TSSM achieves a noticeable reduction in the size of the scenario set generally ranging between 5,544 (the total number of scenarios pared from the database) to around the range of 3750 to 3500 scenarios. This reduction takes place in the approximate regime $0.6 \leq R_{0,S} \leq 1$.

Generally, as $R_{0,c}$ increases, the size of the reduction in the scenario set decreases. For values of $R_{0,c}$ between 0.6 and 0.9 inclusive, the system behavior changes; the size of the reduction becomes very small and the slope of the plot curve becomes very steep in the region very close to $R_{0,S} = 1$. Both this change in behavior and the general tendency of the TSSM to pare these scenarios around the regime $0.6 \leq R_{0,S} \leq 1$ are due to the relatively large number of binary components in the ODD and behavioral competency portfolio chart built for this application.

CHAPTER 5

CONCLUSIONS

In this paper, an in-depth definition of a test selection and scoring methodology (TSSM) for AVs is provided. This methodology satisfies the four conditions outlined in the Introduction section, namely regarding test set generation, tuneability of the specified ODD and behavioral competency portfolio and ranges therein by the AV developer, tuneability of the test method mix by the implementer or a regulatory body, and the generation of a single numerical score for automated driving performance comparison across AVs.

Additionally, two proofs of concept were included that showcased the capabilities of the TSSM, including in paring down available scenarios from a preexisting scenario database and in providing an ODD and behavioral competency portfolio chart specification form for use by the developer in specifying the AV ODD and behavioral competency portfolio.

In the first proof of concept, the TSSM demonstrated an ability to significantly pare down the space of a preexisting scenario database, preserving the relevance of the resulting scenario test set while incorporating less relevant, but possibly significant, scenarios by random chance. This speaks to a potential application of the methodology as a "wrapper" around preexisting scenario databases that offers all the benefits of random scenario generation without having to expend the computational resources required to generate a comprehensive set of scenarios from scratch.

The ODD and behavioral competency portfolio specification form presented in Appendix B, which constitutes the second proof of concept, has already received a measure of feedback from both industry and governmental bodies, including from AV firm May Mobility. This demonstrates the wide applicability of the form, and indicates that the format is a strong one for soliciting ODD and behavioral competency portfolio components from developers.

Future Research

While the TSSM detailed in this thesis is a good first step toward establishing a testing regime that can reliably and truthfully demonstrate the safety (or lack thereof) of an AV, more research and effort is needed to develop the TSSM into a methodology that can reliably be used to bolster an AV safety case as is needed for the AV-TEP mission. Accordingly, the TSSM developed in this paper has a vast potential to be expanded by future research endeavors. A few areas in which those expansions may occur are listed below.

Future work will modify the TSSM to provide a temporal description for each scenario, not just a list of scenario components as detailed in this thesis. To that end, work is currently being done by members of the AV-TEP group to generate an algorithm for the TSSM to specify the dynamics of each scenario component. This may involve conversion of the generated component lists to widely adopted scenario formats, such as the ASAM OpenScenario framework[4].

A logical extension of the proposed methodology to include scenario component dynamics would be to represent those dynamics using a separate, but similarly configured, axis chart. The axes of this second chart, instead of representing scenario components, would represent the possible dynamics of the scenario components

[4] https://www.asam.net/standards/detail/openscenario/

represented by the first chart. These dynamics would describe the time evolution of each scenario component over the duration of the scenario; for example, for the pedestrian axis on the scenario component chart, the scenario component dynamics chart will include pedestrian speed and pedestrian heading axes, and the tick marks on these axes will represent the speeds and headings for each pedestrian in the scenario, respectively. The ranges and increments for these axes may be informed by preexisting or future research conducted on VRU behavior in different scenarios.

The TSSM will randomly assign a speed value to each pedestrian in the scenario in the same way as components are randomly selected from the scenario component chart. For these and other scenario dynamics, a timestep will be specified after which new values are specified by the TSSM; for example, the speed and headings for each pedestrian may be changed in the scenario every second until completion. To avoid a random walk for significant components that are typically restricted to certain patterns of motion, like pedestrians, the axes may further be separated into certain categories of motion to address the assignment of heading values (e.g., pedestrian speed/heading on a sidewalk, through a crosswalk, etc.). All other components in the scenario component chart that are capable of time evolution in the scenario will have corresponding axes in the dynamics chart, and a similar process to the above will be followed for all other dynamic components in the dynamics chart. The dynamics chart will not have a corresponding MRSI value, as it will exist only to provide the components from the first chart with temporal characteristics.

As a result of the inclusion of scenario component dynamics, future work may also change the component random selection process to include differing probabilistic distributions. The current distribution, which calculates scenario component inclusion probability as the ratio between the relevance value of the scenario component and the chosen scenario component relevance value threshold, may be replaced by a distribution that, for the example of a pedestrian, weights movements on the slower end of the pedestrian speed axis range more heavily than faster speeds (as pedestrians are more likely in the scenario to travel at a walking pace, as opposed to running or sprinting). Future work may also make use of well-known probabilistic distributions from statistics, such as Gaussian or Poisson distributions.

The TSSM may be further refined so that it will be competitive with the current state of the art in AV verification and validation. This may take the form of a statistical analysis of the results of the TSSM, which will demonstrate that any results arising from tests conducted using a TSSM-generated scenario library are statistically meaningful. Additionally, future efforts may also look toward incorporating new data types to the TSSM. In particular, incorporating proprietary AV data, while not strictly a requirement, may greatly expand the TSSM’s validity, as it offers AV developers the chance to conduct the TSSM themselves using privileged data.

Future work may also address combinations of test methods, such as the combination of simulation and closed-course testing being developed by Feng, et al. (Feng, Yan, Sun, Feng, & Liu, 2021). To that end, in this thesis, pure simulation and vehicle-in-the-loop (ViL)/dynamometer simulation are not considered apart from one another. In the future, additional work may consider XiL (X-in-the-loop, where the “X” represents hardware, software, or the full vehicle system) test methods, which would include a distinction between pure simulation and ViL testing.

Additional efforts will strengthen the TSSM by ensuring compatibility with existing standards and best practices where applicable, especially those issued by IAM, ISO, SAE, and AVSC. This compatibility will ensure that the TSSM can interface with standards and best practices that already have wide adoption among industry, governmental, and academic players, and may possibly reduce the effort required to integrate the TSSM into preexisting, proprietary AV validation schemes.

There will need to be a method for transitioning the weights of the ODD and behavioral competency portfolio chart axes from their defaults of unity to meaningful values specified by relevant regulatory bodies. This may possibly occur via the incorporation of naturalistic driving data (NDD) into the TSSM, which may give an indication as to which axes should take precedence over others. In the absence of NDD, good engineering judgement may provide guidance as to how the ODD and behavioral competency portfolio chart axes should be weighted.

It may be the case that a change to the VUT's software or hardware may regress in some aspect of its performance relative to their previous iterations. In that case, it may be possible for the VUT to backslide from one TRL to the next lower TRL, as mentioned previously. The TSSM will need to account for this possible TRL backsliding as part of a larger, overarching hazard assessment and risk analysis (HARA) scheme.

Removing self-contradictory or impossible scenarios by hand quickly becomes impractical for any large number of scenarios; therefore, a solver step will need to be included that automatically removes problem scenarios from the TSSM. This is primarily a question pertaining to the design of the software which executes the TSSM, and is therefore far out of the scope of this thesis.

It is possible to run multiple TSSM iterations in parallel in simulation to generate enough scenarios to be comparable to HDV data. Once these parallel scenarios are generated, they can be treated as scenarios from a single iteration would be treated, proceeding through the filtration and edge and corner scenario probing processes as normal. This process will need to be formally enumerated by any future work, but since a process is already in place to deal with a set of randomly generated scenarios of arbitrary size, few, if any, additional conditions or procedures will need to be incorporated into the methodology.

Additional data to support the transition from TRL 8 to TRL 9 will need to be generated on a physical vehicle driving on a closed course. To that end, a central effort of any future work will be to demonstrate a full TSSM process using a physical AV and its digital twin in simulation.

It is theoretically possible for an AV developer to specify component relevance values that may be known to that developer to be favorable for the VUT. Safeguards must therefore be put in place to prevent abuse of the ability to specify scenario component relevance values; these safeguards might come in the form of regulatory oversight or a built-in mechanism to prevent the specification of component relevance values that tend to favor certain components or groups of components too heavily.

The process for deriving scenarios from the results of open road tests will also need to be outlined and automated. This process might involve the use of machine vision and deep learning techniques to extract scenario components and their values from the data; alternatively, if the raw automated driving system (ADS) data is available, as it would be with a white- or clear-box approach, this data could be automatically parsed into components and their values. Both approaches, once executed, yield information that can easily be turned into a set of scenarios representing the conditions encountered during open road testing.

The TSSM algorithm may also be edited to be more computationally efficient. Specifically, there may be more efficient ways to select scenario components other than by the use of a random selection process proportional to specific component relevance values, as outlined in this thesis. To that end, design-of-experiments techniques might be employed in future revisions of the TSSM to ensure that the scenario generation process is as efficient as possible (Jeffrey Wishart, personal communication, September 25, 2023)

The conditions under which it will be permissible for a developer to execute an expedited TSSM process instead of a complete process will need to be specified. This may relate to the magnitude of the change of a tested hardware or software version relative to its previous iteration, and may also take into account whether or not the current software build is slated to be released to production – a distinction common in industrial applications.

The influence of axes on each other in the chart-based formulation presented in this methodology will need to be accounted for. If future researchers on this topic are willing to accept some loss of communicability, it may be possible to represent the influence of the axes on each other by expanding the two-dimensional representation of the spider chart to an n_c-dimensional representation. Otherwise, the ODD and behavioral competency specification form may be expanded to include questions for each component that query the developer for any interactions with other components that may be of note, and these interactions may be incorporated into the two-dimensional spider chart. Depending on the overall size of the RTS, this information may be derived from the results of the execution of RTS scenarios; that is, the influence of certain axes on each other may be evident in the performance of the VUT in scenarios in which the components represented by those axes feature prominently. This information can then be used in future TSSM executions to update the ODD and behavioral competency portfolio chart for the VUT.

To that end, the gradual process of discovery of the inherent influences of chart axes on each other may necessitate the creation and use of a dynamic ODD and behavioral competency specification form. While the current specification form does not include a mechanism for change, future versions of the document may incorporate a method by which components may be "officially" added or removed as the TSSM process is executed. This will allow the TSSM to dynamically adapt to new information pertinent to the construction of the ODD and behavioral competency portfolio chart.

As mentioned previously, the scenario coverage requirement will require additional research. Specifically, the parameter n_0 in the TSI equation will need to be formulated in light of the current lack of consensus on a "standard" number of scenarios to test. To circumvent the differences in estimation of this figure, future work may decompose n_0 into a sum of separate terms, e.g., n_1, n_2, n_3, etc. These sub-terms may represent, for example, a standard number of RTS and STS scenarios, or a standard number of scenarios for each test method. Whichever formulation is chosen, the sub-terms should represent standard numbers of scenarios for some chosen subsets of the overall set of testable scenarios. By decomposing n_0 in this way, it becomes easier to achieve consensus on each of the smaller sub-terms (and therefore achieve consensus on

n_0 itself) rather than attempting to get consensus on n_0 directly. As a result of the inclusion of the n_0 term in the TSI equation, such research may also contribute to different formulations of ODD and behavioral competency portfolio coverage metrics.

Lastly, The TSSM will be further strengthened by addressing any concerns that have been stated to be out of the scope of this thesis.

Comparison with the Prior Art

It is important to define where the methodology proposed in this paper improves upon the methodologies proposed in previous papers. To that end, the TSSM represents an improvement on the prior art for several reasons. For example, several methodologies previously presented in the literature rely on powerful mathematical techniques that are nonetheless very abstract and not likely to be widely comprehensible by the end consumers purchasing AVs tested using these techniques. By contrast, the operation of the TSSM can be broken down into relatively simple concepts that are easily communicated and may therefore lead to increased public confidence in the safety of AVs.

Additionally, the TSSM's general approach, as used in concert with the robust set of current DA metrics, makes it more broadly applicable than some of the techniques using more restrictive analytical tools. For example, as the scenario library proposed by Feng, et al. relies on only two metrics to measure the worth of a scenario (exposure frequency and maneuver challenge), and not three (as the TSSM does with complexity, relevance, and fidelity), the TSSM offers a more comprehensive evaluation of the significance of individual scenarios and the information they contain (Feng, Feng, Yu, Zhang, & Liu, 2021). As Feng, et al. are focused on several AV evaluation categories, they use a simple “accident rate” safety metric, precluding the possibility of more comprehensive safety metric coverage as promised by the DA metrics. Additionally, the finite-sampling metric proposed by Weng, et al breaks down under certain conditions that the TSSM can handle with ease, most notably in the case of the use of machine learning techniques (Weng, Capito, Ozguner, & Redmill, 2023).

The overall advantage offered by the TSSM, then, is that it meshes well with the current set of comprehensive DA metrics and provides a broadly understandable and applicable basis for an AV safety case. The comprehensive V&V framework proposed by the TSSM, along with the development constraints inherent in that framework (e.g., random filtering and generation, mandatory minimum scores, built-in stops for errors and critical scenarios) will accelerate development to full, robust Level 5 autonomy, as AV developers will necessarily have to create AVs that excel when confronted with an arbitrary traffic scenario.

Considerations

Incorporating the changes and improvements listed above into the TSSM will make it more flexible and robust. This will go a very long way toward making the TSSM worthy of being incorporated into a standard or best practice, and will hopefully work toward honoring and advancing one of the most important tenets of engineering, as defined by the National Society of Professional Engineers (NSPE): “…the protection of the public health, safety, and welfare” (National Society of Professional Engineers).

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APPENDIX A

ODD & BEHAVIORAL COMPETENCY SPECIFICATION FORM

The following is an ODD and behavioral competency portfolio specification form. The purpose of this specification form is to aid the AV developer in specifying the set of behavioral competencies their AV can accomplish as well as the ODD for their vehicle for use in the Scenario-Based Testing Pillar of the Automated Vehicle – Test and Evaluation Process (AV-TEP) framework.

The specification form is separated into components corresponding to specific behavioral competencies, ODD-specific components which are applicable to all behavioral competencies, and a section on geofencing. Each entry in the specification form is structured as follows:

All entries share the same first six fields and section classification scheme, as shown below:

Axis Group (Example: Roadway Infrastructure)
(Section #) Axis name (Example: Roadway grade)

- Definition: a short definition that gives an explanation of the current component
- Source(s) (if applicable): The source of reference information from which information about the axis was drawn, if one exists. To save space and avoid repetition, the source is typically only cited in this field; however, the source applies to both the axis name, the definition, and any provided diagrams.
- Metric: what the axis represents (e.g., roadway grade/slope)
- Units: the unit that the axis uses (e.g., percentage)
- Range: the maximum and minimum values on the axis, measured using the axis unit
- Increment: the distance between adjacent tick marks on the axis, measured using the axis unit

The entries differ in what questions they pose to the AV developer. For behavioral competency components that are not binary:

- Question 1: A question asking the AV developer to specify the boundary of the ODD and behavioral competency portfolio for the current component (e.g., Based on the information above, what is the maximum roadway grade that the VUT is expected to be able to handle?)
    - AV Developer Response: The developer’s answer to the information requested in Question 1
- Question 2: A question asking the AV developer about any possible limitations related to the current component (e.g., Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle roadway grades?)
    - AV Developer Response: The developer’s answer to the information requested in Question 2
- Question 3: A question asking the AV developer to specify the relevance for the current component (e.g., What is the relevance for this component in the VUT ODD and behavioral competency portfolio?)
    - AV Developer Response: The developer’s answer to the information requested in Question 3

For behavioral competency components that are binary:

- Question 1: A question asking the AV developer if the AV is able to handle the current component (e.g., Based on the information above, is the VUT expected to be able to handle three-leg directional interchanges?)
    - AV Developer Response: The developer's answer to the information requested in Question 1
- Question 2: A question asking the AV developer about any possible limitations related to the current component, as above
    - AV Developer Response: The developer's answer to the information requested in Question 2
- Question 3: A question asking the AV developer to specify the relevance for the current component, as above
    - AV Developer Response: The developer's answer to the information requested in Question 3

Lastly, for ODD and behavioral competency portfolio components:

- Question 1: A question asking the AV developer to specify the boundary of the ODD and behavioral competency portfolio for the current component, as above
    - AV Developer Response: The developer's answer to the information requested in Question 1
- Question 2: A question asking the AV developer to specify the relevance for the current component, as above
    - AV Developer Response: The developer's answer to the information requested in Question 2

The section on geofencing simply prompts the developer for a short description of the geofenced area and its possible relationships to any other scenario components.

Please provide an answer in red font in the "AV Developer Response" section to each of the questions posed in the "Question" sections for each entry.

All entries in this specification form are adapted from the sources indicated.

BEHAVIORAL COMPETENCY COMPONENTS

Section 1 - Behavior: Maintaining a lane (Automated Vehicle Safety Consortium, 2021)

Specification: Driving along roads predictably and consistently maintaining proper traffic lane position with respect to designated lane markings and speed limits in nominal driving conditions, i.e., conditions that do not require an evasive maneuver, conditions that do not include a road work zone that temporarily deviate from the traffic lanes, etc. (Automated Vehicle Safety Consortium, 2021)

1.1 Dedicated lane

- Definition: Traffic lanes set aside for certain types of road vehicles, including buses, trucks, etc.
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of dedicated lanes in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle dedicated lanes?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle dedicated lanes?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

1.2. Managed lane

- Definition: Lanes under active management by a traffic or transportation authority
- Source: (U.S Department of Transportation Federal Highway Administration, 2022) (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of managed lanes in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle managed lanes?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle managed lanes?

- AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

1.3. Mixed-use lane

- Definition: Traffic lanes explicitly designed for use by two or more specific vehicle types
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of mixed-use lanes in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle mixed-use lanes?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle mixed- lanes?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

1.4. Lane width

- Definition: The measurement between the two edges of a lane
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Width of driving lanes in ODD and behavioral competency portfolio
- Units: Feet
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum lane width that the VUT is expected to be able to handle?
    - AV Developer Response:
    - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle lane widths?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

1.5. Weaving section

- Description: "The common right-of-way that occurs when two or more crossing freeway traffic streams are traveling in the same general direction." (Fazio & Rouphail, 1986)
- Source: (Fazio & Rouphail, 1986)

- Component: Presence of weaving sections in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle weaving sections?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle weaving sections?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

1.6. Are there any behavioral competencies related to the maintenance of a lane by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 2 - Roadway Infrastructure (Automated Vehicle Safety Consortium, 2021)

2.1. Stopping sight distance

- Description: The sum of the distance traveled during perception and reaction time and the distance to stop the vehicle
- Source: (Washington State Department of Transportation, 2022)
- Metric: The stopping sight distance for the VUT as defined above
- Units: Feet
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum stopping sight distance that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle stopping sight distances?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.2. Decision sight distance

- Definition: “The distance at which the VUT can detect a hazard or a signal in a cluttered roadway environment, recognize it or its potential threat, select an appropriate speed and path, and perform the required action safely and efficiently” (McGee, 1979)
- Source: (McGee, 1979)
- Metric: The decision sight distance as defined above
- Units: Feet
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum decision sight distance that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle decision sight distances?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.3. Passing sight distance

- Description: “The distance (on a two-lane highway) used for a driver to execute a normal passing maneuver based on design conditions and design speed.” (Washington State Department of Transportation, 2022)
- Source: (Washington State Department of Transportation, 2022)

- Metric: The passing sight distance as defined above
- Units: Feet
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum passing sight distance that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle passing sight distances?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

2.4 Roadway grade

- Definition: “The rate of change of the vertical alignment [of a road].” (American Association of State Highway and Transportation Officials, 2001)
- Source:
  (American Association of State Highway and Transportation Officials, 2001)
- Metric: Roadway grade/slope
- Units: Percentage
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum roadway grade that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle roadway grades?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

2.5. Roadway superelevation

- Definition: “The rotation of the pavement on the approach to and through a horizontal curve” (U.S. Department of Transportation Federal Highway Administration, 2014)
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Metric: The superelevation of the roadway as defined above
- Units: Percentage
- Range: 0 to Maximum
- Increment: 0.01

- Question 1: Based on the information above, what is the maximum roadway superelevation that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle roadway superelevations?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

2.6. Road vertical curvature

- Description: "The reciprocal of the vertical radius of individual road sections as they connect with one another" (Texas Department of Transportation, 2022)
- Source: (Texas Department of Transportation, 2022)
- Metric: Road vertical curvature (A-Value) as defined above
- Units: Percentage
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum roadway vertical curvature that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle roadway vertical curvatures?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response

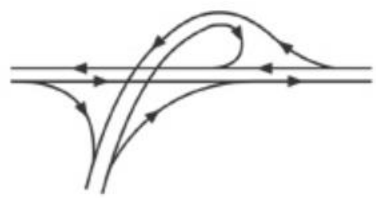
2.7. Road horizontal curvature

- Description: "The reciprocal of the horizontal radius of individual road sections as they connect with one another" (Texas Department of Transportation, 2022)
- Source: (Texas Department of Transportation, 2022)
- Metric: Road horizontal curvature as defined above
- Units: Radii (feet)
- Range: 0 to Maximum
- Increment: 500
- Question 1: Based on the information above, what is the maximum road horizontal curvature that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle road horizontal curvatures?
    - AV Developer Response:

- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.8. Trumpet interchange

- Description: An interchange style with a 180 degree turn on one end of the interchange, resembling a trumpet
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:

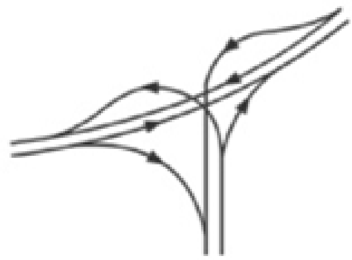


Trumpet

- Component: Presence of trumpet interchanges in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle trumpet interchanges?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle trumpet interchanges?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.9. Three-leg directional interchange

- Description: A style of interchange merging three road segments with differing directions
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:

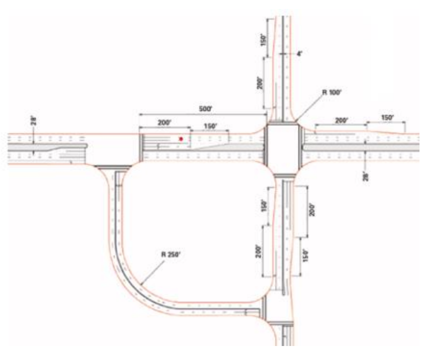


Three Leg Directional

- Component: Presence of three-leg directional interchanges in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle three-leg directional interchanges?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle three-leg directional interchanges?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.10. Quadrant roadway intersection

- Description: An intersection with a connecting road joining two road sections in one quadrant
- Source: (U.S Department of Transportation Federal Highway Administration, 2009)
- Diagram:

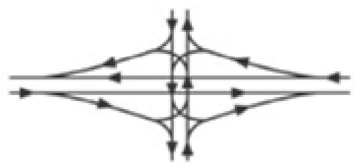


- Component: Presence of quadrant roadway intersections in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1

- Question 1: Based on the information above, is the VUT expected to be able to handle quadrant roadway intersections?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle quadrant roadway intersections?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.11. Diamond interchange

- Description: A symmetric, diamond-shaped interchange
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:

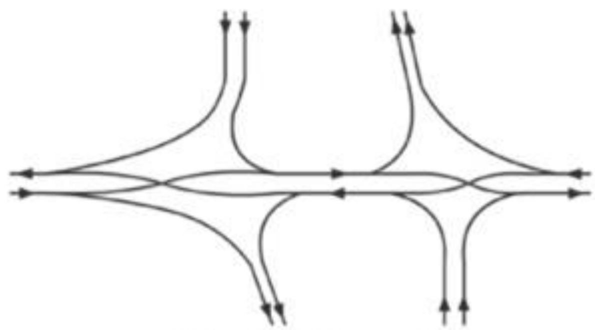


Diamond

- Component: Presence of diamond interchanges in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle diamond interchanges?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle diamond interchanges?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.12. Diverging diamond interchange

- Description: A pair of diamond interchanges connecting six pairs of roadways
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:

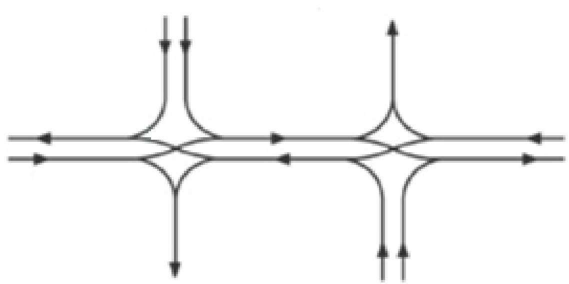


Diverging Diamond

- Component: Presence of diverging diamond interchanges in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle diverging diamond interchanges?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle diverging diamond interchanges?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.13. Double crossover diamond interchange

- Description: A pair of diamond interchanges connecting four pairs of roadways and two non-paired roadways
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:



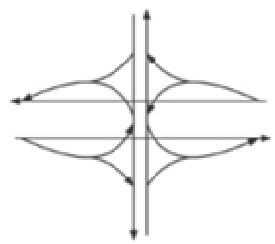
Double Crossover Diamond

- Component: Presence of double crossover diamond interchanges in ODD and behavioral competency portfolio
- Units: Binary

- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle double crossover diamond interchanges?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle double crossover diamond interchanges?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.14. Single-point interchange

- Description: An interchange connecting four pairs of roads
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:

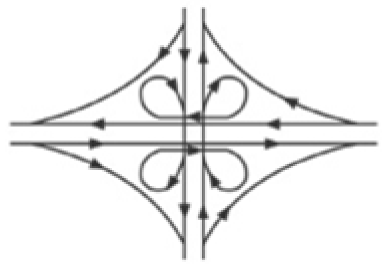


Single Point Interchange

- Component: Presence of single-point diamond interchange ramps in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle single-point interchanges?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle single point interchanges?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.15. Full cloverleaf interchange

- Description: An interchange with four cloverleaf "lobes"
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:

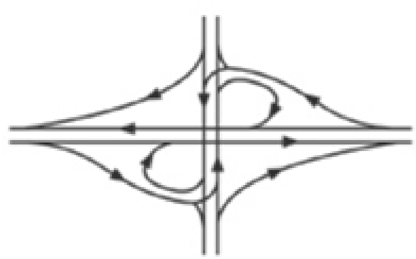


Full Cloverleaf

- Component: Presence of full cloverleaf interchanges in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle full cloverleaf interchanges?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle full cloverleaf interchanges?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

2.16. Partial cloverleaf interchange

- Description: An interchange with two cloverleaf "lobes"
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:



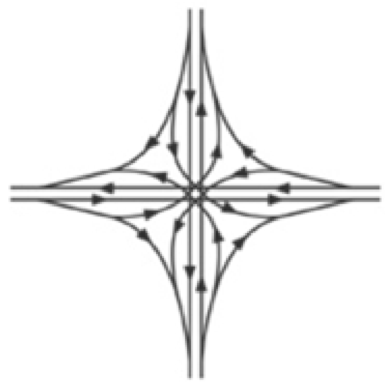
Partial Cloverleaf

- Component: Presence of partial cloverleaf interchanges in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle partial cloverleaf interchanges?

- AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle partial cloverleaf interchanges
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.17. All-directional four-leg interchange

- Description: An interchange connecting each road in four pairs of roads to the others
- Source: (U.S. Department of Transportation Federal Highway Administration, 2014)
- Diagram:



All Directional Four Leg

- Metric: Presence of all-directional four leg interchange in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle all-direction four-leg interchanges?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle all-direction four-leg interchanges?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

2.18. Are there any behavioral competencies related to roadway infrastructure not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 3 - Road markings (Automated Vehicle Safety Consortium, 2020)

3.1. Solid yellow lines

- Description: Solid yellow lines indicating that passing is prohibited (U.S. Department of Transportation Federal Highway Administration, 2020)
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of solid yellow lines in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle solid yellow lines?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle solid yellow lines?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

3.2. Dashed yellow lines

- Description: Dashed yellow lines indicating that passing is allowed (U.S. Department of Transportation Federal Highway Administration, 2020)
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of dashed yellow lines in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle dashed yellow lines?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle dashed yellow lines?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

3.3. Double white line

- Description: Double white lines indicating that changing lanes is prohibited (U.S. Department of Transportation Federal Highway Administration, 2020)

- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: presence of double white lines in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle double white lines?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle double white lines?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

3.4. Single white line

- Description: Single white line indicating that lane changes are discouraged (U.S. Department of Transportation Federal Highway Administration, 2020)
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of single white lines in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle single white lines?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle single white lines?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

3.5. Dashed white line

- Description: Dashed white line indicating that lane changes are allowed (U.S. Department of Transportation Federal Highway Administration, 2020)
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)

- Component: Presence of dashed white lines in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle dashed white lines?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle dashed white lines?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

3.6. Are there any behavioral competencies related to road markings and features not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 4 - Behavior: Changing lanes (Automated Vehicle Safety Consortium, 2021)

Specification: Lane change (right/left) to establish proper lane position in an adjacent lane, which can include merging and passing into oncoming traffic. (Automated Vehicle Safety Consortium, 2021)

4.1. Changing lanes

- Description: Movement of the VUT from one lane to another
- Source: (Automated Vehicle Safety Consortium, 2021)
- Component: Inclusion of VUT changing lanes in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle changing lanes?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle changing lanes?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

4.2. Are there any behavioral competencies related to lane changes by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 5 - Behavior: Navigating intersection (Automated Vehicle Safety Consortium, 2021)

Specification: Approaching, driving through, or turning at junctions adhering to traffic control devices, as defined in Manual on Uniform Traffic Control Devices (MUTCD) (Automated Vehicle Safety Consortium, 2021)

5.1. Three-leg intersections

- Description: Intersections connecting three road segments
- Source: (U.S Army Surface Deployment and Distribution Command Traffic Engineering Agency, n.d.)
- Component: Presence of three-leg intersections in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle three-leg intersections?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle three-leg intersections?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

5.2. Four-leg intersections

- Description: Intersections connecting four road segments
- Source: (U.S Army Surface Deployment and Distribution Command Traffic Engineering Agency, n.d.)
- Component: Presence of four-leg intersections in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle four-leg intersections?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle four-leg intersections?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

5.3. Multileg intersections

- Description: Intersections connecting five or more road segments
- Source: (U.S Army Surface Deployment and Distribution Command Traffic Engineering Agency, n.d.)
- Component: Presence of multileg intersections in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle multileg intersections?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle multileg intersections?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

5.4. Roundabouts

- Definition: "A type of circular intersection where traffic proceeds in a counterclockwise direction around a center island." (Iowa Department of Transportation, n.d.)
- Sources: (U.S Army Surface Deployment and Distribution Command Traffic Engineering Agency, n.d.), (Iowa Department of Transportation, n.d.)
- Component: Presence of roundabouts intersections in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle roundabouts?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle roundabouts?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

5.6. Are there any behavioral competencies related to lane changes by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 6 - Behavior: Navigating, entering, exiting unstructured roadways (Automated Vehicle Safety Consortium, 2021)

Specification: Approaching, driving through, or turning through roadways that do not have lane markings or clear delineations of traffic directional orientation (Automated Vehicle Safety Consortium, 2021)

6.1. Sand and gravel

- Description: Small particulates with the potential to obscure road markings
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Percentage coverage of sand and gravel on road section
- Units: Percentage
- Range: 0 to 100
- Increment: 1
- Question 1: Based on the information above, what is the maximum sand and gravel coverage that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle sand and gravel coverage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

6.2. Leaves

- Description: Dead foliage and plant debris with the potential to obscure road markings
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Percentage coverage of leaves on road section
- Units: Percentage
- Range: 0 to 100
- Increment: 1
- Question 1: Based on the information above, what is the maximum leaf coverage that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle leaf coverage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

6.3. Paint

- Description: Paint spilled from passing vehicles with the potential to obscure road markings
- Source: (Jeffrey Wishart, personal communication, 2023)

- Metric: Percentage coverage of paint spills on road section
- Units: Percentage
- Range: 0 to 100
- Increment: 1
- Question 1: Based on the information above, what is the maximum paint coverage that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle paint coverage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

6.4. Glare

- Description: Glare from the sun with the potential to obscure road markings
- Source: (Jeffrey Wishart, personal communication, 2023)
- Metric: Road glare from sun and other light sources
- Units: log(lux)
- Range: Minimum to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum glare that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle glare?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

6.5. Other road obscurants

- Description: Any other road obscurants (trash, lost equipment, general debris, tree branches, etc.) different from those listed above with the potential to obscure road markings
- Source: (Jeffrey Wishart, personal communication, 2023)
- Metric: Percentage coverage of other obscurants on road section
- Units: Percentage
- Range: 0 to 100
- Increment: 1
- Question 1: Based on the information above, what is the maximum coverage of other road obscurants that the VUT is expected to be able to handle?
  - AV Developer Response:

- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle coverage of other road obscurants?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

6.6. Quality of road markings

- Description: Legibility of any markings on the current road section relative to when they were new
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Percentage of road markings that are degraded
- Units: Percentage
- Range: 0 to 100
- Increment: 1
- Question 1: Based on the information above, what is the minimum quality of road markings that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle road marking quality?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

6.7. Are there any behavioral competencies related to the navigation, entering, and exiting of unstructured roadways by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 7 - Behavior: Navigating pick up and drop off zones and parking situations (Automated Vehicle Safety Consortium, 2021)

Specification: Approaching, driving through, or turning to an area where parking may be restricted or prohibited to improve access for short-term curbside operations (including rideshare, airports, parking lots, parallel parking, school zones, act of stopping, VRUs in and out, and markings) (Automated Vehicle Safety Consortium, 2021)

7.1. Head-in/back out angle parking on one side

- Description: Angled parking spaces on one side of the VUT where parking is with the VUT head into the spot
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of head-in/back out angle parking on one side in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle head-in/back out angle parking on one side?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle head-in/back out angle parking on one side?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

7.2. Head-in/back out angle parking on both sides

- Description: Angled parking spaces on both sides side of the VUT where parking is with the VUT head into the spot
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of head-in/back out angle parking on both sides in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle head-in/back out angle parking on both sides?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle head-in/back out angle parking on both sides?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

7.3. Back-in/head-out angle parking on one side
  - Description: Angled parking spaces on one side of the VUT where parking is with the VUT head out of the spot
  - Source: (Automated Vehicle Safety Consortium, 2020)
  - Component: Presence of back-in/head-out angle parking on one side in ODD and behavioral competency portfolio
  - Units: Binary
  - Range: 0 to 1
  - Increment: 1
  - Question 1: Based on the information above, is the VUT expected to be able to handle back-in/head-out angle parking on one side?
    - AV Developer Response:
  - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle back-in/head out angle parking on one side?
    - AV Developer Response:
  - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

7.4. Back-in/head-out angle parking on both sides
  - Description: Angled parking spaces on both sides of the VUT where parking is with the VUT head out of the spot
  - Source: (Automated Vehicle Safety Consortium, 2020)
  - Component: Presence of back-in/head-out angle parking on both sides in ODD and behavioral competency portfolio
  - Units: Binary
  - Range: 0 to 1
  - Increment: 1
  - Question 1: Based on the information above, is the VUT expected to be able to handle back-in/head out angle parking on both sides?
    - AV Developer Response:
  - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle dedicated lanes?
    - AV Developer Response:
  - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

7.5. Parallel parking on one side
  - Description: Parallel parking spaces on one side of the VUT
  - Source: (Automated Vehicle Safety Consortium, 2020)
  - Component: Presence of parallel parking on one side in ODD and behavioral competency portfolio
  - Units: Binary
  - Range: 0 to 1

- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle parallel parking on one side?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle parallel parking on one side?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

7.6. Parallel parking on both sides

- Description: Parallel parking spaces on both sides of the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of parallel parking on both sides in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle parallel parking on both sides?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle parallel parking on both sides?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

7.7. Are there any behavioral competencies related to the navigation of pick up and drop off zones and parking situations by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?

        - AV Developer Response:
    - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

Section 8 - Behavior: Responding to vulnerable road users (VRUs) (Automated Vehicle Safety Consortium, 2021)

Specification: Maintaining a safety envelope with respect to VRUs (Automated Vehicle Safety Consortium, 2021)

Non-motorized micromobility vehicles

8.1. Bicyclists

- Description: VRUs riding non-motorized bicycles
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant bicyclists that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of bicyclists that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle bicyclists?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

8.2. Bicyclists with trailers

- Description: VRUs riding non-motorized bicycles with attached bicycle trailers
- Source: (Automated Vehicle Safety Consortium, 2020) Metric: Number of safety-relevant bicyclists with trailers that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of bicyclists with trailers that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle bicyclists with trailers?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

8.3. Scooter riders

- Description: VRUs riding non-motorized (kick) scooters

- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant scooter riders that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of scooter riders that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle scooter riders?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

8.4. Skateboarders

- Description: VRUs riding skateboards and longboards
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant skateboarders that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of skateboarders that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle skateboarders?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

8.5. Pedestrians

- Description: People traveling on foot in the vicinity of the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant pedestrians that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of pedestrians that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle pedestrians?

        - AV Developer Response:
    - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

8.6. Pedestrians with carts

- Description: People traveling on foot in the vicinity of the VUT while pushing shopping carts, utility carts, tool carts, medical carts, etc.
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant pedestrians with carts that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of pedestrians with carts that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle pedestrians?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

8.7. Pedestrians with strollers

- Description: People traveling on foot in the vicinity of the ODD and behavioral competency portfolio while pushing strollers or baby carriers
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant pedestrians with strollers that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of pedestrians with strollers that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle pedestrians with strollers?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

8.8. Pedestrians using walkers

- Description: People traveling on foot in the vicinity of the ODD and behavioral competency portfolio while using medical walkers for support
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant pedestrians using walkers that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of pedestrians using walkers that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle pedestrians using walkers?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Powered micromobility vehicles (e.g., e-scooters, e-bikes and motorized skateboards) as defined by SAE J3194_201911 (SAE, 2019) (Automated Vehicle Safety Consortium, 2020)

8.9. E-scooter riders

- Description: VRUs riding motorized scooters, which may be present in the ODD and behavioral competency portfolio as part of a rental vehicle system
- Source: (Automated Vehicle Safety Consortium, 2020), (SAE, 2019)
- Metric: Number of safety-relevant e-scooter riders that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of e-scooter riders that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle e-scooter riders?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

8.10. E-bike riders

- Description: VRUs riding motorized bicycles, which may be present in the ODD and behavioral competency portfolio as part of a rental vehicle system
- Source: (Automated Vehicle Safety Consortium, 2020), (SAE, 2019)
- Metric: Number of safety-relevant e-bike riders that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of e-bike riders that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle e-bike riders?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

8.11. Motorized skateboard riders

- Description: VRUs riding motorized skateboards and longboards
- Source: (Automated Vehicle Safety Consortium, 2020), (SAE, 2019)
- Metric: Number of safety-relevant motorized skateboard riders that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of motorized skateboard riders that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle motorized skateboard riders?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

8.12. Motorized wheel riders

- Description: VRUs riding motorized wheels
- Source: (Automated Vehicle Safety Consortium, 2020), (SAE, 2019)
- Metric: Number of safety-relevant motorized wheel riders that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum

- Increment: 1
- Question 1: Based on the information above, what is the maximum number of motorized wheel riders that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle motorized wheel riders?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Wheelchairs/wheeled mobility assistance devices (Automated Vehicle Safety Consortium, 2020)

8.13. Pedestrians using motorized wheelchairs

- Description: People using motorized wheelchairs and other motorized mobility assistance devices
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant pedestrians using motorized wheelchairs that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of pedestrians using motorized wheelchairs that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle pedestrians using motorized wheelchairs?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

8.14. Pedestrians using motorized carts

- Description: People using motorized carts (of the type that are available for use in and around retail stores)
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant pedestrians using motorized carts that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1

- Question 1: Based on the information above, what is the maximum number of pedestrians using motorized carts that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle pedestrians using motorized carts?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

8.15. Pedestrians using manual wheelchairs

- Description: People using manual (non-motorized) wheelchairs or other manual mobility assistance devices
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant pedestrians using manual wheelchairs that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of pedestrians using manual wheelchairs that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle pedestrians using manual wheelchairs?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Animals (Automated Vehicle Safety Consortium, 2020)

8.16. Dogs

- Description: Dogs and doglike animals, including coyotes, foxes, etc.
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant dogs that can be that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of dogs that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle dogs?

        - AV Developer Response:
    - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

8.17. Cats
    - Description: Cats and catlike animals
    - Source: (Automated Vehicle Safety Consortium, 2020)
    - Metric: Number of safety-relevant cats that can be handled by the VUT simultaneously
    - Units: Number
    - Range: 0 to Maximum
    - Increment: 1
    - Question 1: Based on the information above, what is the maximum number of cats that the VUT is expected to be able to handle?
        - AV Developer Response:
    - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle cats?
        - AV Developer Response:
    - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

8.18. Raccoons
    - Description: Raccoons and similar animals, including opossums, etc.
    - Source: (Automated Vehicle Safety Consortium, 2020)
    - Metric: Number of safety-relevant racoons that can be handled by the VUT simultaneously
    - Units: Number
    - Range: 0 to Maximum
    - Increment: 1
    - Question 1: Based on the information above, what is the maximum number of raccoons that the VUT is expected to be able to handle?
        - AV Developer Response:
    - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle racoons?
        - AV Developer Response:
    - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

8.19. Animal crossing VUT path
    - Description: maneuver by an animal across the path of the VUT
    - Source: (International Organization for Standardization, 2019)
    - Component: Inclusion of animals crossing VUT path in ODD and behavioral competency portfolio
    - Units: Binary
    - Range: 0 to 1

- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle animals crossing the VUT path where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle animals crossing the VUT path where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

8.20. Are there any behavioral competencies related to the response to VRUs by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 9 - Behavior – Responding to other vehicles (Automated Vehicle Safety Consortium, 2021)

Specification: Maintaining a safety envelope with respect to other vehicles where another vehicle may be moving from an adjacent lane into the subject lane, ahead of the subject vehicle, either from the same direction or oncoming (e.g., leading, adjacent, encroaching, oncoming, stopped, cut-ins, cut-outs/reveal, wrong direction) (Automated Vehicle Safety Consortium, 2021)

Road Users – Automobiles (passenger-carrying motor vehicle other than bus or heavy truck) (Automated Vehicle Safety Consortium, 2020)

9.1. Sedan

- Description: A vehicle having three separate "boxes", or compartments, for the engine, passengers, and storage (J.D. Power and Associates, 2021)
- Source: (Automated Vehicle Safety Consortium, 2020), (J.D. Power and Associates, 2021)
- Metric: Number of safety-relevant sedans that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of sedans that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle sedans?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.2. Minivan

- Description: A vehicle with a van format that is smaller than a typical van
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant minivans that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of minivans that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle minivans?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?

        - AV Developer Response:

9.3. Convertible
   - Description: A vehicle with a retractable roof
   - Source: (Automated Vehicle Safety Consortium, 2020)
   - Metric: Number of safety-relevant convertibles that can be handled by the VUT simultaneously
   - Units: Number
   - Range: 0 to Maximum
   - Increment: 1
   - Question 1: Based on the information above, what is the maximum number of convertibles that the VUT is expected to be able to handle?
        - AV Developer Response:
   - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle convertibles?
        - AV Developer Response:
   - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

9.4. Station wagon
   - Definition: A vehicle in the sedan format with a longer body and no trunk
   - Source: (Automated Vehicle Safety Consortium, 2020)
   - Metric: Number of safety-relevant station wagons that can be handled by the VUT simultaneously
   - Units: Number
   - Range: 0 to Maximum
   - Increment: 1
   - Question 1: Based on the information above, what is the maximum number of station wagons that the VUT is expected to be able to handle?
        - AV Developer Response:
   - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle station wagons?
        - AV Developer Response:
   - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

9.5. Coupe
   - Definition: A vehicle in the sedan format with a smaller body and two doors
   - Source: (Automated Vehicle Safety Consortium, 2020)
   - Metric: Number of safety-relevant coupes that can be handled by the VUT simultaneously
   - Units: Number
   - Range: 0 to Maximum
   - Increment: 1

- Question 1: Based on the information above, what is the maximum number of coupes that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle coupes?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.6. Sports car

- Definition: Any vehicle with a streamlined exterior and higher performance than a typical passenger vehicle.
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant sports cars that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of sports cars that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle sports cars?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.7. SUV

- Definition: Short for “sports utility vehicle”
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant SUVs that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of SUVs that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle SUVs?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.8. Hatchback

- Definition: A vehicle where the trunk space is not separate from the main passenger compartment of the car
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant hatchbacks that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of hatchbacks that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle hatchbacks?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.9 Crossover

- Definition: A vehicle with a platform containing a mix of sedan and SUV features
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant crossovers that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of crossovers that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle crossovers?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Motorcycles and tricycles (Automated Vehicle Safety Consortium, 2020)

9.10. Motorcycles

- Definition: A motorized vehicle with two wheels aligned on a single axis
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant motorcycles that can be handled by the VUT simultaneously
- Unit: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of motorcycles that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle motorcycles?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.11. Tricycles

- Description: A motorized vehicle with three wheels
- Metric: Number of safety-relevant tricycles that can be accounted for simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of tricycles that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle tricycles?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Maneuvers (Automated Vehicle Safety Consortium, 2020)

9.12. Running red light – perpendicular

- Definition: A vehicle traveling through a junction with a red light at a perpendicular angle to the direction of VUT travel
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles running red lights perpendicular to direction of VUT travel in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1

- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles running red lights perpendicular to the direction of VUT travel where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles running red lights perpendicular to the direction of VUT travel where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.13. Running red light – left turn

- Description: A vehicle traveling through a junction with a red light and turning left where its path intersects with that of the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles running red lights and turning left to cross path of VUT travel in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles running red lights and turning left to cross the path of VUT travel where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles running red lights and turning left to cross the path of VUT travel where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Running stop sign (National Highway Traffic Safety Administration, 2007)

9.14. Running stop sign – perpendicular

- Definition: A vehicle traveling through a junction with a stop sign at a perpendicular angle to the direction of VUT travel
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles running stop signs perpendicular to direction of VUT travel in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1

- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles running stop signs perpendicular to the direction of VUT travel where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles running stop signs perpendicular to the direction of VUT travel where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.15. Running stop sign – left turn

- Description: A vehicle traveling through a junction with a stop sign and turning left where its path intersects with that of the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles running stop signs and turning left to cross path of VUT travel in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles running stop signs and turning left to cross the path of VUT travel where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles running stop signs and turning left to cross the path of VUT travel where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.16. Vehicle reversing towards VUT

- Description: A vehicle traveling in reverse toward the current location of the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles reversing toward VUT in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1

- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles reversing toward the VUT where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles reversing toward the VUT where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.17. Vehicle(s) turning – same direction

- Description: A vehicle in close proximity to the VUT turning in the same direction as the VUT at the same time as the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles turning in the same direction as the VUT in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles turning in the same direction as the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles turning in the same direction as the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.18. Vehicle(s) parking – same direction

- Description: A vehicle in close proximity to the VUT parking near the VUT at the same time and direction as the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles parking in the same direction as the VUT in the ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles parking in the same direction as the VUT?
  - AV Developer Response:

- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles parking in the same direction as the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.19. Vehicle(s) changing lanes – same direction
- Description: A vehicle in close proximity to the VUT and traveling in the same direction changing lanes near the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles changing lanes in the same direction as the VUT in the ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles changing lanes in the same direction as the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles changing lanes in the same direction as the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.20. Vehicle(s) drifting – same direction
- Description: A vehicle in close proximity to the VUT and traveling in the same direction drifting laterally near the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles drifting in the same direction as the VUT in the ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle drifting vehicles that are traveling in the same direction as the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle drifting vehicles that are traveling in the same direction as the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?

- AV Developer Response:

9.21. Vehicle(s) drifting – opposite direction

- Description: A vehicle in close proximity to the VUT and traveling in the opposite direction drifting laterally near the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles drifting in the opposite direction as the VUT in the ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle drifting vehicles that are traveling in the opposite direction as the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle drifting vehicles that are traveling in the opposite direction as the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Following vehicle making a maneuver (International Organization for Standardization, 2019)

9.22. Following vehicle suddenly decelerating

- Description: A vehicle following in close proximity to the VUT suddenly decelerating
- Source: (International Organization for Standardization, 2019), (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of following vehicles to the VUT suddenly decelerating in the ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a following vehicle to the VUT suddenly decelerating?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a following vehicle to the VUT suddenly decelerating?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.23. Following vehicle decelerating

- Description: A vehicle following in close proximity to the VUT decelerating at a moderate rate
- Source: (International Organization for Standardization, 2019), (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of following vehicles to the VUT decelerating in the ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a following vehicle to the VUT decelerating?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a following vehicle to the VUT decelerating?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.24. Following vehicle accelerating

- Description: A vehicle following in close proximity to the VUT accelerating at a moderate rate
- Source: (International Organization for Standardization, 2019), (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of following vehicles to the VUT accelerating in the ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a following vehicle to the VUT accelerating where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a following vehicle to the VUT accelerating where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.25. Following vehicle suddenly accelerating

- Description: A vehicle following in close proximity to the VUT suddenly accelerating

- Source: (International Organization for Standardization, 2019), (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of following vehicles to the VUT suddenly accelerating in the ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a following vehicle to the VUT suddenly accelerating where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a following vehicle to the VUT suddenly accelerating where a collision will occur if no action is taken by the VUT?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.26. Lead vehicle accelerating

- Description: A vehicle in front of and in close proximity to the VUT accelerating at a moderate rate
- Source: (International Organization for Standardization, 2019), (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of lead vehicles to the VUT accelerating in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a leading vehicle to the VUT accelerating?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a leading vehicle to the VUT accelerating?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.27. Lead vehicle suddenly accelerating

- Description: A vehicle in front of and in close proximity to the VUT suddenly accelerating
- Source: (International Organization for Standardization, 2019), (National Highway Traffic Safety Administration, 2007)

- Component: Inclusion of lead vehicles to the VUT suddenly accelerating in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a leading vehicle to the VUT suddenly accelerating?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a leading vehicle to the VUT suddenly accelerating?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.28. Lead vehicle moving at lower constant speed

- Description: A vehicle in front of and in close proximity to the VUT traveling at a lower speed than the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of lead vehicles to the VUT moving at slower constant speeds in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a leading vehicle to the VUT traveling at a lower constant speed than surrounding traffic?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a leading vehicle to the VUT traveling at a lower constant speed than surrounding traffic?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.29. Lead vehicle suddenly decelerating

- Description: A vehicle in front of and in close proximity to the VUT suddenly decelerating
- Source: (International Organization for Standardization, 2019), (National Highway Traffic Safety Administration, 2007)
- Components: Inclusion of lead vehicles to VUT suddenly decelerating in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1

- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a leading vehicle to the VUT suddenly decelerating where a collision will occur if no action is taken by the VUT?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a leading vehicle to the VUT suddenly decelerating where a collision will occur if no action is taken by the VUT?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.30. Lead vehicle decelerates

- Description: A vehicle in front of and in close proximity to the VUT decelerating at a moderate rate
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of lead vehicles to VUT decelerating in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a leading vehicle to the VUT decelerating where a collision will occur if no action is taken by the VUT?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a leading vehicle to the VUT decelerating where a collision will occur if no action is taken by the VUT?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.31. Lead vehicle stopped

- Description: A vehicle in front of and in close proximity to the VUT stopping on the roadway
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of stopped lead vehicles to VUT in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1

- Question 1: Based on the information above, is the VUT expected to be able to handle a leading vehicle to the VUT being stopped where a collision will occur if no action is taken by the VUT?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a leading vehicle to the VUT being stopped where a collision will occur if no action is taken by the VUT?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.32. Left turn across path from opposite directions at signalized junction

- Description: A vehicle traveling toward the VUT from the direction opposite to the direction of VUT travel making a left turn across that path of the VUT at a signalized junction
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles taking left turn across VUT path from opposite directions at signalized junctions in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a left turn by another vehicle across its path from the opposite direction at a signalized junction?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a left turn by another vehicle across its path from the opposite direction at a signalized junction?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.33. Vehicle turning right at signalized junction

- Description: A vehicle in close proximity to the VUT making a right turn at a signalized junction near the VUT
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles taking right turns at signalized junctions in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1

- Question 1: Based on the information above, is the VUT expected to be able to handle a right turn by another vehicle at a signalized junction?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a right turn by another vehicle at a signalized junction?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.34. Left turn across path from opposite directions at non-signalized junctions

- Description: A vehicle traveling toward the VUT from the direction opposite to the direction of VUT travel making a left turn across that path of the VUT at a non-signalized junction
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles taking left turns across VUT path from opposite directions at non-signalized junctions in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle a left turn by another vehicle across its path from the opposite direction at a non-signalized junction?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle a left turn by another vehicle across its path from the opposite direction at a non-signalized junction?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.35. Straight crossing paths at non-signalized junctions

- Description: A vehicle traveling at a right angle to the direction of VUT travel crossing the path of the VUT at a non-signalized junction
- Source: (National Highway Traffic Safety Administration, 2007)
- Component: Inclusion of vehicles crossing VUT path from perpendicular direction to direction of VUT travel at non-signalized junctions
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle vehicles crossing the VUT path from the perpendicular direction to the direction of VUT travel at non-signalized junctions?

        - AV Developer Response:
    - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles crossing the VUT path from the perpendicular direction to the direction of VUT travel at non-signalized junctions?
        - AV Developer Response:
    - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

9.36. Vehicle(s) turning at non-signalized junctions
    - Description: A vehicle in close proximity to the VUT making a turn at a non-signalized junction near the VUT
    - Source: (National Highway Traffic Safety Administration, 2007)
    - Component: Inclusion of vehicles turning at non-signalized junctions in ODD and behavioral competency portfolio
    - Units: Binary
    - Range: 0 to 1
    - Increment: 1
    - Question 1: Based on the information above, is the VUT expected to be able to handle vehicles turning at non-signalized junctions?
        - AV Developer Response:
    - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles turning at non-signalized junctions?
        - AV Developer Response:
    - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

9.37. Evasive action with prior vehicle maneuver
    - Description: Evasive action of the VUT arising from a scenario instantiated by a prior maneuver of the VUT
    - Source: (National Highway Traffic Safety Administration, 2007)
    - Component: Inclusion of evasive actions in ODD and behavioral competency portfolio
    - Units: Binary
    - Range: 0 to 1
    - Increment: 1
    - Question 1: Based on the information above, is the VUT expected to be able to make evasive maneuvers?
        - AV Developer Response:
    - Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to be able to make evasive maneuvers?
        - AV Developer Response:

- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.38. Interrupting/cut-in vehicle

- Description: A vehicle near the VUT suddenly cutting into the lane of VUT travel in front of and very close to the VUT
- Source: (International Organization for Standardization, 2019)
- Component: Inclusion of vehicles cutting off VUT in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle being cut off by other vehicles?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to be handle being cut off by other vehicles?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.39. Trailing vehicle in stop-and-go traffic

- Description: Trailing action by the VUT of another vehicle in traffic that frequently stops and starts
- Source: (International Organization for Standardization, 2019)
- Component: Inclusion of VUT trailing vehicles in stop-and-go traffic in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle trailing another vehicle in stop-and-go traffic?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle trailing another vehicle in stop-and-go traffic?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

9.40. Motorcycle lane splitting

- Description: A motorcyclist near the VUT traveling between traffic lanes and the vehicles in those lanes, including the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)

- Metric: Inclusion of motorcycles performing lane splits in ODD and behavioral competency portfolio
- Unit: binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle motorcycles performing lane splits?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle motorcycles performing lane splits?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

9.41. Are there any behavioral competencies related to the response to other vehicles by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 10 - Behavior: Responding to special purpose vehicles (Automated Vehicle Safety Consortium, 2021)

Specification: Where "special purpose vehicles" include emergency vehicles as defined in the Fixing America's Surface Transportation (FAST) Act, government-owned vehicles, hearses, safety vehicles, school busses, etc. (Automated Vehicle Safety Consortium, 2021)

Transit vehicles (Automated Vehicle Safety Consortium, 2020)

10.1. Buses
- Definition: Large vehicles with multiple rows of seats capable of transporting a large number of passengers at once
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant buses that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of buses that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle buses?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

10.2. Articulated buses
- Definition: Buses with two compartments connected by a flexible middle section
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant articulated buses that can be accounted for simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of articulated buses that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle articulated buses?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

10.3. Streetcars

- Description: Light-rail vehicles that generally maintain the shape of buses
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant streetcars that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of streetcars that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle streetcars?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

10.4. Trolleys

- Definition: Streetcars with vintage styling
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant trolleys that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of trolleys that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle trolleys?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

10.5. Light rail vehicles

- Description: Tracked vehicles operating in urban and suburban areas that do not share the same weight classification as freight trains
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant light rail vehicles that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1

- Question 1: Based on the information above, what is the maximum number of light rail vehicles that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle light rail vehicles?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Trucks (heavy trucks, such as classes 6, 7, and 8) (Automated Vehicle Safety Consortium, 2020)

10.6. Trucks

- Description: Trucks designed to haul freight containers. Also referred to as tractor trailers.
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant trucks that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of trucks that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle trucks?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Emergency vehicles (Automated Vehicle Safety Consortium, 2020)

10.7. Fire trucks

- Description: Specialized large vehicles used by fire departments to put out fires
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant fire trucks that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of fire trucks that the VUT is expected to be able to handle?
    - AV Developer Response:

- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle fire trucks?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

10.8. Police vehicles

- Description: Any vehicle owned and operated by a police department for the purposes of law enforcement, and demarcated as such
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant police vehicles that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of police vehicles that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle police vehicles?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

10.9. Ambulances

- Description: Any vehicle owned and operated by a hospital or other medical facility for the purposes of medical transportation and demarcated as such
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant ambulances that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of ambulances that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle ambulances?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

10.10. Tow vehicles

- Description: Any vehicle specifically designed and possessing the necessary equipment to tow another vehicle
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant tow vehicles that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of tow vehicles that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle tow vehicles?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Other vehicles (Automated Vehicle Safety Consortium, 2020)

10.11. Golf carts

- Description: Small utility carts typically used for transportation of one or two people and their equipment around golf courses
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant golf carts that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Question 1: Based on the information above, what is the maximum number of golf carts that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle golf carts?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

10.12. Garbage trucks

- Description: Any vehicle capable of collecting and transporting solid municipal waste
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant garbage trucks that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1

- Question 1: Based on the information above, what is the maximum number of garbage trucks that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle garbage trucks?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

10.13. Postal vehicles

- Description: Any vehicle owned and operated by a mail carrier service or the U.S. Postal Service for the purposes of transportation of mailed goods and demarcated as such
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant postal vehicles that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of postal vehicles that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle postal vehicles?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

10.14. Street sweepers

- Description: Any vehicle capable of performing cleaning operations on a road
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant street sweepers that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of street sweepers that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle street sweepers?

- AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

10.15. Are there any behavioral competencies related to the response to special purpose vehicles by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 11 - Behavior: Responding to lane obstructions and obstacles (Automated Vehicle Safety Consortium, 2021)

Specification: Responding to lane obstructions or obstacles can involve partial or complete lane obstructions with static or dynamic objects but is not meant to capture situations where a formal lane change is required to pass, and which is considered a complete lane blockage (Automated Vehicle Safety Consortium, 2021)

Non-static roadside objects (NSROs) (Automated Vehicle Safety Consortium, 2020)

11.1. Trash cans

- Description: Any container meant for the storage of domestic solid waste
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant trashcans that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of trash cans that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to trash cans?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

11.2. Vehicle stopped on roadside

- Description: Any vehicle that is stopped near the road of VUT travel but not present directly on that road
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Number of safety-relevant vehicles stopped on roadside that can be handled by the VUT simultaneously
- Units: Number
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum number of vehicles stopped on the roadside that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle vehicles stopped on the roadside?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

11.3. Are there any behavioral competencies related to the response to lane obstructions and obstacles by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 12 - Behavior: Responding to confined road structures (Automated Vehicle Safety Consortium, 2021)

Specification: Driving straight through sections of road with limited or no shoulders, potentially restricted or reduced lanes, overhead constraints, atypical reflections, and rapidly changing environmental conditions (lighting, surface conditions, etc.) from the normal roadway (Automated Vehicle Safety Consortium, 2021)

12.1. Tunnels

- Description: Any passage that surrounds a portion of road on all sides
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of tunnels in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle tunnels?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle tunnels?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

12.2. Overhead wires

- Description: Overhead power transmission wires near the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of overhead wires in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle overhead wires?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle overhead wires?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

12.3. Tall buildings

- Description: Any building near the VUT that is over ten stories in height
- Source: (Automated Vehicle Safety Consortium, 2020)

- Component: Presence of tall buildings in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle tall buildings?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle tall buildings
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

12.4. Overpasses

- Description: A road segment that is built over another, lower road segment
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of overpasses in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle overpasses?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle overpasses?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

12.5. Are there any behavioral competencies related to the response to confined road structures by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:

- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 13 - Behavior: Responding to work zones (Automated Vehicle Safety Consortium, 2021)

Specification: Navigating work zones can involve detecting the work zones and temporary signage, and responding appropriately, including with respect to speeds, human traffic controllers, and navigating lane overrides or shifts (Automated Vehicle Safety Consortium, 2021)

13.1. Mobile work zone

- Description: Any work zone with boundaries that change over the course of the work
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of mobile work zones in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle mobile work zones
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle mobile work zones?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

13.2. Are there any behavioral competencies related to the response to work zones by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Section 14 - Behavior: Responding to relevant traffic control devices (Automated Vehicle Safety Consortium, 2021)

Specification: Per MUTCD (2021), “traffic control devices include all signs, signals, markings, channelizing devices, or other devices that use color, shapes, symbols, words, sound, and/or tactile information for the primary purpose of communicating a regulatory warning, or guidance message to road users on a street, highway, pedestrian facility, bikeway, pathway or private roadway open to public travel” (Automated Vehicle Safety Consortium, 2021)

Traffic Control Devices (Automated Vehicle Safety Consortium, 2021)

14.1. Regulatory (red) signage
- Description: Signage indicating the presence of a traffic regulation or rule in the current area
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of regulatory (red) signage in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle regulatory (red) signage?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle regulatory (red) signage?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

14.2. Warning (yellow) signage
- Definition: Signage displaying warnings and information regarding upcoming road features and conditions
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of warning (yellow) signage in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle warning (yellow) signage?
    - AV Developer Response:

- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle warning (yellow) signage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.3. Guide (green) signage

- Definition: Signage providing (non-critical) guide information
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of guide (green) signage in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle guide (green) signage?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle guide (green) signage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.4. Services (blue) signage

- Definition: Signage indicating the nearby presence of relevant services (restaurants, gas stations, etc.)
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of services (blue) signage in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle services (blue) signage?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle services (blue) signage?
  - AV Developer Response:

- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.5. Construction (orange) signage

- Description: Signage indicating that construction work is being conducted or construction zones are nearby
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of construction (orange) signage in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle construction (orange) signage?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle construction (orange) signage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.6. Recreation (brown) signage

- Description: Signage indicating the presence of nearby recreational opportunities
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of recreation (brown) signage in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle recreation (brown) signage?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle recreation (brown) signage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.7. School zone (yellow) signage

- Description: Signage indicating the presence of a school zone

- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of school zone (yellow) signage in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle school zone (yellow) signage?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle school zone (yellow) signage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.8. Incident management (pink) signage

- Description: Signage indicating the implementation of an incident management scheme in the area
- Source: (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of incident management (pink) signage in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle incident management (pink) signage?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle incident management (pink) signage?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.9. Traffic control signals

- Description: Any device controlling the flow of traffic; most commonly traffic lights
- Source: (Automated Vehicle Safety Consortium, 2020), (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of traffic control signals in ODD and behavioral competency portfolio
- Units: Binary

- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle traffic control signals?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle traffic control signals?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.10. Railway crossing

- Description: Any intersection between a set of railway tracks and a roadway Source:
- Source: (International Organization for Standardization, 2019)
- Component: Presence of railway crossings in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle railway crossings?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle railway crossings?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.11. Crosswalk

- Description: A dedicated path used by pedestrians to cross a roadway
- Source: (Automated Vehicle Safety Consortium, 2020), (U.S. Department of Transportation Federal Highway Administration, 2020)
- Component: Presence of crosswalks in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle crosswalks?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle crosswalks?

            - AV Developer Response:
    - Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
        - AV Developer Response:

14.12. Posted speed limits
- Description: Signage limiting the speed of vehicles on a particular road section
- Source: (Automated Vehicle Safety Consortium, 2020), (U.S. Department of Transportation Federal Highway Administration, 2020)
- Metric: Permissible speeds in the ODD and behavioral competency portfolio
- Units: Miles per hour (mph)
- Range: 0 to Maximum
- Increment: 5
- Question 1: Based on the information above, what is the maximum posted speed limit that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle posted speed limits?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Fixed Zones (Automated Vehicle Safety Consortium, 2020)

14.13. Hospital zone
- Description: Any area immediately surrounding a hospital or emergency medical center and demarcated as such
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of hospital zones in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle hospital zones?
    - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle hospital zones?
    - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

14.14. School zone
- Description: Any area surrounding a school and demarcated as such

- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of school zones in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle school zones?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle school zones?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.15. Flood zone

- Description: Any area of a roadway that has been flooded with water
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of flood zones in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle flood zones?
  - AV Developer Response:
- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle flood zones?
  - AV Developer Response:
- What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

14.16. Are there any behavioral competencies related to the response to relevant traffic control devices by the VUT not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:

- Question 2: Are there any ODD and behavioral competency portfolio-related limitations on the capabilities of the VUT to handle this component?
  - AV Developer Response:
- Question 3: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

ODD-SPECIFIC COMPONENTS

Section 15 - Weather-Related Environmental Conditions (Automated Vehicle Safety Consortium, 2020)

15.1. Temperature

- Description: Air temperature at ground level near the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Temperature
- Units: Degrees Celsius
- Range: Minimum to Maximum
- Increment: 5
- Question 1: Based on the information above, what are the minimum and maximum temperatures that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.2. Rain

- Description: Precipitation from overhead clouds
- Source (Automated Vehicle Safety Consortium, 2020)
- Metric: Rainfall per hour
- Units: Inches
- Range: 0 to Maximum
- Increment: 0.1
- Question 1: Based on the information above, what is the maximum rainfall that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.3. Drizzle

- Description: Precipitation from overhead clouds with droplet sizes that are smaller than usual and less frequent
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Visibility
- Units: Feet and miles
- Range: 0 to Maximum
- Increment: 200 feet
- Question 1: Based on the information above, what is the minimum visibility from drizzle that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.4. Mist/Fog/Haze

- Description: Water-based aerosol particulates in the air immediately surrounding the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Visibility
- Units: Feet and miles
- Range: Minimum to Maximum
- Increment: 200 feet
- Question 1: Based on the information above, what is the minimum visibility from mist/fog/haze that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.5. Snow

- Description: Frozen precipitation from overhead clouds
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Snowfall per hour
- Units: Inches
- Range: 0 to Maximum
- Increment: 0.1
- Question 1: Based on the information above, what is the maximum snowfall that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.6. Snow depth

- Description: Average depth of snow deposits in the VUT's area of operation
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Snow depth
- Units: Inches
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum snow depth that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.7. Snow intensity

- Description: Density of snowfall immediately surrounding the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)

- Metric: Visibility
- Units: Feet and miles
- Range: Minimum to Maximum
- Increment: 200 feet
- Question 1: Based on the information above, what is the minimum visibility from snow that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.8. Sleet

- Description: A mixture of frozen and non-frozen precipitation from overhead clouds
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Sleetfall per hour
- Units: Inches
- Range: 0 to Maximum
- Increment: 0.1
- Question 1: Based on the information above, what is the maximum sleetfall that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.9. Freezing rain

- Description: Precipitation from overhead clouds that freezes upon contact with the ground
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Freezing rainfall per hour
- Units: Inches
- Range: 0 to Maximum
- Increment: 0.1
- Question 1: Based on the information above, what is the maximum freezing rainfall that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.10. Hail

- Description: Large, frozen pellets of water precipitated from overhead clouds
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Hailfall per hour
- Units: Inches
- Range: 0 to Maximum

- Increment: 0.1
- Question 1: Based on the information above, what is the maximum hailfall that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.11. Sky condition

- Description: Percentage of the sky that is obscured by clouds
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Cloud cover
- Units: Percentage cloud cover
- Range: 0 to 100
- Increment: 1/8
- Question 1: Based on the information above, what is the maximum percentage cloud cover that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.12. Illuminance

- Description: Ambient light level in the area surrounding the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Light level
- Units: log(lux)
- Range: Minimum to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum and minimum illumination that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

15.13. Sun angle

- Description: Angle of the sun in the sky relative to the horizon
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Position of sun in sky
- Units: Degrees relative to horizon
- Range: Minimum to Maximum
- Increment: 15
- Question 1: Based on the information above, what is the minimum and maximum sun angle that the VUT is expected to be able to handle?
  - AV Developer Response:

- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

15.14. Wind

- Description: Wind speed in the area surrounding the VUT
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Wind speed
- Units: Miles per hour (mph)
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum wind speed that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

15.15. Are there any behavioral competencies related to weather related environmental conditions not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Section 16 - Road Surface Conditions (Automated Vehicle Safety Consortium, 2020)

16.1. Cracking

- Description: Unrepaired cracks or separations in the surface of the road
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Percentage of road surface that is cracked
- Units: Percentage
- Range: 0 to 100
- Increment: 1
- Question 1: Based on the information above, what is the maximum cracking that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

16.2 Rutting

- Description: Vertical deflection of the road surface
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Rutting deflection
- Units: Centimeters
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum rutting deflection that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

16.3 Raveling

- Description: Unrepaired roughness of the road surface
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Surface roughness as percentage of total surface
- Units: Percentage
- Range: 0 to 100
- Increment: 1
- Question 1: Based on the information above, what is the maximum raveling that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

16.4. Asphalt repairs

- Description: Repairs done to the road surface to offset cracking, raveling, rutting, etc.
- Source: (Automated Vehicle Safety Consortium, 2020)

- Metric: Asphalt repairs as a percentage of total surface
- Units: Percentage
- Range: 0 to 100
- Increment: 1
- Question 1: Based on the information above, what is the maximum severity of asphalt repairs that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

16.5. Pothole size

- Description: Diameter of potholes occurring in the road surface
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Pothole size
- Units: Centimeters
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum pothole size that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

16.6. Pothole frequency

- Description: Frequency at which the VUT encounters potholes or other holes in the road surface
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Pothole frequency when driving
- Units: Number of potholes encountered per five driving minutes
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum pothole frequency that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

16.7. Are there any behavioral competencies related to road surface conditions not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:

- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
    - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
    - AV Developer Response:

Section 17 - Other Components

17.1. Buffer width

- Description: Width of separation between curb and pedestrian facilities
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Buffer width between curb and pedestrian facilities
- Units: Feet
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum buffer width that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

17.2. Shoulder width

- Description: Width of shoulder as measured from edge of road to edge of shoulder
- Source: (Automated Vehicle Safety Consortium, 2020), (U.S. Department of Tranportation Federal Highway Administration, 2014)
- Metric: Width of shoulder expected in ODD and behavioral competency portfolio
- Units: Feet
- Range: 0 to Maximum
- Increment: 1
- Question 1: Based on the information above, what is the maximum shoulder width that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

17.3. Sidewalks

- Description: Concrete paths for use by pedestrians
- Source: (Automated Vehicle Safety Consortium, 2020)
- Component: Presence of crosswalks in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle sidewalks?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

17.4. Pedestrian islands

- Description: Small concrete areas in road sections allowing for protection of pedestrians in an otherwise unprotected road segment
- Source: (Automated Vehicle Safety Consortium, 2020), (U.S. Department of Transportation Federal Highway Administration, 2002)
- Component: Presence of pedestrian islands in ODD and behavioral competency portfolio
- Units: Binary
- Range: 0 to 1
- Increment: 1
- Question 1: Based on the information above, is the VUT expected to be able to handle pedestrian islands?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

17.5. Are there any behavioral competencies related to other components not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 18 - Operational Constraints (Automated Vehicle Safety Consortium, 2020)

18.1 Intended operational times

- Description: Time range in which the VUT is intended to operate, as specified by the VUT developer
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Intended operational times
- Units: Hours
- Range: 24 hours
- Increment: 30 minutes
- Question 1: Based on the information above, during what times is the VUT expected to operate?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

18.2. Signal strength

- Description: Strength of any necessary wireless signals for operation of the VUT relative to their full strength
- Source: (Automated Vehicle Safety Consortium, 2020)
- Metric: Percentage of expected signal strength
- Units: Percentage
- Range: Minimum to 100
- Increment: 1
- Question 1: Based on the information above, what is the minimum signal strength that the VUT is expected to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

18.3. Are there any behavioral competencies related to other components not included in this specification form that should be included? Please use the format below to include any such competencies, should they exist:

- Description:
- Source:
- Metric:
- Units:
- Range:
- Increment:
- Question 1: What are the maximum and minimum values of this component that the VUT is expected to be able to handle?
  - AV Developer Response:
- Question 2: What is the relevance for this component in the VUT ODD and behavioral competency portfolio?
  - AV Developer Response:

Section 19 – Geofencing

19.1 Geofencing

- Description: The geographic boundaries in which an AV is allowed to operate
- Source: (Jeffrey Wishart, personal communication, September 26, 2023)
- Question 1: Please describe any geofencing put in place for the VUT.
    - AV Developer Response:
- Question 2: Is the geofencing described in Question 1 related to or affected by any other components in this specification form?
    - AV Developer Response:

APPENDIX B

SAFETYPOOL FILTERING PYTHON SCRIPT

```
## SafetyPool Filter Script ##

#Imports#
import os
import json
import random
import matplotlib.pyplot as plt

#Function and class definitions#
class Axis:
    def __init__(self, name, criticality, axisrange):
        self.name = name
        self.axisrange = axisrange
        self.criticality = criticality

        if type(axisrange) == range:
            self.axisrange = list(axisrange)

        self.value = self.axisrange[0]

def readout(list1_label, list2_lists):
    string = ""
    for i in range(len(list1_label)):
        for item in list2_lists[i]:
            if list2_lists[i].index(item) == 0:
                string = string + list1_label[i] + item + ", "
            elif list2_lists[i].index(item) != len(list2_lists[i]) - 1:
                string = string + item + ", "
            else:
                string = string + item  + "\n"
    print(string)
    text_file = open("ODD.txt", "w")
    text_file.write(string)
    text_file.close()

def pull_component(parent_string, start_here, appendlist):

    index = parent_string.find(start_here)

    start_pulling = False
    done = False
    character = index
    result = ''
```

```
    if index != -1:
        while done == False and character < len(parent_string):
            if parent_string[character] == "]":
                start_pulling = False
                done = True

            if start_pulling == True:
                result = ''.join((result, parent_string[character]))

            if parent_string[character] == "[":
                start_pulling = True

            character = character + 1

    if result not in appendlist and result != '':
        appendlist.append(result)

    return result

def map_to_ODD(component, index):
    if index == range(0,5):
        if component == "Normal roundabout":
            ODD[0].value = 1
        elif component == "Y-Junction":
            ODD[1].value = 1
        elif component == "Crossroad":
            ODD[2].value = 1
        elif component == "T-Junction":
            ODD[3].value = 1
        elif component == "Large roundabout":
            ODD[4].value = 1
    elif index == 5:
        if component == "Traffic light":
            ODD[5].value = 1
    elif index == 6:
        if component != "":
            ODD[6].value = int(component)
    elif index == 7:
        ODD[7].value = int(component)
    elif index == range(8, 11):
        if component == "Diameter: 10 to 12":
            ODD[8].value = random.randrange(10, 13)
        if component == "Width: 10 to 12, Depth: 10 to 12":
            ODD[9].value = random.randrange(10, 13)
```

```
            ODD[10].value = random.randrange(10, 13)
    elif index == range(11, 17):
        if component == "Motorway":
            ODD[11].value = 1
        if component == "Distributor road":
            ODD[12].value = 1
        if component == "Radial road":
            ODD[13].value = 1
        if component == "Minor road":
            ODD[14].value = 1
        if component == "'Test Track'":
            ODD[15].value = 1
        if component == "'Slip road'":
            ODD[16].value = 1
    elif index == 17:
        ODD[17].value = 1
    elif index == 18:
        if component != "N/A" and component != '':
            if component == "Part1: 50, Part2: 30":
                ODD[18].value = 50
            else:
                ODD[18].value = int(component)
    elif index == range(19, 21):
        if component == "Rural":
            ODD[19].value = 1
        if component == "Urban":
            ODD[20].value = 1
    elif index == range(21, 23):
        if component == "Right-handed":
            ODD[21].value == 1
        if component == "Left-handed":
            ODD[22].value == 1
    elif index == 23:
        if component == "Traffic lane":
            ODD[23].value = 1
    elif index == 24:
        if component == "Broken line":
            ODD[24].value = 1
    elif index == 25:
        if component == "Uniform":
            ODD[25].value = 1
    elif index == range(26, 30):
        if component == "Wet":
            ODD[26].value = 1
```

```
        if component == "Snow":
            ODD[27].value = 1
        if component == "Icy":
            ODD[28].value = 1
        if component == "Contaminated":
            ODD[29].value = 1
    elif index == 30:
        if component == "Straight":
            ODD[30].value = 1
    elif index == range(31, 34):
        if component == "Level plane":
            ODD[31].value = 1
        if component == "Down-slope":
            ODD[32].value = 1
        if component == "Up-slope":
            ODD[33].value = 1
    elif index == range(34, 37):
        if component == "Divided":
            ODD[34].value = 1
        if component == "Undivided":
            ODD[35].value = 1
        if component == "Pavement":
            ODD[36].value = 1
    elif index == range(37, 43):
        if component == "Solid barriers":
            ODD[37].value = 1
        if component == "Line markers":
            ODD[38].value = 1
        if component == "Shoulder (grass)":
            ODD[39].value = 1
        if component == "Shoulder (paved or gravel)":
            ODD[40].value = 1
        if component == "Temporary line markers":
            ODD[41].value = 1
        if component == "Pavement":
            ODD[42].value = 1
    elif index == 43:
        if component.find("Part1") != -1 and component.find("Part2") != -
1:
            parse1 = component[6:(component.find("Part2")-2)]
            parse2 = component[component.find("Part2")+6:len(component)]

            middle1 = parse1.find("to")
            int1 = int(parse1[0:middle1-1])
```

```
        int2 = int(parse1[middle1+3:len(parse1)])
        if int1 != int2:
            rand1 = random.randrange(int1, int2)
        else:
            rand1 = int1

        middle2 = parse2.find("to")
        int3 = int(parse2[0:middle2-1])
        int4 = int(parse2[middle2+3:len(parse2)])
        if int3 != int4:
            rand2 = random.randrange(int3, int4)
        else:
            rand2 = int3

        if random.randint(0, 1) == 0:
            ODD[43].value = rand1
        else:
            ODD[43].value = rand2
    elif component == "300 to 300":
        ODD[43].value = 300
    else:
        if component != '':
            middle = component.find("to")
            int1 = int(component[0:middle-1])
            int2 = int(component[middle+3:len(component)])
            ODD[43].value = random.randrange(int1, int2)
elif index == 44:
    if component != '':
        middle = component.find("to")
        int1 = int(float(component[0:middle-1])*10)
        int2 = int(float(component[middle+3:len(component)])*10)
        ODD[44].value == random.randrange(int1, int2)/10
elif index == 45:
    middle = component.find("to")
    int1 = int(float(component[0:middle-1])*10)
    int2 = int(float(component[middle+3:len(component)])*10)
    ODD[45].value = random.randrange(int1, int2)
elif index == 46:
    middle = component.find("to")
    int1 = int(component[0:middle-1])
    int2 = int(component[middle+3:len(component)])
    ODD[46].value = random.randrange(int1, int2)
elif index == 47:
    if component == "Light Rain: 0 to 2.5":
```

```
            ODD[47].value = random.randrange(0, 26)
        if component == "Moderate Rain: 2.5 to 7.6":
            ODD[47].value = random.randrange(25, 77)
        if component == "Heavy Rain: 7.6 to 50":
            ODD[47].value = random.randrange(76, 501)
        if component == "Heavy Rain: 50 to 100":
            ODD[47].value = random.randrange(50, 101)
        if component == "Heavy Rain: 100 to 150":
            ODD[47].value = random.randrange(100, 151)
    elif index == 48:
        if component == "Light Snow : 1 to 500":
            ODD[48].value = random.randrange(10, 5001)
        elif component == "Heavy Snow : 0 to 0.5":
            ODD[48].value = random.randrange(0, 60)
        elif component == "Light Snow : 1 to 10":
            ODD[48].value = random.randrange(10, 110)
        elif component == "Moderate Snow : 0.5 to 1.0":
            ODD[48].value = random.randrange(50, 110)
    elif index == 49:
        if component == "00:00 to 03:00":
            ODD[49].value = random.randrange(0, 4)
        if component == "03:00 to 06:00":
            ODD[49].value = random.randrange(3, 7)
        if component == "06:00 to 09:00":
            ODD[49].value = random.randrange(6, 10)
        if component == "09:00 to 12:00":
            ODD[49].value = random.randrange(9, 13)
        if component == "10:00 to 14:00":
            ODD[49].value = random.randrange(10, 15)
        if component == "12:00 to 15:00":
            ODD[49].value = random.randrange(12, 16)
        if component == "15:00 to 18:00":
            ODD[49].value = random.randrange(15, 19)
        if component == "18:00 to 21:00":
            ODD[49].value = random.randrange(18, 22)
        if component == "21:00 to 00:00":
            ODD[49].value = random.randrange(21, 25)

        if ODD[49].value == 24:
            ODD[49].value = 0
    elif index == range(50, 53):
        if component == "Day":
            ODD[50].value = 1
        if component == "Night Lit":
```

```
            ODD[51].value = 1
        if component == "Night Dark":
            ODD[52].value = 1
    elif index == range(53, 56):
        if component == "Sun":
            ODD[53].value = 1
        if component == "Street Lighting":
            ODD[54].value = 1
        if component == "Headlamp":
            ODD[55].value = 1
    elif index == 56:
        if component != "":
            middle = component.find("to")
            int1 = int(component[0:middle-1])
            int2 = int(component[middle+3:len(component)])
            ODD[56].value = random.randrange(int1, int2)
    elif index == range(57, 65):
        if component == "F":
            ODD[57].value = 1
        if component == "FSL":
            ODD[58].value = 1
        if component == "R":
            ODD[59].value = 1
        if component == "SR":
            ODD[60].value = 1
        if component == "SL":
            ODD[61].value = 1
        if component == "FSR":
            ODD[62].value = 1
        if component == "RSR":
            ODD[63].value = 1
        if component == "RSL":
            ODD[64].value = 1

def finalize_scenario(scenarios_list):
    placeholder = []
    for axis in ODD:
        placeholder.append(axis.value)
    scenarios_list.append(placeholder)

#Begin script here#
os.system("cls")

#Load scenario#
```

```
paths = ['E:\Thesis\SafetyPool Scenarios\Automated Lane Keeping System
(ALKS) (14)', 'E:\Thesis\SafetyPool Scenarios\Automated Lane Keeping
System (ALKS) 2 (2,112)', 'E:\Thesis\SafetyPool Scenarios\Automated Lane
Keeping System (ALKS) STPA (1,949)', 'E:\Thesis\SafetyPool Scenarios\Brake
By Wire (BBW) STPA Analysis (133)', 'E:\Thesis\SafetyPool Scenarios\EURO-
NCAP (5)', 'E:\Thesis\SafetyPool Scenarios\Full Self-Drive (FSD) STPA
Analysis (149)', 'E:\Thesis\SafetyPool Scenarios\Insurance Claims
(3,866)', 'E:\Thesis\SafetyPool Scenarios\LSAD (ISO 22737) (13)',
'E:\Thesis\SafetyPool Scenarios\STATS-19 (2,447)']

#Initiate lists for each element and components

### scenery_elements ###
junction_type = []
connection_control = []
number_of_connections = []
number_of_lanes = []
dimensions = []
road_type = []
zone = []
speed_limit = []
environment = []
number_of_lanes = []
road_traffic_direction = []
lane_type = []
lane_markings = []
road_surface_type = []
surface_condition = []
horiz_road_geometry = []
vert_road_geometry = []
trans_road_geometry = []
roadway_edge_features = []
length = []
lane_width = []

## environmental_elements ##
wind = []
cloudiness = []
rainfall = []
snowfall = []
time_of_day = []
illumination = []
light_source = []
```

```
elevation = []
position = []

scenario_container = []
scenarios = []

ODD = [Axis("Junction Type: Normal Roundabout", 1, range(2)),
       Axis("Junction Type: Y-Junction", 1, range(2)),
       Axis("Junction Type: Crossroad", 1, range(2)),
       Axis("Junction Type: T-Junction", 1, range(2)),
       Axis("Junction Type: Large Roundabout", 1, range(2)),
       Axis("Connection Control Type: Traffic Light", 1, range(2)),
       Axis("Number of Connections", 1, range(3, 6)),
       Axis("Number of Lanes", 1, range (1, 4)),
       Axis("Dimensions: Diameter", 1, range(10, 13)),
       Axis("Dimensions: Width", 1, range(10, 13)),
       Axis("Dimensions: Depth", 1, range(10, 13)),
       Axis("Road Type: Motorway", 1, range(0, 2)),
       Axis("Road Type: Distributor road", 1, range(2)),
       Axis("Road Type: Radial road", 1, range(2)),
       Axis("Road Type: Minor Road", 1, range(2)),
       Axis("Road Type: Test Track", 1, range(2)),
       Axis("Road Type: Slip road", 1, range(2)),
       Axis("Zones", 1, range(2)),
       Axis("Speed Limits", 1, range(5, 71, 5)),
       Axis("Environment: Rural", 1, range(2)),
       Axis("Environment: Urban", 1, range(2)),
       Axis("Road Traffic Direction: Right-Handed", 1, range(2)),
       Axis("Road Traffic Direction: Left-Handed", 1, range(2)),
       Axis("Lane Types: Traffic Lane", 1, range(2)),
       Axis("Lane Markings: Broken Line", 1, range(2)),
       Axis("Road Surface Types: Uniform", 1, range(2)),
       Axis("Road Surface Conditions: Wet", 1, range(0, 100)),
       Axis("Road Surface Conditions: Snow", 1, range (0, 100)),
       Axis("Road Surface Conditions: Icy", 1, range(0, 100)),
       Axis("Road Surface Conditions: Contaminated", 1, range(0, 100)),
       Axis("Horizontal Road Geometry: Straight", 1, range(2)),
       Axis("Vertical Road Geometry: Level Plane", 1, range(2)),
       Axis("Vertical Road Geometry: Down-Slope", 1, range(2)),
       Axis("Vertical Road Geometry: Up-Slope", 1, range(2)),
       Axis("Transverse Road Geometry: Divided", 1, range(2)),
       Axis("Transverse Road Geometry: Undivided", 1, range(2)),
       Axis("Transverse Road Geometry: Pavement", 1, range(2)),
       Axis("Roadway Edge Features: Solid barriers", 1, range(2)),
```

```
        Axis("Roadway Edge Features: Line markers", 1, range(2)),
        Axis("Roadway Edge Features: Shoulder (grass)", 1, range(2)),
        Axis("Roadway Edge Features: Shoulder (paved or gravel)", 1,
range(2)),
        Axis("Roadway Edge Features: Temporary Line Markers", 1, range(2)),
        Axis("Roadway Edge Features: Pavement", 1, range(2)),
        Axis("Road Lengths", 1, range(0, 11001)),
        Axis("Lane Widths", 1, range(34, 38)),
        Axis("Winds", 1, range(0, 245)),
        Axis("Cloudiness", 1, range(13)),
        Axis("Rainfall", 1, range(501)),
        Axis("Snowfall", 1, range(0, 5001)),
        Axis("Time of Day", 1, range(0, 24)),
        Axis("Illumination: Day", 1, range(2)),
        Axis("Illumination: Street Lighting", 1, range(2)),
        Axis("Illumination: Headlamp", 1, range(2)),
        Axis("Light Sources: Sun", 1, range(2)),
        Axis("Light Sources: Street Lighting", 1, range(2)),
        Axis("Light Sources: Headlamp", 1, range(2)),
        Axis("Elevations", 1, range(10, 91)),
        Axis("Positions: F", 1, range(2)),
        Axis("Positions: FSL", 1, range(2)),
        Axis("Positions: R", 1, range(2)),
        Axis("Positions: SR", 1, range(2)),
        Axis("Positions: SL", 1, range(2)),
        Axis("Positions FSR", 1, range(2)),
        Axis("Position: RSR", 1, range(2)),
        Axis("Positions: RSL", 1, range(2))]

total = 0
j = 0

for i in range(len(paths)):

    path = paths[i]
    os.chdir(path)

    for scenariofile in os.listdir(path):
        total = total + 1

        #Reset all axis values to defaults
        for axis in ODD:
            axis.value = axis.axisrange[0]
```

```
        with open(scenariofile) as file:

            data = json.load(file)

            #Parse data into scenario description#
            if i == 0 or i == 1 or i == 2 or i == 3 or i == 4 or i == 5:
                tagindex = "6"
            else:
                tagindex = "7"

            scen_desc = 
data["openlabel"]["tags"][tagindex]["tag_data"]["text"][0]["val"]

            ### Parse scenario description into elements/components ###
            index1 = scen_desc.find("\n\nSCENERY ELEMENTS:\n")
            index2 = scen_desc.find("\n\nDYNAMIC ELEMENTS:\n")
            index3 = scen_desc.find("\n\nENVIRONMENT ELEMENTS:\n")

            # Generate lists of all possible values for each component
            if  index1 != -1 & index2 != -1 & index3 != -1:
                j = j + 1
                scenery_elements = scen_desc[index1:index2]
                dynamic_elements = scen_desc[index2:index3]
                environment_elements = scen_desc[index3:len(scen_desc)]

                map_to_ODD(pull_component(scenery_elements,"Junction 
type", junction_type), range(0, 5))
                map_to_ODD(pull_component(scenery_elements, "which has", 
connection_control), 5)
                map_to_ODD(pull_component(scenery_elements, "connection 
control", number_of_connections), 6)
                map_to_ODD(pull_component(scenery_elements, "Number of 
lanes", number_of_lanes), 7)
                map_to_ODD(pull_component(scenery_elements, "Dimensions", 
dimensions), range(8, 11))

                scenery_elements_roads = []
                parse = 
scenery_elements[scenery_elements.find("Roads:"):len(scenery_elements)]

                while parse.find("END") != -1:
                    index1 = parse.find("START")
                    index2 = parse.find("END")
                    scenery_elements_roads.append( parse[index1:index2])
```

```
                    parse = parse[index2+2:len(parse)]

                for road in scenery_elements_roads:
                    map_to_ODD(pull_component(road, "Road type",
road_type), range(11, 17))
                    map_to_ODD(pull_component(road, "zone as", zone), 17)
                    map_to_ODD(pull_component(road, "speed limit of",
speed_limit), 18)
                    map_to_ODD(pull_component(road, "in an", environment),
range(19, 21))
                    map_to_ODD(pull_component(road, "Road traffic
direction", road_traffic_direction), range(21, 23))
                    map_to_ODD(pull_component(road, "Lane type",
lane_type), 23)
                    map_to_ODD(pull_component(road, "Lane markings",
lane_markings), 24)
                    map_to_ODD(pull_component(road, "Road surface type",
road_surface_type), 25)
                    map_to_ODD(pull_component(road, "with surface
condition", surface_condition), range(26, 30))
                    map_to_ODD(pull_component(road, "Horizontal road
geometry", horiz_road_geometry), 30)
                    map_to_ODD(pull_component(road, "Vertical road
geometry", vert_road_geometry), range(31, 34))
                    map_to_ODD(pull_component(road, "Transverse road
geometry", trans_road_geometry), range(34, 37))
                    map_to_ODD(pull_component(road, "Roadway edge
features", roadway_edge_features), range(37, 43))
                    map_to_ODD(pull_component(road, "Length", length), 43)
                    map_to_ODD(pull_component(road, "Lane width",
lane_width), 44)

                map_to_ODD(pull_component(environment_elements, "Wind",
wind), 45)
                map_to_ODD(pull_component(environment_elements,
"Cloudiness", cloudiness), 46)
                map_to_ODD(pull_component(environment_elements,
"Rainfall", rainfall), 47)
                map_to_ODD(pull_component(environment_elements,
"Snowfall", snowfall), 48)
                map_to_ODD(pull_component(environment_elements, "Time of
the day", time_of_day), 49)
                map_to_ODD(pull_component(environment_elements,
"Illumination", illumination), range(50, 53))
```

```
                map_to_ODD(pull_component(environment_elements, "with",
light_source), range(53, 56))
                map_to_ODD(pull_component(environment_elements, "as light
source", elevation), 56)
                map_to_ODD(pull_component(environment_elements, "degree
elevation", position), range(57, 65))

                finalize_scenario(scenarios)

label_list = ["Junction types: ", "Connection control types: ", "Numbers
of connections: ", "Number of lanes: ", "Dimensions: ", "Road types: ",
"Zones: ", "Speed limits: ", "Environments: ", "Numbers of lanes: ", "Road
traffic directions: ", "Lane types: ", "Lane markings: ", "Road surface
types: ", "Road surface conditions: ", "Horizontal road geometry: ",
"Vertical road geometry: ", "Transverse road geometry: ", "Roadway edge
features: ", "Road lengths: ", "Lane widths: ", "Winds: ", "Cloudiness: ",
"Rainfalls: ", "Snowfalls: ",  "Times of day: ",  "Illuminations:
",  "Light sources: ",  "Elevations: ",  "Positions: "]
list_list = [junction_type, connection_control, number_of_connections,
number_of_lanes, dimensions, road_type, zone, speed_limit, environment,
number_of_lanes, road_traffic_direction, lane_type, lane_markings,
road_surface_type, surface_condition, horiz_road_geometry,
vert_road_geometry, trans_road_geometry, roadway_edge_features, length,
lane_width, wind, cloudiness, rainfall, snowfall, time_of_day,
illumination, light_source, elevation, position]

final_scenarios = []

def filter_scenarios(ODD_chart):

    for scenario in scenarios:

        rand_val_1 = random.choice(range(0,101))/100
        rand_val_2 = random.choice(range(0,101))/100

        sum_component_relevance = 0

        for i in range(len(scenario)):

            include_component = False

            while include_component == False:
```

```
                component_relevance =
ODD_chart[i].criticality*((((list(ODD_chart[i].axisrange).index(scenario[i
]))+1)/(len(list(ODD_chart[i].axisrange)))))
                if component_relevance >= component_relevance_threshold:
                    include_component = True
                    sum_component_relevance += component_relevance
                else:
                    if (component_relevance/component_relevance_threshold)
>= rand_val_1:
                        include_component = True
                        sum_component_relevance += component_relevance
                    else:
                        scenario[i] =
random.choice(ODD_chart[i].axisrange)

        scenario_relevance = sum_component_relevance/len(ODD_chart)

        if scenario_relevance >= scenario_relevance_threshold:
            final_scenarios.append(scenario)
            print("here1")
        else:
            if (scenario_relevance/scenario_relevance_threshold) >=
rand_val_2:
                final_scenarios.append(scenario)

master_vector_list = []

for i in range(1,11):
    j_vals = []
    scenario_list_lengths = []

    for j in range(1,101):
        print("Current pair: " + str(i/10), str(j/100))
        final_scenarios = []
        component_relevance_threshold = i/10
        scenario_relevance_threshold = j/100
        j_vals.append(j/100)
        filter_scenarios(ODD)
        scenario_list_lengths.append(len(final_scenarios))

    master_vector_list.append(j_vals)

    plt.plot(j_vals, scenario_list_lengths)
    plt.xlabel("Scenario Relevance Threshold")
```

```
    plt.ylabel('Number of Preserved Scenarios')
    plt.title("Component Relevance Threshold: " + str(i/10))
    plt.show()
```

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APPENDIX C
TRLS AND THEIR DESCRIPTIONS

Table 1

TRLs and Descriptions

Development Phase	TRL	Description
Basic Research	1	Basic principles and research: AV ODD and behavioral competency portfolio and use case are established.
	2	Technology concept formulated: ADS architecture and basic design completed.
	3	Proof of concept: ADS-equipped vehicle built in simulation environment.
Applied Research	4	Components validated in laboratory environment: ADS sub-systems meet requirements and specifications.
	5	System demonstrated in laboratory environment: Simulated ADS-equipped vehicle has demonstrated competency in simulation testing and is ready for prototype build.
Development	6	Prototype demonstrated in relevant environment: Prototype ADS-equipped vehicle has demonstrated competency in closed course testing and is ready for open road testing with a fallback test driver.
	7	Prototype demonstrated in operational environment: Prototype ADS-equipped vehicle has demonstrated competency in open road testing with a fallback test driver and is ready for open road testing without a fallback test driver.
	8	Technology proven in operational environment: Prototype ADS-equipped vehicle has demonstrated competency in open road testing without a fallback test driver and is ready for commercial build and deployment.
Deployment	9	Technology refined and adopted: ADS-equipped vehicle commercially deployed.

APPENDIX D

SAFETYPOOL SCENARIO COMPONENTS AND VALUES

Table 2

SafetyPool Scenario Components and Values

Component	Value(s)
Junction types	Normal roundabout, Y-Junction, Crossroad, T-Junction, Large roundabout
Connection control types	None, Traffic light
Numbers of connections	3, 4, 5
Number of lanes	1, 2, 3
Dimensions:	Diameter: 10 to 12, Width: 10 to 12, Depth: 10 to 12
Road types	Motorway, Distributor road, Radial road, Minor road, Test track, Slip road
Zones	N/A
Speed limits	N/A, 5, 20, 30, 40, 50, 60, 70
Environments	Rural, Urban
Road traffic directions	Right-handed, Left-handed
Lane types	Traffic lane
Lane markings	Broken line
Road surface types	Uniform
Road surface conditions	Dry, Wet, Snow, Icy, Contaminated
Horizontal road geometry	Straight
Vertical road geometry	Level plane, Down-slope, Up-slope
Transverse road geometry	Divided, Undivided, Pavement
Roadway edge features	Solid barriers, Line markers, Shoulder (grass), Shoulder (paved or gravel), Temporary line markers, Pavement
Road lengths	100 to 150, 100 to 200, 110 to 160, 120 to 170, 130 to 170, 130 to 180, 140 to 160, 140 to 190, 150 to 200, 160 to 210, 170 to 220, 180 to 220, 180 to 230, 190 to 230, 190 to 240, 200 to 240, 200 to 250, 210 to 250, 210 to 260, 220 to 260, 220 to 270, 230 to 270, 230 to 280, 240 to 280, 240 to 290, 250 to 290, 250 to 300, 260 to 300, 260 to 310, 265 to 265, 270 to 310, 270 to 320, 275 to 275, 280 to 320, 280 to 330, 290 to 340, 300 to 300, 300 to 350, 300 to 400, 305 to 305, 310 to 360, 315 to 365, 330 to 380, 340 to 390, 345 to 345, 355 to 405, 380 to 430, 390 to 440, 395 to 395, 415 to 475, 420 to 420, 430 to 430, 440 to 440, 445 to 495, 1000 to 1100, 9000 to 11000, 10000 to 10250
Lane widths	3.4 to 3.7, 3.4 to 3.6
Winds	0 to 0.2, 0.3 to 1.5, 0.3 to 3.3, 1.6 to 3.3, 3.4 to 5.4, 5.5 to 7.9, 8.0 to 10.7, 10.8 to 13.8, 13.9 to 24.4, 13.9 to 17.1, 17.2 to 20.7, 20.8 to 24.4
Cloudiness	0 to 1, 1 to 2, 3 to 4, 5 to 7, 8 to 10, 8 to 12

Component	Value(s)
Rainfalls	None, Light Rain: 0 to 2.5, Moderate Rain: 2.5 to 7.6, Heavy Rain: 7.6 to 50, Heavy Rain: 50 to 100, Heavy Rain: 100 to 150
Snowfalls	None: N/A, Light Snow: 1 to 500, Heavy Snow: 0 to 0.5, Light Snow: 1 to 10, Moderate Snow: 0.5 to 1.0
Times of day	00:00 to 03:00, 03:00 to 06:00, 06:00 to 09:00, 09:00 to 12:00, 10:00 to 14:00, 12:00 to 15:00, 15:00 to 18:00, 18:00 to 21:00, 21:00 to 00:00,
Illuminations	Day, Night Lit, Night Dark
Light sources	Sun, Street Lighting, Headlam
Elevations	10 to 30, 30 to 60, 60 to 90
Positions	F, FSL, R, SR, SL, FSR, RSR, RSL