Incorporating Human Factors into Scenario Languages for Automated Driving Systems

Tudor Dodoiu*, Antonio Bruto da Costa†, Siddartha Khastgir‡, Paul Jennings§
WMG, University of Warwick
Coventry, United Kingdom
*tudor.dodoiu@warick.ac.uk, †antonio.bruto-da-costa@warwick.ac.uk,
‡s.khastgir.1@warwick.ac.uk, §paul.jennings@warwick.ac.uk

***Abstract*— Scenario-based testing for automated driving systems (ADS) is an industry norm for safety assurance. A scenario describes situations that an automated driving systems may encounter during its operation. To ensure accurate representation of real-world situations, including human behavior and system interactions, a formal language is essential. It ensures consistent testing across diverse scenarios and facilitates compatibility with simulation tools. However, while existing scenario languages excel in describing environmental and road structure aspects, they lack the same detail for road users and drivers. We have developed a methodology to identify and incorporate relevant human factors elements into scenario languages. Our methodology focuses on understanding diverse individuals and their interactions with ADS on the road, enabling their representation in scenarios. We offer practical examples to improve language representation of human elements and actions, in WMG-SDL Level-2 for logical scenarios and BSI Flex 1889 for abstract scenario descriptions. This methodology serves as a starting point for language designers to accurately represent all road users and their interactions with ADS.**

I. Introduction

In the evolving landscape of automated driving systems (ADS), Verification & Validation (V&V) frameworks and scenarios are pivotal. Scenarios, the key assets used to identify failures, are the lifeblood of the V&V lifecycle for an ADS. They are the stories we tell our systems to prepare them for the real world, the challenges they might face, and the decisions they might have to make. However, the language we use to tell these stories, to describe these scenarios, is of utmost importance. Scenario Description Languages (SDLs) provide a structured, formal way to describe these scenarios, ensuring consistency and comprehensibility.

Ulbrich et al [1] define a scenario as a 'temporal development between several scenes in a sequence of scenes. Every scenario starts with an initial scene. Action and events as well as goals & values may be specified to characterize this temporal development in a scenario. Other than a scene, a scenario spans a certain amount of time.' Various SDLs exist, each with unique features and levels of abstraction to address the needs of various stakeholders. These include the WMG two-level abstraction SDL [2], [3], Scenic [4], GeoScenario [5], and ASAM OpenX Standards (OpenScenario v1.x, OpenScenario v2.x, and OpenDrive v1.x) [6], [7]. Other specification techniques, such as graphical interfaces for scenario generation and testing, including IPG CarMaker [8] and MATLAB toolboxes [9].

No universal SDL for ADS scenarios exists currently due to different preferences in specification among various parties. Despite this, it's crucial that scenario languages are capable of completely representing all elements of scenario description. This includes richness in specifying scenery elements, dynamic elements, and environmental elements. More specifically, within the dynamic elements and scenery, there is a pressing need to represent human factors elements. At the time of writing this article, this component of scenario representation has not received the attention it demands. Human factors capture the unpredictability and complexity of human behavior, making the scenarios more realistic and robust. However, achieving this comprehensive representation is a challenging task. It's hard to know when we have achieved an accurate representation, but it's important that we keep up with the pace of development in this field. As the field of automated driving systems (ADS) continues to evolve, so too must scenario description languages. By ensuring SDLs can represent all elements of scenario description, we can make ADSs more robust, reliable, and safe.

Given the diverse range of stakeholders involved in the V&V process, a four-tiered language system has been suggested: (1) functional, (2) abstract, (3) logical, and (4) concrete [10]. The Functional level uses unstructured natural language, video, or images and is designed for easy comprehension, often supported by images. The Abstract level specifies the use of structured natural language following a formal syntax and semantic, allowing the description to be less detailed. The Logical level describes the scenario in detail while allowing for scenario parameters to be described using ranges. Lastly, the Concrete level involves scenarios where any of its parameters and variables are determined with a fixed value for any point in time. These levels of abstraction form a spectrum, allowing transitions between levels of detail. The abstraction can focus on the actor, maneuver, or road element level, allowing a tool to accept more abstract scenario descriptions with multiple dependencies and produce multiple concrete scenarios that adhere to an abstract description. This multilingual approach caters to the varying levels of expertise and detail required by different stages of the V&V pipeline. Within this framework, the language described in BSI Flex 1889 [11] is an abstract language, whereas WMG-SDL Level-2 is a language for logical scenarios.

The human element, unpredictable yet crucial, adds a new dimension to testing frameworks. Incorporating human factors allows us to test ADSs against the richness of real-world human behavior, making them more robust and safer. However, this requires a deep understanding of human behavior, a sophisticated representation language, and a robust testing framework. As we strive for a world where automated vehicles understand and anticipate human actions, every human factor incorporated brings us one step closer to this reality.

Human factors cover a wide range of topics, but in the context of scenarios for ADS, we broadly consider how people interact with the environment. This not only covers the behavior of road users, but also any elements of the road that they may interact with. This is very important to consider when the goal of scenarios within the V&V framework is to ensure the safety of all road users, both within an ADS and outside of it. There is therefore an intrinsic need to represent people accurately in these scenarios, to ensure that they are safe. This coverage can be achieved in a scenario language through adding elements that enable an accurate representation of road users. The way these elements are implemented could differ from language to language, however these elements should be consistent between languages in their abstract forms. The factors that need to be considered when implementing human factors elements into a language are the level of abstraction of the scenario, and the determined use case for the scenario. Additionally, extending the language to include a more accurate representation for road users should be considered within the context of the language itself, as many may already contain ways to describe road users, and as such the scope of the additions could differ.

The case for including human factors elements goes past ensuring an accurate representation of people on the road. The process of analyzing the language for adding human factors elements may reveal gaps in the coverage of the SDL that were previously unidentified, or otherwise useful potential new language features that are not directly human factors related. Additionally, there are a variety of tools built upon scenarios that help with execution and analysis. Including a more accurate representation of road users could lead to the tools being a viable option for use in research and beyond with reduced overhead due to already existing supporting infrastructure. It should be noted that for this, it is not enough to modify the language, but also the tools using the scenario language would need to support the additions. While the scope of the additions may be on human factors, the research questions that the additions would enable could extend to other fields as well.

A crucial component of ADS design is the definition of its Operational Design Domain (ODD), which comprises specific conditions (which include the static and dynamic attributes) within which an ADS is designed to function, and Target Operational Domain (TOD), which represents the real-world conditions that an ADS may experience in during its deployment. ISO-34503 standardizes vocabularies for ODD definition by defining a taxonomy for ODD for an ADS [12]. Importantly, this standard mentions vulnerable road users(VRUs) as an aspect of ODDs, without going into detail about them. This highlights a lack of standardization in the area of human factors. Thus, standardization efforts are needed for specifying real-world operating conditions involving people and their interactions with an ADS.

This paper aims to provide an in-depth methodology for approaching the introduction of human factors elements into scenario description languages for ADS testing. The methodology highlights some areas that language designers should consider in the context of human factors. The areas highlighted are the different road user categories in Section III, and use cases that the language is intended to be used for in Section IV. We have used this methodology to derive the elements that would be appropriate in section V.

II. Methodology Overview

A multifaceted approach is required to analyze the human factors elements to be included in a scenario language. This is especially important considering the complex nature of people and their behavior as road users. As such, the two main approaches followed are:

- Systematically identifying the categories of road users, analyzing how they differ from a scenario perspective, and then identifying what elements are needed to represent all categories of road users. There are no specific standards currently that cover this area specifically, so we propose combining road user breakdowns from multiple sources. We have chosen to combine a research-based taxonomy [13] and a generic taxonomy standard that covers some relevant elements [14], with the UK highway code [15] used to identify any gaps.
- Highlighting use cases that may be relevant, and which may require additional language elements for scenarios to be able to represent them. They also provide a method to verify that the language additions are fit-for-purpose when implemented. These will therefore depend on the scope of the language and the decided scope of the extension. In the use-case section we provide some examples along with why they are relevant as design guidance.

After identifying the elements that may be relevant to the SDL, the language extension can be planned to incorporate the elements, ensuring that the language is viable for the identified use cases. When introducing new grammar into the language is to ensure that it is consistent with the rest of the language, and not over-complex. Additionally, with SDLs already in use, backwards compatibility should be considered. This is more nuanced than making all additions optional, as introduced language elements may involve making assumptions that had not previously been present.

Considering all the previous points, the identified elements can be abstracted and combined with each other or already existing elements in the language. This is an important step to ensure that the language does not get unnecessarily bloated or too complicated, while providing the desired level of complexity. When this is done, the new version of the

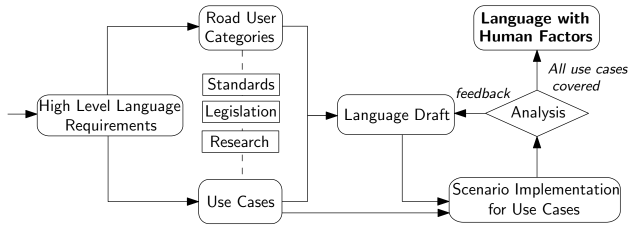

Fig. 1. Methodology for adding Human Factors into a SDL

language should be used to write scenarios that cover the use-cases. This may reveal that additional language constructs are needed, or those that were introduced are hard to use, impractical or otherwise inadequate. This should prompt an iterative process of making changes and verifying them until the language is satisfactory to the designer and relevant stakeholders. Figure 1 showcases this proposed process.

III. Human Factors across Road User Categories

A. All Road Users

There are a wide range of road users, so before analyzing the different categories of road users individually, we should identify elements that can be relevant to all road users. By road users here, we refer to drivers, passengers, remote users, pedestrians, any other person on the road and animals. The two categories of elements identified are communication and internal elements that can affect the behavior of the road user.

1) Communication: Communication is a vital part of using roads, and every traffic participant engages with it. There is therefore a need to represent it in scenarios. Implementing communication in scenarios is a complex issue as there are a variety of ways different road users communicate. While there are differences between road users in the methods of communication, we consider a unified approach that covers all road users would be more effective than having a separate approach for protected and vulnerable road users. This therefore leads to a need to identify what are the important aspects of a message, in the scenario context. These aspects can then be abstracted to create the necessary language elements to accurately represent communication.

We propose modeling communication as a series of discrete messages. This approach may not be ideal for all applications; however, it provides relevant insights, nonetheless. In this context, we can further break down a message into its relevant aspects:

- How is the message transmitted? Most messages are going to be transmitted visually, but they may also be audio or tactile messages.
- What is the content of the message? The content of the message will depend on the modality of the message, and could be a specific arm movement, a noise, or the press of a button. The other road user may interpret the meaning of the message, so this does not refer to what the intent of the road user conveying the message, but the specific action they are taking to convey it.
- Who is the message aimed at? This may not be relevant in for all communication but there are messages that can be directed at a specific road user or place.
- Does the message have a specific meaning? Some messages have specific legal meaning attached to them. There are scenarios where this meaning would be relevant, whereas the actual content of the message wouldn't strictly be. This is especially relevant for officers directing traffic. Laws may differ from country to country, how the message is conveyed might be different, but it is important for the meaning to remain the same when localizing a scenario.

2) Human Behaviour States: The other identified category of relevant elements to scenarios are states that can affect the user's behavior. By state here we refer to any physical or mental condition of the road user. When referred to in a scenario these states can be either descriptive or prescriptive, both depending on the language and the simulation tool used. Prescriptive elements are those that have a direct effect on the road user during simulation, such as the speed of the vehicle. A specific application of this would be using a driver-simulation model where the emotional state of a driver would use a different behavioural model than from a calm driver. A descriptive state on the other hand would not have a direct impact on the simulation but add additional information to the scenario file itself. For example, the locale of a scenario may inform where the scenario takes place, however this does not affect the simulation without specifying the specific infrastructure specific to the locale. One application of a descriptive state would be mutating a scenario from one to another, by mutating a particular actor from being calm to being angry. When thinking about adding elements into a language, it is important to understand what role the additions would have.

Another way to approach the different states would be from the perspective of whether they are temporary or not. Thus, we can look at these as either long-term conditions or temporary ones. Long-term conditions are aspects of a road user that are not expected to change over the duration of the scenario. This includes for example a road user's disability, which will be discussed under especially vulnerable road users. Temporary conditions are short-term states of a person that can either change during the scenario, or within a short time span. This includes but is not limited to road users being surprised, blinded by a light, inebriated, or distracted.

One instance of temporary conditions that is particularly relevant is a road user's emotional state. This has been proven to be an important factor on how drivers and other road users behave [16], [17],so it follow that it could be important to have a means of representing this in a scenario. Additionally, driver behavior models that include the emotional state of the driver have gained traction and there is research being done in the field. These research efforts could be supported through being able to assign an emotional state to road users in scenarios, thus enabling an easier integration with existing simulation tools.

Before moving on to analyzing the different types of road users, it is important to consider that how road users interact on the road may not only be limited to the dynamic aspect of a scenario but is also an important aspect of the static aspect of it as well. Roads are designed have certain features to aid a specific category of road users. This can be as simple as a pedestrian crossing, but may also be more complex, modifying the road geometry, like a protected bicycle lane.

To systematically approach the different categories of relevant road users, two different classifications were used. A taxonomy of vulnerable road users [13] was used to identify the different kinds of road users. While this covers a wide variety of relevant users, it is less detailed around the users of ADS. SAE J3016 [14] provides a taxonomy of users specific to these systems, that can be overlaid over the initial taxonomy. This gives a language designer an in-depth overview of the different road users that need consideration. The main categories are highlighted in the next paragraphs.

B. Vulnerable Road Users

"Vulnerable road users" refers to all road users that are physically present and not protected within a vehicle. These road users have a higher risk of injury and death compared to protected road users [18]. For this reason, it is important to ensure that an ADS handles situations with vulnerable road users appropriately and in a safe manner. Scenarios containing VRUs therefore need to have the capacity to accurately describe them. The main categories of VRUs are:

- **Pedestrians:** They are the most common VRU type and have some actions specific to them, along with spaces dedicated to them on most roads. Regarding static elements, the necessary elements are a way to represent pavements and pedestrian crossings. Additional features such as islands between certain lanes to help pedestrians cross should also be considered. Finally, one communication aspect for pedestrians that is missing in most scenario languages is representing a pedestrian's intent to cross the road. When a pedestrian looks both ways before crossing the road, it implicitly signals to other road users that they intend to cross the road. This form of communication is one of the most common on the road and should be considered explicitly.
- **Cyclists:** They can have dedicated infrastructure, mainly through protected or unprotected cycle lanes and other associated elements such as cycle traffic lights. Additionally, these road users can communicate intent through hand signals, which are shared with motorcyclists.
- **Motorcyclists:** They are one of the few categories of VRUs using motorized vehicles which could bring challenges to an ADS through speed. From a scenario language perspective, they do not have any associated infrastructure, and in the only identified action specific to motorcyclists is filtering, in addition to the communication elements shared with cyclists.
- **Other micromobility users:** This is a category of road users that includes more traditional means of transportation as well as relatively new ones, developing in many parts of the world. With the legal status of some of the micromobility devices still being in review [19], they should be considered broadly when designing a language. There are no additional specific elements that we consider should be included, however with the micromobility industry developing, this could change.
- **Horse riders (or similar):** There are no specific language elements for this category of road users past their existence (however there are for the animals themselves, which are described in a later section).

C. Especially Vulnerable Road Users

There are some vulnerable road users that have characteristics that may put them at a greater risk compared to others. These are Especially Vulnerable Road Users (EVRU), and additional scenarios may be needed to ensure that ADS ensure their safety, but more research in the area is necessary. Some of characteristics that can affect this identified in the VRU taxonomy [13] are:

- **Age:** Young and old road users may be more at risk compared to an adult road user [15]. Both are important to consider separately, especially for children on the road, as a small size could lead to difficulties in being perceived by an ADS. For old road users however, the increase in risk is linked to health conditions, which are covered by the next category.
- **Disabilities and health conditions:** Road users with disabilities or other health conditions that affect them may be put at additional risk [20]. More research is needed on the topic of accessibility in road situations with ADS [21]. Providing the tools in scenarios to include these types of users could provide better insights and lead to a better experience on the road for these types of users, as well to all road users. To accurately represent this, we propose analyzing the different relevant aspects that may be affected:
- **Mobility:** Road users with different mobility needs need to be considered both from the perspective of mobility aids and the change in behavior. It is important to be able to represent these mobility aids as they may completely change how the road user would move around, such as wheelchairs.
- **Visual:** As this is one of the most important senses, these road users are especially vulnerable. It is important to be able to represent any distinguishing features, such as a white cane. These road users may respond differently or be unresponsive to visual stimuli, so it is important to be able to represent them in a scenario.
- **Auditory:** This is another way in which users may respond differently or be unresponsive to auditory stimuli. It is important to recognize that some users may be unresponsive, while others hypersensitive.
- **Cognitive:** This is one of the more complex ways in which a road user's behavior might be affected, and the range of behaviors varies with the specific conditions that may affect someone.

- **Other:** There may be other ways in which people are affected on the road not included in these categories, therefore an option for this could cover any user not covered by any of the previous categories.

It is also important to consider that while these characteristics are not mutually exclusive, and a user may be affected in multiple compounding ways. Additionally, the qualities presented in the context of EVRUs may be relevant not only in the context of VRU. This creates a potential need for more research in areas such as the safety of drivers with disabilities in the context of ADS. Additionally, it is also important to consider that these characteristics also extend to animals and may not be that uncommon, as for example juvenile animals may behave differently from adult ones.

D. ADS users

The first category of road users that needs to be considered consists of the ADS road users. Based on SAE J3016 [14], the following considerations need to be made:

- For in-vehicle users, including in-vehicle drivers, fallback-ready users and passengers, they can physically interact with the vehicle. The language designers need to consider what aspects of these interactions should be represented, depending on the abstraction level of the language.
- For remote users, including remote driver, remote fallback-ready users, driverless operation dispatcher and remote assistant, they can interact with the system virtually. This adds complexity to the interaction through the necessity of V2X integration [22] to account for aspects like communication delay and method.
- Drivers, both in-vehicle and remote, have a direct influence on the DDT, and therefore require additional consideration. The main issue is deciding what actions a driver can take that are relevant to the operation of the ADS, and how to represent them. Additionally, drivers may take direct or indirect actions to disengage the ADS.
- Change between states, specifically between driver, fallback-ready user and passenger. For these situations, we are interested in both driver-initiated changes as well as system-initiated ones. If the scenario contains a simulated fallback-ready user, there may be also a need to define actions (or lack of actions) that the user may take. This could cover both accepting or rejecting the request, as well as driver specific actions afterwards. This change of state could also be considered for a partial DDT, where the role of the user does not change, but their involvement in the DDT does.

Moving on from the users themselves to the infrastructure that may be specific to ADSs, there may need to be additional V2I elements that should be considered, especially if remote users are expected to be part of the scenarios. Depending on the TOD that the scenarios are required to represent, these may be as simple as being able to describe satellite connectivity in the are to more complex ones like connected traffic lights. These ensure that the remote users are given a layer of detail past not being physically present in the vehicle.

E. Other Road Users

To verify the analysis, the UK Highway code [15] was analyzed to ensure that all road users have been covered through one of the two taxonomies above. One additional category of road users was identified that has not been previously covered, relating to emergency vehicles and certain officers. This category of road users is important to consider from a scenario perspective as these road users bring additional legal requirements to road situations. These legal requirements may differ from country to country, and this should be considered when designing a language addition. It is also important to recognize that this category of road users may overlap with other categories of road users. For example, either a pedestrian or a driver could be a traffic officer.

One important aspect when designing a scenario language is that road users may not follow the law, and a scenario should be able to capture that. For example, in a scenario pedestrians should be able to cross the road at any point where it makes sense, even when the scenario is written for somewhere where jaywalking is not legal. Therefore, when analyzing legal documents, it is important to not only think about what is within the boundaries of the law, but also what is outside of them.

Finally, animals were also identified as a category of road users. All the characteristics of a generic road user may apply to them, but additional consideration is required. Animal behavior is different from a person, and differs from species to species, and therefore may be very complex. To simplify this, we propose that the most relevant aspects of an animal in a scenario are its size and whether it can fly. While each individual animal may have complex characteristics, most could be inherited from these two qualities. Another layer of complexity comes from the fact that some animals can be ridden and may appear on the road.

IV. Analysis of Use Cases

The other approach to identify the language elements needed is to identify use cases that a scenario language should fulfill. This ensures that the language elements previously identified fulfill their intended role. Additionally, each use case serves as a practical way to verify that the language can be used as intended. When designing a language addition, the use cases will depend on the requirements of the designer, so may differ from the ones presented below. We have split the use cases into two main categories, safety testing and human factors experiments. For each category, there are a plethora of use cases which could be considered, but we have chosen to show the most relevant ones for each category. Additionally, for each use-case, a plain text functional scenario will be provided. These functional scenarios will then be used after implementing the language elements to showcase how the new language elements achieve the use case.

A. Safety Testing

Scenarios' main function is to ensure that ADSs are safe. It is therefore important for the scenarios to test an ADS's response to the different road users.

1) ALKS regulation: It is important for scenarios to be able to fulfill regulators needs. Uniform provisions concerning the approval of vehicles with regard to Automated Lane Keeping Systems(ALKS) [23] provides test specifications for ALKS. Some of the highlights regarding human factors are:

- Driver state in vehicle, including status of seat belt
- Driver actions that may lead to disengagement of ADS such as steering, braking or acceleration.
- Driver attentiveness
- Driver unresponsive
- Emergency vehicles and personnel directing traffic.

Using some of the elements above, we wrote the following functional scenario:

"The ego is on the outer lane of a motorway with ALKS engaged and a lead vehicle in front of the ego. An ambulance is approaching from behind, with the siren on. The vehicle in front of the ego breaks suddenly. As a result, the driver of the Ego breaks and attempts to swerve into the emergency lane."

2) Modelling accidents: One of the ways scenarios are intended to be used is to replicate historical accidents. This is important in ensuring safety as the scenario leading up to a road incident is a safety concern. When a single vehicle is involved, one of the significant types of scenarios are crashes with animals [24]. The document provides a functional scenario description for one of these situations:

"Vehicle is going straight in a rural area at night, under clear weather conditions, with a posted speed limit of 55 mph or more; and encounters an animal at a non-junction location." [24]

3) Inclusive safety testing: Certain road users may be more vulnerable than each other, so it is important to ensure that ADS are safe around these users. As ADS technology is linked with electric vehicles, people with visual impairments who rely on their hearing are at risk [25]. One aspect highlighted is that the distance for an electric vehicle at low speed to be detected by this category of EVRU is only a few meters away. We can create a logical scenario centered around such an event:

"The ego is on a minor road, approaching an unsignalized crossroad at 10 km/h. There is a pedestrian with a white cane and a visual impairment at the corner of the street waiting to cross. When the vehicle is 10 m away, the pedestrian starts crossing the road. If the vehicle gets within 4 m of the pedestrian, the pedestrian will be surprised and stop in place."

B. Human Factors Experiments

We want to introduce scenarios for human factors experiments. It is therefore important for the scenarios to test a road user's response to different road situations, especially when an ADS is involved. In these scenarios, one of the road users will be an unscripted agent, with up to one unscripted vehicle. To ensure that the scenarios are fit for purpose, we have extracted three scenarios based on human factors experiments, to ensure that the scenarios are relevant to research:

1) Risk perception: A very important area of research for ADSs is the perceived risk of the users. One such instance is investigating the acceptable distance for braking for an ADS at a pedestrian crossing [26]. Part of this study, multiple similar scenarios were used to empirically determine the acceptable braking times. One of the scenarios is described below:

"There is a vehicle on a one way-road, approaching an intersection with a cycle lane, at 30 km/h. Inside of the vehicle there is a fallback ready user. When the vehicle gets close to the intersection, a cyclist will cross through the intersection. When the user presses a button, the car will start braking."

2) Changes in performance of the DDT: Another area of interest are take overs and hand overs between the ADS and the driver of the vehicle. One question of the field is how the cognitive load of a person affects the quality of a take over of the DDT [27]. The paper uses multiple scenarios as part of the experiment, and we have extracted an interesting segment from one of those:

"There is a vehicle on a motorway, approaching a lane that is blocked at 80 km/h. There is a fallback-ready user in the vehicle. When the vehicle is within 200 m of the blocked lane, the vehicle issues a take over request to the user."

3) Human Machine Interfaces: As previously stated, communication is an important aspect of using the road. Another area of interest for human factors are technologies to improve the communication between vehicles and road users. One such technology is Human Machine Interfaces (HMIs), which are still in the early stages of development and standardization. The usage of scenarios in these differs from other use-cases as the road user being tested is no longer within the ADS, but outside of it. As such this use case may be of particular interest. One study in the area used a virtual reality simulation to examine a pedestrian's response to the HMI at a pedestrian crossing [28]. We have derived a functional scenario that is based on the study:

"There is a pedestrian Ego waiting at a pedestrian crossing. A vehicle equipped with an HMI is approaching the crossing and stops before the pedestrian crossing. The vehicle displays a message for the pedestrian on its HMI while braking."

V. Scenario Language Implementation

Using the methodology presented, we implemented the appropriate language elements into both WMG-SDL Level 2 and BSI Flex 1889 to show how these elements fit into multiple levels of scenario abstraction. In this section, we will refer to WMG-SDL Level 2 as level 2 or as the logical language, and BSI Flex 1889 as level 1 or abstract language. It is important to mention that the changes have been implemented in level 2, but for any changes to be made to level 1, they would need to go through the standardization process, to be available in the next version. As such, the examples provided reflect an example of how the new features could be implemented. Both scenario languages follow a similar structure, so the language extensions can be shown in parallel. We have provided explanations for why we have introduced the elements as we have. For each change, a snippet for both levels of scenarios has been provided where applicable.

A. Header Elements

We identified that some additional information about a scenario could be useful. It is evident that different countries have different road conditions, rules of the road and even preferred methods of communication, which are reflected in scenarios. As such a locale element can be introduced into a scenario, to both indicate what assumptions might have been made about the environment, and to also help with mutating a scenario library from a locale into another. This element is relevant to both level 1 and level 2, and already partly present in the former. Another piece of information that could be relevant is how the scenarios were generated, as there are many sources that can be used to author scenarios [29]. This is relevant to level 2 only, as this is aimed at distinguishing whether a scenario was hand-authored or generated through a script. Finally, there may be other meta information relevant to a scenario that is not part of the scenario, such as whether the scenario was intended to be run on a particular test bed, where the road geometry is relatively fixed. SDL Description 1 showcases these new elements.

```
Locale : ‘UK‘
Source : ‘Rules of the road‘
Other : ‘State – Final‘
```

SDL Description 1. New Header Elements

B. Scenery Elements

Through the analysis of the different road users and standards (ISO 34503) we identified that in level 2, the ability to declare different lane types was missing, especially regarding VRUs. Additionally, declaring lane types per lane needed to be introduced to enable the additional lane types to be used. This should enable more complex scenario descriptions, in a simple way, as well as ensuring compliance with existing standards. A road with a cycle lane on the right side of a road using these new elements is shown in Scenario Description 2.

```
Roads: R1: START
...
with number of lanes [3] as [R1.L–1, R1.L1, R1.L2]
...
Lane types [ L–1, L1 as traffic lane, L2 as bus lane] ...
```

SDL Description 2. Description of a road with a cycle lane

While considering the use case for cyclists on the road, we found that an additional road feature that could still not be represented is an advanced stop line, because there was no way to represent stop lines. This is not an unusual road feature however is rarely mentioned in standards. Adding the ability to represent these regulatory lines adds the benefit of being able to declare both stop and yield lines at specific distances from the start/end of the road to give scenario designers more options when authoring scenarios, as shown in Scenario Description 3. While these can be implemented in both languages, in level 1 we consider that describing an advanced line may be unnecessarily complex, but being able to describe that there is a stop or yield line could be a good addition, as shown in Scenario Description 4.

```
Roads: R1: START
...
Lane markings [Solid line] AND [Stop line] at [2 to 2] from [END] ...
```

SDL Description 3. Advanced stop line

```
’Road 1 is a 100 m straight minor road. There is 1 lane on Road 1,
lane 1. Lane 1 has a stop line at its end.’
```

SDL Description 4. Stop Line

Another feature that has been considered was better descriptions for pedestrian crossings to be able to describe more complex scenarios involving road crossings. This was not added and delegated to a further extension as we determined that for the feature to be fit for purpose, the ability to define islands would be necessary. The features intended to be added to pedestrian crossings are being able to define the type of crossing and different types of speed bumps.

C. Dynamic Elements

When introducing new language elements to logical scenario languages, we need to ensure that they can be used effectively, and that they can be simulated. For an abstract scenario, this is not the case as it is not intended to be used in simulation, but to provide a human-readable scenario. As such, the focus is not on the usability of the new elements but on their ability to easily convey the meaning of the scenario to a reader. In level 2, the dynamics aspect of a scenario is split into multiple sections, Initialization and Synchronized Serial Maneuver Sequence (SSMS) and End conditions. Level 1 has a similar structure. Starting with actor initialization, the first major change is how actors can be initialized. Previously, all actors needed to be initialized the same way, however, with introducing actor type specific elements, we decided to split initialization into general and actor specific initialization. General initialization covers all the previous elements of initialization such as the position of the agent. All agents can be split into three categories of actors:

- Human – covering all people on the road including pedestrians, drivers, passengers, cyclists and wheelchair users

- Vehicle – covering all vehicles, including cars, busses, cycles, motorcycles and trucks.
- Animal

Human specific initialization is novel relative to scenarios and covers a few of the elements previously discussed. The new elements here are:

- The age of a road users, which is defined as an age group, and optionally can be given a value as well for specificity.
- The impairment status of the individual, with the categories of impairment described in the previous section, and an option to further describe the impairment. This should enable much better descriptions for people with disabilities. Additionally, a mobility aid can be specified to provide specificity. This can be also used when defining a wheelchair user to give a more detailed description of the type of wheelchair they are using.
- Temporary states, which are states that may affect the user, are an unordered list of states that may affect the user. These may change during the scenario.
- Emotional states, which are a specific type of temporary states that we consider should be treated separately. This is because as opposed to the multiple temporary states, in a scenario, only the strongest emotion of the user would be relevant. As the strength of an emotion is relevant, we cannot add multiple emotions to an unordered list of temporary states. The emotional states can be chosen from a list of relevant states that affect driving [16], or a custom one, provided as a string.
- Responsiveness and response time, representing whether the person is going to respond to a stimulus, and optionally the time in milliseconds for the user to respond. This can be used in scenarios to define the driver's behavior to a handover, or to introduce specific timings in the maneuver phase.
- Officer status, which denotes whether a user has powers over traffic which a normal road user wouldn't. This covers both officers in vehicles, but also those outside. This addition should enable writing scenarios in which an intersection is directed by a traffic officer.

```
Passenger [Officer1] in [Vehicle1] with Officer status,
    Emotional state [Surprise]
Pedestrian [P1] in [R1.PL1] ...
    Age group [Old] with [Mobility, Hearing]
    Impairment ['Reduced mobility and total hearing loss']
    Mobility aid ['Walking cane']
```

SDL Description 5. Description of a traffic officer as a passenger and a pedestrian with hearing and mobility impairments

Level 1 could be extended with an abstracted version of this, with most of the elements related to a state being included. Additionally, the language does not support all ISO road users, which it could benefit from. "There is 1 wheelchair user, P1. P1 has a visual impairment and is calm. " For vehicles, the following language elements have been identified for use in logical scenarios:

- Vehicle lights are an important aspect of communicating on the road, as such it is important to define whether any lights are not functioning as intended. To achieve this, we have given the ability so that a user can define the status of all working lights, including break lights, signal lights, headlights, and siren lights.
- Driver and passenger list to be able to place passengers and drivers in the intended vehicle. The driver can be defined within the vehicle initialization and can be defined as a remote driver. Additionally, the involvement of the driver in the DDT can be defined here. An assumption is made that a fallback-ready user is defined as a driver even though they may not take the role of a driver during the scenario. For passengers, they can also be defined here following a human initialization if needed.
- DDT capability of the vehicle in case the scenario is meant for vehicles with certain DDT capabilities.

```
Truck [T1] in [R1.L1] ...
  Light status [non–functional break lights]
Vehicle [EGO] in [R1.L1] ...
  with DDT capability [Full] Containing [P1]
Remote Driver [D1] DDT involvement [Fallback–ready]
  Temporary state [Distracted] Responsiveness [Not Responsive]
```

SDL Description 6. Definition for a truck, and a vehicle containing passenger and with a remote driver who is not responsive

This level of detail may be unnecessary for level 1, but this may depend on the scope the regulators would want to cover some of these elements. For animals, we have implemented the different states (temporary, emotional, and permanent) of the animals in level 2. In addition to these, the other two elements that we considered would be relevant is the animal type, given as the size of the animal and weather the animal can fly, with an optional to specify the animal species. Additionally, for horseback riders, they can be initialized here to inherit the position of the horse. Level 1 may not need the latter feature, but the former would have use-cases.

```
Animal [Cat1] in [R1.L1] ...
Type ['Cat': small terrestrial]
Age [Young] Temporary state ['Dazed', 'Confused']
```

SDL Description 7. Definition of an animal

With the additions in the initialization, we have also needed to make changes to the temporal elements of the scenario, both to extend the capabilities already there and to ensure new features added in initialization work as intended.

Communication is an important aspect on the road and needs to be represented appropriately. One of the most important ways in which drivers communicate is through the directional blinkers, however, many do not signal their intentions, so the assumptions that the maneuvers an agent takes are always accompanied by the appropriate blinker cannot be made. As such, we have made it so a user can explicitly specify what a user is signaling every maneuver.

We also introduced a general approach to communication for road users, through messages. The messages can be described for any road user in parallel with maneuvers or in a separate sequence. These messages are defined based on their modality, content, optionally meaning and intended receiver or direction. This is an addition that can benefit both levels of abstraction, however, the modality and meaning of the message would not be relevant for abstract scenarios as they do not need to be translated. A sample for a traffic officer can be seen in Scenario Description 8 for Level 2 and a simpler approach in Scenario Description 9 for Level 1. These element should enable users to write more dynamic and realistic scenarios.

```
[O1]: Comms Phase 1:
Send: [Audio,Visual] message [‘Palm raised and blowing whistle‘]
meaning [Stop] towards [Ego]
```

SDL Description 8. Defining a common interaction with a traffic officer

```
‘Officer O1 has palm raised and is blowing a whistle towards [Ego].‘
```

SDL Description 9. Defining a common interaction with a traffic officer

To enable using the different temporary emotional state, we have added the ability to describe a state change as part of a maneuver. Without the ability to change these states in the scenarios, they wouldn't be temporary, and as such would not function as intended. Additionally, these state changes may occur because of other road agents, and as such, we have added the ability to change an agent's state within another's action. Scenario Description 10 contains such an example for level 2, whereas for Level 1 scenarios it would be more appropriate to use the messaging framework, as seen previously in Scenario Description 9. Previously,

```
[V1]: Phase 1: [LaneChangeLeft_Towards] [–,20 to 25, 1 to 2]
        [Ego: 5 to 10, F] WHILE [not signalling]
[EgoDriver]: Emotional state [Surprise]
```

SDL Description 10. Vehicle executing a lane change without signalling

level 2 could be used to describe maneuvers specific to vehicles and pedestrians, but road users within vehicles were not considered. To effectively represent drivers and passengers, they need to be given actions specific to them (although other road users may use them as well): pressing (a button), pressing a pedal, switching (gear, indicator position), steering, request (DDT changes), open/close, fasten/unfasten (seatbelt), wait, continue. The simple actions are straightforward to implement in Level 2, as shown in Scenario Description 11. There is an argument for implementing these grammar elements in Level 1 as well if the use cases extend to it, however at the moment of writing it was considered unnecessary.

Not all actions are this simple, there are some that require additional details to be simulable, however, for including

```
[Passenger1]: Phase 1: [Unfasten:‘Seatbelt’]
              Phase 2: [Open:‘Back Left Door’]
```

SDL Description 11. Passanger unfastening seatbelt and opening a door

them in abstract scenarios they will not need the same level of detail. Switching requires an additional field to define what position the switch is changed to. This applies for indicators, windshield wipers and gears. For requesting a change in DDT, agnostic of the ADS, the change needs to be defined based on how much of the DDT the user is handing over or taking over. For steering and pressing a pedal, these actions can be quite complex, so multiple ways to accomplish them can be defined. One way is by defining the end goal, as in steering until the car is at a certain angle, and the other by describing the action itself, such as pressing down the break with a certain force for an amount of time. One such example of a human-driver manually steering until the vehicle reaches an angle of 20 degrees with its initial position can be seen in Scenario Description 12.

```
[Driver1]: Phase 1: [Steer] [Left] until Vehicle angle is [20]
```

SDL Description 12. Driver steering until an angle condition is met

New ways to define triggers have been added to enable traffic agents to change their behavior based on communication or the state of a certain agent. This should enable user to use temporary states and emotional states prescriptive and define different user behaviors based on them. Additionally, communication conditions, both V2X and human communication, are needed to ensure that road agents can react to the messages being sent. The conditions can use the same structure for both, even though the messages have different qualities depending on the message type. Scenario Description 13 shows how these features can be useful to create more reactive scenarios in Level 2. We have considered this in Level 1 but the addition was outside of the scope of the language at the moment of writing.

```
WHEN: [Driver1] is [Distracted]
DO:
[V1]: Phase 1: [LaneChangeLeft_Towards] [–,20 to 25, 1 to 2]
               [Ego: 5 to 10, F] WHILE [not signalling]
```

SDL Description 13. Maneuvre triggered on the state of a human driver

Using the methodology we have proposed, we have implemented all 6 use case scenarios in SDL Level 2 using the grammar described in this Section IV, and have been made publicly available: `https://files.warwick.ac.uk/tudordodoiu/files/HumanFactorsSDL.zip`.

VI. Discussion and Conclusion

This study's methodology offers a promising foundation for better human inclusion in ADS scenarios. It's up to SDL developers and the industry to integrate these elements into their language frameworks. The elements are assumed to be added to an existing language structure, providing a basis for new SDLs.

The examples used in the cases studies, although simple, showcase the new language elements, which are designed to be usable in scenarios having more complex dynamics. Nonetheless, further development in this area must ensure the added elements don't over-complicate scenarios.

To fully utilize the additions, simulation tools need to adopt these elements. This is expected as it's the first step towards simulation representation. Despite being time-consuming, including the elements beforehand allows scenario drafting prior to simulation support, aiding simulation tool developers.

A key challenge is the lack of standardization. A unified approach could benefit all stakeholders by determining what aspects of people on the road and in an ADS need to be represented in scenarios and ensuring consistent vocabulary. This would enhance communication and collaboration.

The idea of extending scenarios to cover additional uses holds potential. Leveraging existing infrastructure can reduce effort, cut costs, and increase efficiency, enhancing the scenario-based V&V framework's utility and effectiveness.

In conclusion, striving for a comprehensive and standardized representation of human factors in scenario languages is challenging but worthwhile. Continued innovation and collaboration can make ADS more robust, reliable, and safe.

VII. Acknowledgement

The work presented in this paper has been supported by UKRI Future Leaders Fellowship (Grant MR/S035176/1), Department of Transport, UK (Contract No. TETI0042), and Transport Canada (Contract No. T8080-220112). The authors would like to thank the WMG center of HVM Catapult, and WMG, University of Warwick, UK for providing the necessary infrastructure for conducting this study. No new data were created in this study

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