Accidents in ADScene: a specific survey on AD L2+ functions

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Abstract: The development of Automated Driving Systems requires validations based most often on physical tests, driving tests, but also simulation. One of the advantages of simulation is that it can easily vary the context and thus quickly test millions of scenarios. The objective of ADScene is to capitalize ~~on~~ all the scenarios needed for validation, with a same and common structure. Since its creation, scenarios from road accidents have been taken into account. Indeed, the ADScene library now totals more than 500 accident scenarios collected mainly in France. For the past 2 years, an accident survey has been put in place regarding accidents involving a SAE level 2+ vehicle. Different sources are used to collect these accidents: reports on automated vehicle investigations (NTSB, NHTSA, etc.), publications in the media, social networks (Youtube, etc.). For each listed accident, an initial check is carried out to identify whether the data content is sufficient to be able to characterize the scenario in ADScene. Among these indispensable data we have the location for the data related to the infrastructure, the activation of automated features (type of vehicle and automated feature available), the course of the accident.
Once the content of the accident has been validated, the scenario enters a codification process in 4 steps: 1) identification of the actors, 2) identification of the main sequences of the accident, 3) identification of the main characteristics associated with each sequence and each actor, including the positioning of the actor on the infrastructure, its direction, its associated speed, etc. 4) fill-in the scenario into ADScene.
Each scenario entered is then reviewed by a group in charge of validating its content in order to guarantee homogeneity in the rules for codifying information and a requirement in its content.
ADScene currently contains 88 accident scenarios involving a SAE level 2+ vehicle.

Keywords: Scenario database, L2+ road accidents, AD/ADS validation

1. Introduction

The design, the validation, the safety and the type approval of Assisted and Automated Driving Systems are based on the absence of unreasonable risks during Millions or Billions of hours of operation.
Some companies are driving fleets of vehicles equipped with such systems during hundreds of thousands, or billions of hours to prove their Safety. These hours of driving test make it possible to validate the behavior of the system under test both in nominal conditions (situations where the system is operational and must operate correctly) and in situations involving more or less common disturbances (traffic, meteorological, environmental conditions, etc.). In these hours of driving in real life only few timeslots are relevant. Maybe you have heard of edge cases or golden cases that cause issues for Automated Driving Systems like sun glare, particular adverse weather conditions, firetrucks, interaction with first responders [1] … During the final validation phases, system faults become increasingly rare and the number of km to be covered to find new ones quickly becomes exponential.
Safety-critical/relevant events are of course searched for here. Fortunately for test drivers, but unfortunately for the validation process, all these events have characteristics that make them extremely rare in normal driving situations.
The best way for a robust and safe by design system is to capitalize and take into account since the very beginning of the design all traffic scenarios gathering all relevant information concerning the objects, actors, road infrastructure, and environmental conditions.
Among all types of scenarios, accidents were the first to be capitalized in the frame of research projects to establish a ‘’common good’’.
This is Renault's avant-garde approach since 2013, which has now entered the state of the art of:

- systems engineering methods: we speak of “Use Cases”, or “Nominal Scenarios”,
- operational safety methods: we speak of capitalization of accidents and of functional limitation scenarios for ISO 21448 SOTIF standards.
- verification and validation methods: we speak of “test scenarios” or “test cases”.

Nowadays, while physical testing is still a must in the validation process, it is becoming more and more common to use virtual tests. Thanks to simulation, they make it easy to confront the system with several situations, for each of which to propose a multitude of realistic scenarios based on the variations of each preponderant dimension, but also to subject the vehicle to very dangerous or even known crash configurations without endangering its driver. All of these tests and requests constitute a state of the art to date which must therefore be capitalized. In case of a dispute, this state of the art could be used as evidence. It is therefore important to capitalize on these scenarios in a database in a sustainable way. The main difficulty is to find a common structure that can bring together scenarios as diverse as regulations, consumer tests, functional requirements, safety, near-accidents, crashes or those observed during driving.

2. ADScene database

2.1 Objectives

Many initiatives were set up to propose such scenarios catalogue such as Sakura in Japan [9], Pegasus in Germany [10], Safety Pool in UK [8], StreetWise [18], AVL Scenius [17] or ADScene [11,12].

ADScene is the tool designed during research projects and now industrialized with Renault for the description, the capitalization and the dissemination of scenarios, under a harmonized formalism that allows the improvement of the safety of our automated driving systems at a sustainable cost. Since the beginning of the ''scenario-based safety approach'' in 2019, the French Ministry of Transport has been supportive providing fundings to research projects and providing methodological documents written on the basis of consensus [1,2,3].
In ADScene, scenarios are stored under containers which can be either shared (e.g. scenarios from 1Mkm driving in Europe, injured accidents in France, Regulatory or NCAP scenarios financed by PFA …). Or private to store your own scenarios or edge cases from yours real world driving tests.

In ADScene, a first source of scenarios was related to real road crashes with injuries. These accidents have been provided by LAB and CEESAR from the VOIESUR database. More than 500 scenarios were re-analysed to be converted to ADScene format [5]. While these scenarios are important to capitalize on for ADAS feature (e.g. pedestrian accident for AEB VRU, lane departure for LDW/LKA …), they do not directly concern AD feature unless to describe the context of "usual road traffic".
For the past 2 years, a dedicated accident survey has been in place for accidents involving an L2+[1] level vehicle. The objective is to supply ADScene to complete this knowledge database.

This paper describes the entire process of specific data collection, from the search of SAE L2+ accidents to its entry and validation in ADScene.

2.2 Methodology

The accident scenarios we are interested here are accidents involving at least a personal vehicle of SAE level of automation 2+ where the autonomous delegation mode is active. This concerns accidents with vehicles alone or involved against other users such as cars or vulnerable users (pedestrian, bicycle etc.) on all types of roads, in rural or urban area.
The collection of accident data has always been a sensitive issue. Indeed, it is imperative to comply with the GDPR (General Data Protection Regulation) and therefore to ensure that the data, once collected, meets the obligations imposed by European regulations. For this reason, once the data has been collected, it is processed in such a way that only the essential information is kept in our database, and anything that could provide personal and irrelevant information is 'deleted' (anonymization process).
For accident research, several types of sources were explored: Tesla's database of fatal accidents [13] the DMV administers the Autonomous Vehicles Program of California state [14], NTSB investigation on Highway [15] and of course the internet (Youtube, articles, newspapers, etc.).
The media is a prolific source of information, especially when it comes to subjects such as traffic accidents and automated vehicles. Nevertheless, as Internet users are also very fond of videos of this kind, it is possible to find numerous compilations of accidents in which automated vehicles are involved. Finally, in the USA, it's even possible to find a wealth of expert reports and accident reports freely available on the Internet.
The method used to register an accident in the ADScene database is not in itself complex. The first step is to identify an accident involving an automated driving vehicle. Then, all related articles, reports, expert reports and even videos are collected. Once this stage has been completed, the accident is analyzed to check that it meets our search criteria, which are as follows:

- Vehicle equipped with a L2+ features;
- L2+ features active during the breakdown situation that led to the accident;
- Possibility of coding the infrastructure (type of road, condition of road, road markings, etc.);
- Weather conditions known;
- Sufficient information to describe the course of the accident.

[1] See glossary

Once all the criteria have been validated, the accident is broken down into relevant phases to make it easier to understand and describe. At least 3 phases are mandatory. A phase is created each time a participant acts or suffers a disturbance. The accident scenario begins with an initial phase showing the vehicles in a stabilized dynamic position before the collision, and ends with the final phase showing the rest position of those involved once they have stopped. Between these two phases are the collision phase (moment of impact) and possible intermediate phases representing, for example, an evasive maneuver (braking, steering wheel movement, etc.) or even another minor collision (e.g. against sidewalk, trees …).

Finally, all data needed for ADScene are collected, processed, anonymized before to be coded in the database.

2.2 From analysis to ADScene

After the content of the accident has been validated, the scenario will be coded in the ADScene tool using several parameters. Coding the scenario requires a five steps process:

Step 1 -Description of the accident: this part gives general information such as a summary of circumstances and accident process, some references (source, year and country where accident take place ...) and the severity (number of killed, injured and uninjured people).

Step 2 - Infrastructure description: this part is dedicated to the road infrastructure information where the accident take place. We can find here information regarding to the type of road (junction, curve, straight line ...), the speed limit, the geometry, the number of strips (traffic lane and road verge included) and for each strip its marking (type, colour, visibility ...), the vertical signs and all others relevant elements presents (tree, pole, pedestrian crossing…).

Step 3 - Description of the actors: this part is dedicated to the description of all the participants involved in the accident. This can be the vehicle with the L2+ AD function as well as other road users (pedestrians, cyclists, trucks, etc.), objects or animals. The list of actors should be limited to those who are directly involved in the accident or who played a role in the accident process (having directly provoked the conflict or in traffic and having blocked a possible avoidance solution). For each actor, we add several properties:

- The vehicle characteristics: geometry, weight, colour and dynamic capabilities with the max speed and the max acceleration, maximum number of passengers it can hold.
- The occupant part: For each vehicle, it consists to give information about the driver and the number of passengers seated in the vehicle. We try to determine the state of the driver at the time of the accident (drunk, tired…) and the Human Functional Failure associated [6,7]
- Vehicle equipment like type of ADAS/ADS function available or vehicle lights can be associated with the actors. They make it possible to specify some of their characteristics which may be relevant in the situation described by the scenario.

Step 4 – The storyboard: The Storyboard describes chronology of the accident through the identified relevant phases during the accident analysis. In each phase the longitudinal and transversal position and the speed of each actor are given. It shows the dynamics of the actors and their interactions over time and space. In complement, some various information can be added to complete the storyboard description:

- Vehicle Equipment Status: For each equipment assigned to a vehicle, its status must be fill in for each phase. For example, the state of the L2+ function should be described throughout the storyboard according to the list of choice defined by the user.
- List of behaviours: One or more behaviours attached to a vehicle can be added to the storyboard. They correspond either to manoeuvres (acceleration, braking, lane change …) or erratic dynamic behaviours (roll-over, zig zag, loss of control ...) or collision configuration (frontal, rear, left side, side-swipe, ...). Each behaviour has to be defined temporally with a starting and ending phase associated to some predefined characteristics.

Step 5 – Environmental conditions: They consist of the weather conditions (luminosity type, light intensity, rain, fog visibility, wind, nebulosity, snow, hail, smoke visibility), road state (dry, wet, flooded, icy, snow covered …), traffic conditions (no other vehicles, smooth, heavy, saturated) to be defined for each scene of the scenario. We find also in this section all infrastructure equipment for which a state property has been define such as example for traffic light (green, orange, red, flashing, off).

The first scene corresponds to the initial scene. It specifies the initial parameters of the scenario, describes the position of actors in the environment before the critical event. Then, for each new event from one of the actors such as manoeuvres or sudden change of the environmental conditions or crash, a new scene must be created to make parameters fit the new conditions. These scenes are called intermediate scenes. We will also find one or more crash scenes (depending on the number of collisions occurred in the accident), and at the end the final scene which describes the position of the actors in their rest position.

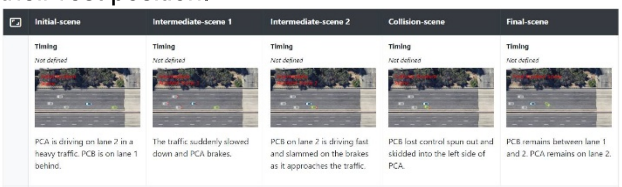

Figure 1: Example of storyboard describes with 5 phases

To facilitate the codification work, some ‘’frames of reference’’ have been created in ADScene for infrastructures and their equipment, actors and their equipment and for behaviours. These repositories contain predefined elements (the most common ones such as 4-branch junction, 3-lane highway, traffic light, guardrail, pedestrian, bicycle, M1 vehicle, brake lights, ACC, AEB …) that the user can load and modify according to the needs dictated by the scenario.

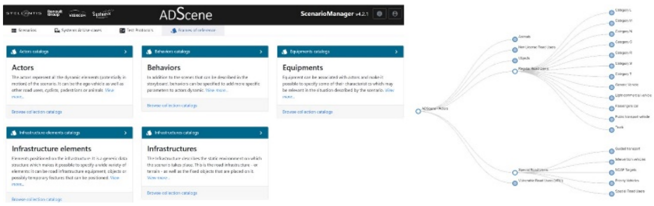

Figure 2: On the left: Frame of reference available in ADScene; On the right: short list of predefined ‘’Actors’’

For each scenario in ADScene, a status is assigned to know its progress:

- Draft - script entry has begun but is not yet complete. This is the default status.
- Ready: the script entry is complete and it must now go through the validation process
- Feedback - scenario validation has been rejected and changes need to be made
- Validated - the scenario is validated; it is in line with expectations.

When the status of the scenario is ‘’Ready’’ it is then reviewed by a dedicated group responsible for validating its content to ensure that the rules for coding information and requirements are consistent in its content. During the session, all the parameters included in the scenario are reviewed. Depending on their consequences, errors are either corrected directly or listed for further modification. In the latter case, the status of the scenario is put in "feedback". If the validation did not find any errors, the scenario is then moved to the most appropriate logical scenario and the status of the concrete scenario changes to "validated".

The list of functional and logical scenarios was established during the first coding campaigns based on accidents extracted from VOIESUR database. This list is given in the annex.

Today ADScene contains 88 accident scenarios involving a SAE level 2+ vehicle.

3. Example of an accident case

To illustrate the method, we will follow the procedure on a real case filled in ADScene.
This case is related to a mediatic accident involving an automated vehicle and a vulnerable road user at night.


Figure 3: Aerial view of crash location showing the path of VRU (orange) and car (green). On the picture on the right, the deformation on the front face of the car due to the crash.

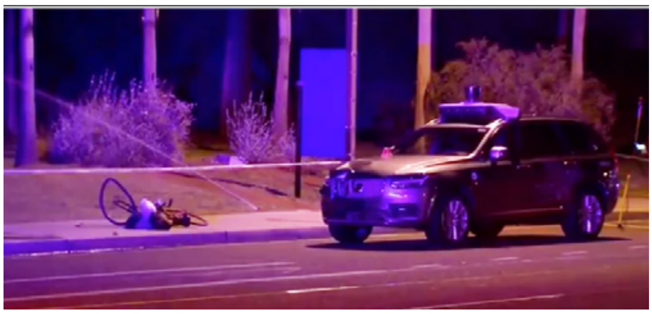
Figure 4: Rest positions of the road users when rescue services arrived

The severity of the accident and the fact that it was linked to an "autonomous" vehicle put into service by a self-driving operator well known from the public contributed to its dissemination on the internet (blogs, New York Times, BBC, ... and more recently in Wikipedia). Quickly, the videos from the vehicle's internal and external cameras were published on the net. These videos allow us to better understand what happened and to understand why the driver had not reacted.

Figure 5: Pictures extracted from the videos

Although in the photos above the driver's face was blurred, we could see on the video that his attention was turned to a secondary task other than the driving task. The person also admitted that he was using his mobile phone at the precipitating event time.

Once all needed information gathered, the codification process in ADScene can start:

3.1 Description of the accident

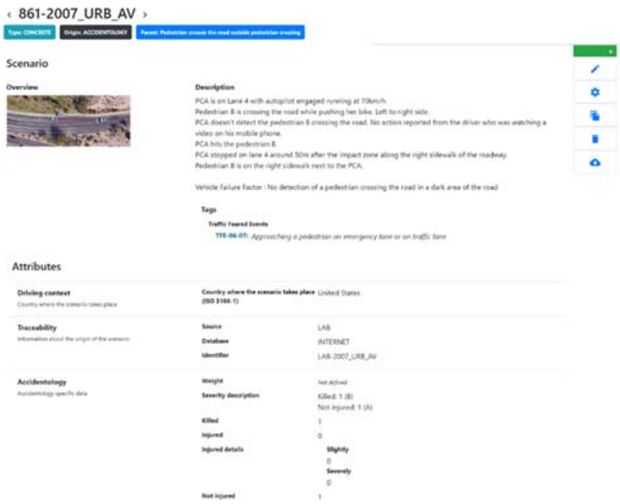

Figure 6: Screenshot from ADScene for description

3.2 Infrastructure description

At the site of the accident, the infrastructure is composed of 4 lanes of traffic bordered on the right by an emergency lane followed by a concrete barrier placed on a road verge and a sidewalk on the left. The speed limit is 70 km/h.

The marking is composed by a continuous line between traffic lane 1 and 2, and 2 and 3, dashed line between lane 3 and 4 and a continuous line between lane 4 and emergency lane (lane are numbered from left to right).

3.3 Actors description

3 actors have been defined in this case, the passenger car, the pedestrian and the bicycle. We had to distinguish these last 2 objects because following the impact they will be ejected and follow different trajectories.

Figure 6: Screenshot from ADScene for Actors

3.4 The Storyboard

Since no evasive maneuvers have been performed and all kinematic parameters during the pre-crash phase were not subject to variation, the storyboard only include 3 scenes.
For each scene, a picture or a drawing associated to a description is presented.

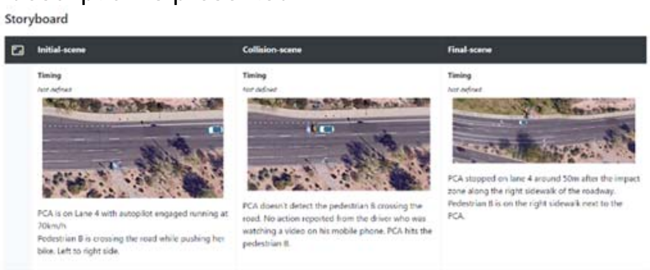

Figure 7: Screenshot from ADScene for storyboard

Once the storyboard defined, the kinetic parameters for each included actor in the scenario have to be filled in, such as longitudinal and lateral positions, speed, direction, etc.
For each parameter, it is possible to give a specific value (e.g. 70km/h for the speed), an interval (e.g. between 50km/h-70km/h) or an abstract value (e.g. ‘’under speed limit’’).

Because an ADS L4 function was attached to the vehicle, the status of the feature has to be defined in all scenes. This is the case for all equipment predefined in the ''Actor'' section.

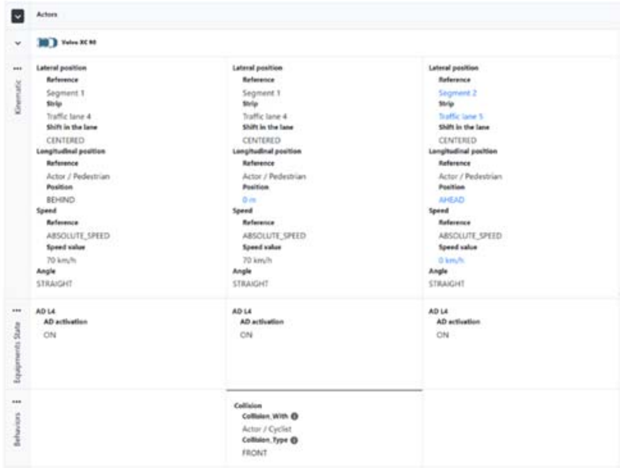

Figure 8: The storyboard of the Volvo

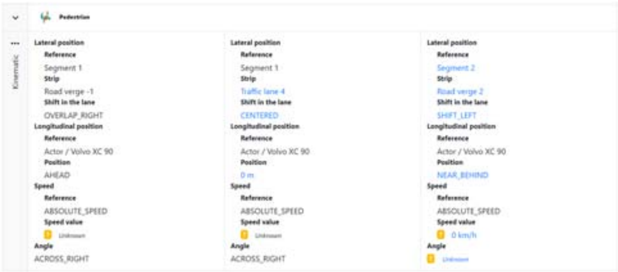

Figure 9: The storyboard of the pedestrian

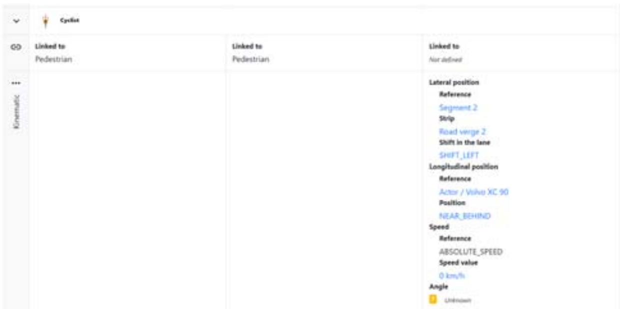

Figure 10: The storyboard of the bicycle

On the first and second scene related to the bicycle, we can see that the vehicle is linked to the pedestrian. This property means that the dynamic parameters of the bicycle are identical as the pedestrian one's during these phases. This option allows to describe the situation where the pedestrian pushed her bicycle before the crash.

3.5 Environmental conditions

Regarding the environmental conditions the accident taken place at night with street light on, no wind, no rain, no fog and smoke.

The road state was noted dry and the traffic smooth.

4. Conclusion and perspectives

Because working, and safety of ADS is a continuous work, we will continue this activity of collecting accidents in several regions of the world because they are these known or foreseeable dangerous scenarios for which you can design preventive actions.

Because working on safety is working on the dissemination of these accident scenarios, ADScene team is working in the frame of European Funded Projects (Sunrise [19] and Synergies [20]) on interoperability of scenarios databases and on standards scenarios format beyond OpenScenario from ASAM for simulation scenarios.

Because working on safety and improving safety is the ultimate goal, ADScene partners bring their expertise to UNECE Scenario database workshops to draw a worldwide model to exchange relevant scenarios for ADS Safety!

5. Acknowledgement

The authors thank their colleagues at CEESAR and LAB for their contribution, their experiences in accident analysis and their patience in codifying cases.

6. References

[1] DGITM/DMR/TUD-VA (2022), ''*Scenarios for interactions with first responders (inception)*'', French report, https://www.ecologie.gouv.fr/sites/default/files/DGITM-Scenarios_AFO-juillet_2022.pdf.

[2] DGITM/DMR/TUD (2022), ''*Safety demonstration of automated road transport systems: contribution of driving scenarios*'', https://www.ecologie.gouv.fr/sites/default/files/DGITM-L1-septembre_2022-EN.pdf.

[3] DGITM/DMR/TUD (2024), ''*Scenario selection process*'', French report, https://www.ecologie.gouv.fr/sites/default/files/DGITM-Approche_selection_scenarios-2024.pdf.

[4] L. Guyonvarch et al. (2019), ''*Data Driven Scenarios for AD/ADAS Validation*'', TRB Annual meeting Washington 2020

[5] L. Guyonvarch et al. (2022), ''*ADSCENE: Focus on accident data support for validation of Automated Driving functions*'', TRA Conference Lisbon, Vol.72 (2023) pages 9-16

[6] P. Van Elslande (2008), K. Fouquet, ''*Drivers' needs and safety systems*'', Proceedings of the 15th European Conference on Cognitive Ergonomics: Ergonomics of Cool Interaction (2008), pp. 1-4

[7] P. Van Elslande et al (2012), DACOTA project - Deliverable 5.5 Drivers Needs and Validation of Technologies, IFSTTAR, France (2012)

[8] SAFETY POOL : Safety Pool Scenario Database

[9] SAKURA : SAKURA Scenario Database (sakura-prj.go.jp)

[10] PEGASUS: 15 Scenario-Database (pegasusprojekt.de)

[11] ADSCENE, ADScene, a scenario database for the validation of automated driving and driving-assistance systems via digital simulation - IRT SystemX (irt-systemx.fr)

[12] ADSCENE, tuvsud-case-study-adscene.pdf

[13] Tesla Deaths database: https://www.tesladeaths.com/

[14] Autonomous Vehicles - California DMV: https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/

[15] NTSB investigations on Highway: Investigation Report (ntsb.gov)

[16] SAE Levels of Driving Automation™ Refined for Clarity and International Audience

[17] AVL Scenius: AVL SCENIUS™ | AVL

[18] StreetWise :**StreetWise: scenario-based safety validation of connected and automated driving (tno.nl)**

[19] SUNRISE : SUNRISE - CCAM

[20] SYNERGIES : SYNERGIES - CCAM

8. Glossary

ADS: Automated Driving Systems

AEB: Automatic Emergency Braking

ASAM: Association for Standardization of Automation and Measuring Systems

L2+: Automated functions are classified by SAE [16] from level L0 (features are limited to providing warnings and momentary assistance) to level L5 (feature can drive the vehicle under all conditions). L2+ designs here all vehicles equipped with an ADS at least level 2.

LDW: Lane Departure Warning

LKA: Lane Keeping Assist

PFA: Plateforme Française de l'Automobile

PMD: Personal Mobility Device

PTW: Powered Two Wheelers

OV: Other Vehicle

7. Annex

List of functional and logical scenarios available in ADSCene in accident context

- ❖ Bicycles and Personal Mobility Device (PDM) accident
  - Crossing – Bicycle/PDM coming from left
  - Crossing – Bicycle/PDM coming from right
  - Door opening accidents
  - Opposite direction – Vehicles going straight forward
  - Same direction – Bicycle/PDM swerving to the left
  - Same direction – Vehicle moving in same direction
  - Turning – OV turning left while bicycle/PDM coming from left
  - Turning – OV turning left while bicycle/PDM coming in opposite direction
  - Turning – OV turning left, vehicles in same direction
  - Turning – OV turning right, vehicles in same direction
  - Turning – OV turning right while bicycle/PDM coming in opposite direction
  - Remaining / Other bicycle/PDM cases
- ❖ Pedestrian accidents
  - Pedestrian along the road
  - Pedestrian crosses the road outside pedestrian crossing
  - Pedestrian crosses the road on pedestrian crossing
  - Pedestrian crosses the road while vehicle turns to the left
  - Pedestrian crosses the road while vehicle turns to the right
  - Pedestrian in interaction with shuttle
  - Pedestrian lying on the road
  - Reverse maneuver with pedestrian
- ❖ Junction accidents
  - Roundabout
  - Straight crossing path
  - Turning left – OV coming from left
  - Turning left – OV coming from right
  - Turning left – OV coming in opposite direction
  - Turning left – OV on same direction
  - Turning right – OV coming from left
  - Turning right – OV coming from right
  - Turning right – OV coming in opposite direction
  - Turning right – OV on same direction
- ❖ Lane Change accidents
  - Lane change maneuver in front with or without indicator
  - Lane change in rear with or without indicator
  - Lane change with PTW moving between two traffic lane
- ❖ Lane departure and loss of control accidents
- ❖ Longitudinal regulation issue
  - Rear-end collision, same direction same lane
  - Rear-end collision with a vehicle ahead stopped
  - Rear-end collision with a vehicle turning left
  - Rear-end collision with a vehicle turning right
- ❖ Specific maneuver
  - Car park maneuver
  - Overtaking
  - Reversing maneuver
  - Turn left or right out of junction
  - U-turn
- ❖ Railway crossing
- ❖ Unexpected event
  - Animals
  - Obstacles on road
  - Working or accident zones
  - Wrong way on-coming scenario
- ❖ Others cases