# STREETWISE SCENARIO MINING FOR SAFETY ASSESSMENT OF PLATOONING TRUCKS

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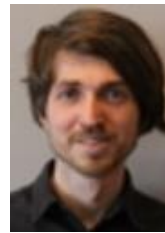
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Abstract

One option to increase the efficient use of roads and vehicles is the formation of platoons in which trucks follow each other at short distance, e.g. with a time-head-way of less than 0.5 seconds. The industry is putting large efforts into the development of technologies to make this possible. This includes vehicle-to-vehicle communication through Wi-Fi and cooperative control technology.

An important aspect is the safety assessment of developed systems. Not only is an assessment needed before providing a final sign-off to allow vehicles commercially on the road, also in a testing phase during development when vehicles need to be driven for many kilometres in realistic circumstances on the public road. It is common practice to implement a fall-back system into the test vehicles for such a testing campaign. Generally, during all tests, professional test drivers are present in each of the vehicles to take over full control of the vehicle in case of errors or calamities.

In any case, the vehicles also need to undergo an assessment before starting such a testing campaign on public roads. This paper shows how to define relevant and realistic test cases for such an assessment making use of a data driven scenario-based approach called StreetWise.

Keywords: driver support and platooning, operational safety, virtual testing, data driven test case generation

1. Introduction

To meet the carbon-dioxide emission reduction according to the Paris Agreement [1], there is a strong focus in the transport sector on the reduction of fuel consumption. Several technical solutions are being implemented such as more energy efficient and clean combustion engines, electric powered propulsion, use of alternative fuels, light weight constructions, and improved aerodynamics. Another solution is found in truck platooning. It has been shown [2] that in a platoon of 3 trucks, a fuel consumption reduction for the 2nd and 3rd following truck between 4% and 10% can be achieved, depending on the time-head-way (THW) between the trucks in the platoon. The head-way-distance is defined as the distance of the rear of the preceding truck and the front of the following truck, divided by the vehicle speed. The smaller the THW, the larger the potential fuel consumption reduction. Trials have been performed with a THW between platooning trucks as small as 0.3 sec., whereas in normal traffic a THW of 2 sec. between vehicles is considered safe.

To allow trucks to platoon with a THW << 2 sec., communication between the trucks is introduced. So far, the first truck in the platoon is driven by a normal truck driver. All actions taken by the driver to manoeuvre through traffic is communicated in an instant to the following truck. The 2nd and 3rd truck have an automated platooning system on board to establish and maintain the distance to the preceding truck when possible. The automated system uses camera and radar to continuously measure the speed and the distance to the preceding truck and its position on the road. With the communicated information on acceleration or braking, the following trucks can act simultaneously without significant delays, maintaining a short distance in a safe way and reduce fuel consumption and the associated emission of carbon-dioxide.

When platooning at low THW, safety might be compromised e.g. by failing communication between the trucks -which would result in a functional safety issue, or by the occurrence of unexpected events on the road – i.e. an operational safety issue. Functional safety issues are subject to ISO26262 [3] and though important, outside the scope of this paper. The paper focuses on operational safety, more specifically on a method established by TNO called *StreetWise* to collect scenarios to describe what can happen on the road, from normal non-critical traffic situations to near-critical or even full-critical situations. The descriptions of these situations, called scenarios, are stored in a scenario database and used to generate realistic and relevant test cases for safety evaluation of a newly designed control system before the trucks are used to platoon on the public road.

The paper describes the TNO StreetWise method from the collection of data on the road with vehicles with a state-of-the-art sensor set, the processing of these data to identify and parameterize scenarios and the generation of test cases from these parameterized scenarios given the specifications and key performance indicators of the control system-under-test. An example, based on data collection by passenger cars, is provided to clarify how the method works in practice to support operational safety evaluation by means of combined virtual and physical testing.

2. Research question

The system-under-test is a platooning function, comparable to connected advanced cruise control (C-ACC), for a platoon of 3 trucks with a THW between 2nd and lead truck and between 3rd and 2nd truck equal to 0.3 s. At 80 km/h the distance between the trucks is as small as 7 m. The basic research question to be answered is: What are the relevant test cases that need to be

addressed in virtual and physical testing to ensure safe operation on the road of the system-under-test, in our case 3 platooning trucks at small THW?

Figure 1: Platooning trucks at small THW

As an example, we take a closer look at the process that resulted in test cases for the evaluation of Autonomous Emergency Braking System (AEBS) onboard trucks. Based on EU Regulation No. 347-2012 [4] newly build trucks from November 2013 are required to be equipped with an Autonomous Emergency Braking System (AEBS) to reduce collisions of trucks, especially those resulting from running into the tail of a traffic jam. The AEBS receives input from sensors on-board the truck (usually radar and camera) that scan the environment in front of the truck to determine any obstacles, i.e. slow driving or standstill vehicles that cause a safety hazard. The sensors simultaneously measure the speed of the obstacles and the distance to the obstacles. In case the time-to-collision (TTC: the distance to the obstacle divided by the speed difference between the truck and the obstacle) drops below a critical value (typically 2 to 3 seconds), a warning is issued to the truck driver. Should the driver not respond appropriately and the TTC continues to decrease, the AEBS system will autonomously issue a full braking action in order to avoid or at least mitigate the collision.

At the introduction of this system for trucks, no testing procedure had yet been developed. The applied tests to evaluate whether or not the truck equipped with AEBS shows appropriate responses on the road, were converted from an Euro NCAP AEB-test protocol that was already in place to evaluate the performance of AEB-systems for passenger cars. The tests in such protocol are usually based on an analysis of accident databases. It is investigated which accidents frequently happen, and what typical conditions and manoeuvres of the accident partners have led to the crash reported in the accident database. In this way, there is a large library of tests that need to be performed to assess the performance of the different safety systems that are nowadays being introduced in passenger cars.

Euro NCAP tests only assess the response of the vehicle in case a critical situation is imminent. Additionally, car and truck manufacturers spend large efforts to test the robustness of such safety systems. The system should only respond in case the probability of a collision is close to 100%. In all other cases, the system is not allowed to provide a response, to make sure that no safety issue results. A vehicle suddenly braking to a full stop on a highway in normal traffic

would certainly compromise the safety on the road. These robustness tests further increase the test burden of car and system manufacturers.

Considering the transition towards connected automated driving, the test burden will increase exponentially as systems become more complex, and can no longer be tested independently. The number of tests will continue to increase, and consequently virtual testing becomes indispensable in addition to physical tests. In virtual testing, computer models are made of the system-under-test which are tested in a virtual world. It is relatively easy to run large numbers of test cases for system evaluation. Many variations can consequently be tested in a relatively short period of time.

To determine relevant and realistic test cases for the platooning trucks, we make use of the StreetWise method to generate test cases for passenger cars but that can as well be applied to trucks. The output of StreetWise is input for any safety assessment framework such as provided by P.E.A.R.S. [5] or CETRAN in Singapore [6].

3. StreetWise approach

Specifically for platooning trucks, we distinguish scenarios that the platoon might encounter on the road (what are the scenarios that the lead trucks runs into), and scenarios that consider the platoon itself due to the character of the platoon (vehicles cutting into the gap between the platooning trucks). Tests are preferably based on a broad spectrum of real world scenarios to make sure that the tests are representative for the real world. In StreetWise, we interpret real world traffic as an endless sequence of scenarios. Herein, a scenario is defined as a typical manoeuver on the road with the complete set of relevant conditions and trajectories of other traffic participants that have an interaction with the host vehicle (with the system-under-test) over a relevant time period (order of seconds). A ride on the road can in this way be described by a continuous sequence of scenarios, where scenarios might overlap in time [7].

In the StreetWise approach, the scenarios are identified from big data collected by a large number of vehicles equipped with a state-of-the-art sensor set that are on the road on a daily basis as test vehicles for car manufacturers and automotive suppliers. TNO also has a number of vehicles on the road that take part in the data collection. Whenever the trucks with the platooning system are riding on public road, the data is collected for scenario mining as well.

The on-board sensor systems provide object level data, i.e. for the road users in the sensor field of view, an object identification is given (passenger car, truck, pedestrian, cyclist, etc.) and the relative position and velocity of the object with respect to the ego vehicle (the data collecting vehicle). Also road markers are considered objects that are being stored. Synchronously, the GPS location, the speed and the acceleration of the ego vehicle is logged. Based on the GPS location and a detailed road map (such as Open Street Map), a description of the infrastructure (or static environment) can be made. Descriptions of weather and lighting conditions are separately recorded as disturbances to the scenario.

Parameterized models are constructed for the events (basic manoeuvres of the different actors in the scene), for the infrastructure and for the disturbances, to enable the generation of test cases from sampling the resulting parameter distributions. These parameter distributions show how often instances of events with its parameter values are encountered in the collected dataset. The distributions also show the range of realistic parameter values on the road. In [8], it is presented how to select relevant scenarios and to specify parameters for the generation of relevant test cases.
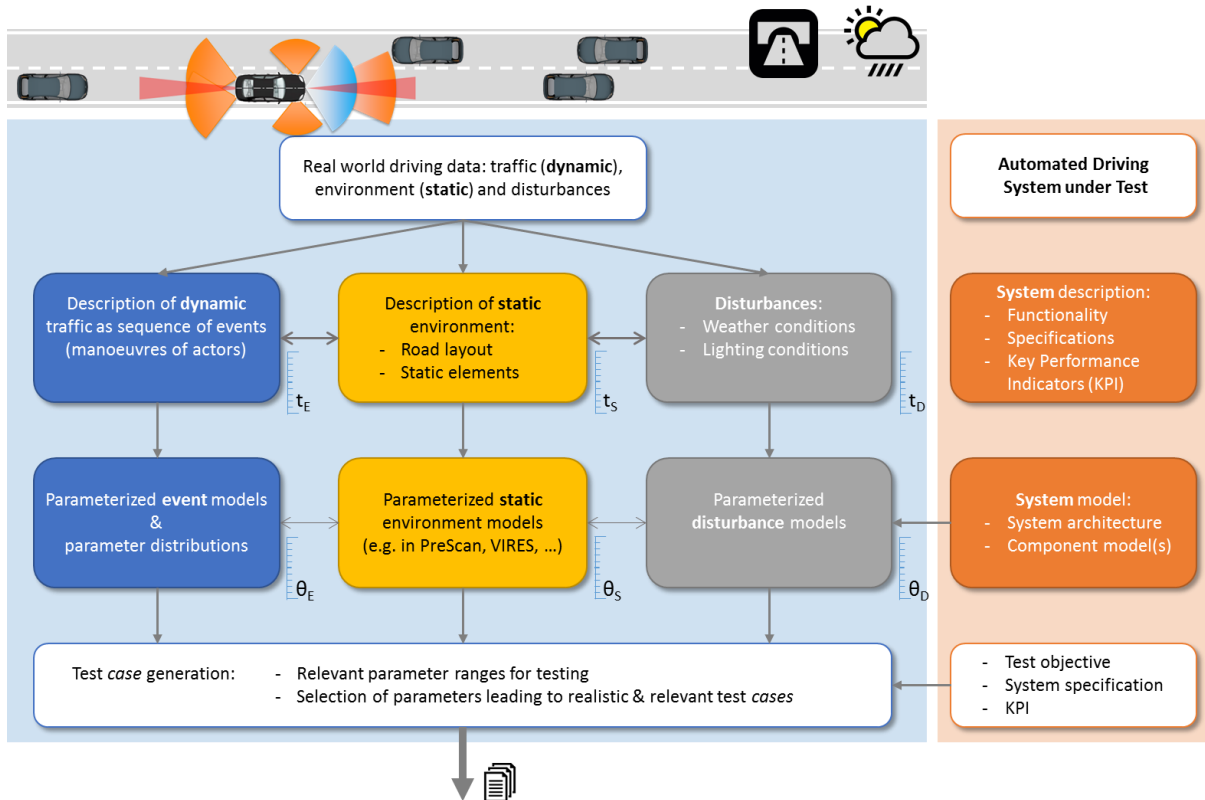
Figure 2: Schematic overview how to generate test cases from data driven scenario identification and classification.

It should be noted that StreetWise is not considered a one-time data collection and analysis campaign. It is merely a philosophy to continuously analyse the occurrence of scenarios in traffic to get access to what is actually happening on the road on a day to day basis. There are large similarities with the continuous updating of in-depth accident databases such as GIDAS [9]. With the continuous analysis of real world data, the StreetWise database will become more and more complete, and depending on where data collection takes place, provide important information regarding similarities and differences in scenarios and in the distribution of parameters for different regions within Europe (e.g. the difference between traffic in Italy and Germany) or between different regions in the world (e.g. differences between Europe, US, Japan, China, Singapore, etc.)

4. Data collection and scenario identification

To demonstrate the StreetWise approach, a data set collected of 36 hours driving in the Netherlands has been analysed. A data collection vehicle (ego or host vehicle) was equipped with a forward looking camera and radar sensor, providing a view on the behaviour of vehicles in front of the host vehicle. On a typical highway, such behaviour consists of lane change, acceleration, deceleration, swerving in lane, etc. Figure 3 shows a view from the data collection vehicle on the traffic in front, including the vehicles interpretation of the environment.

In the left side of the view, we see a dynamic representation of the driving lane of the ego vehicle and the position of the ego vehicle in the lane (the origin of the figure). The ego vehicle (H) shows one detection of a passing vehicle (target T) at approximately a distance of 15 m.

Figure 3: View on a cutting-in vehicle from the data collection vehicle

This vehicle is changing lane, entering the driving lane of the ego vehicle. The right side of the view shows the image of the dashcam (reference view), the current speed of the ego vehicle, and a schematic of the scenario, in this case a cut-in from the passing vehicle onto the ego vehicle. The current scenario parameters such as Δx, the longitudinal distance between ego and target vehicle in [m], Δv$_x$, the speed difference in longitudinal direction in [km/h], and v$_y$, the lateral velocity of the object in [m/s] are shown as well.
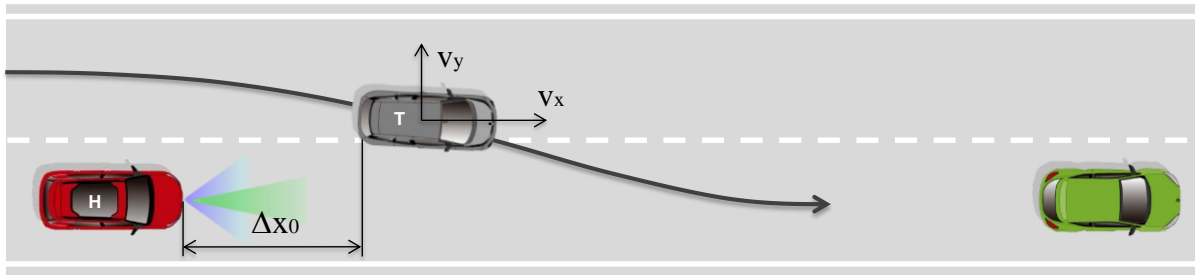

Figure 4: Schematic representation of a cut-in by a passenger car from left to right lane

The automatic cut-in detection is triggered when the 2 right wheels of the target have just crossed the lane separating line (or the 2 left wheels in case of a cut-in from right to left). The object level data that is provided by the ego vehicle for the detected targets consists of an identification of the type of object in the ego vehicle's sensor field-of-view (passenger car, truck, motorcycle, etc.), and the relative position, heading, speed and acceleration of each target with respect to the ego vehicle. The ego vehicle will record the object level data of each target for the complete duration of the target being within the field-of-view of the sensor set of the ego vehicle. Easily up to 10 targets can be followed simultaneously.

The resulting data set from a data collection campaign consists of a record of the ego vehicle's CAN bus, a record of the output of the ego vehicle's sensor fusion providing object level data

on the dynamic traffic participants in front of the ego vehicle, and a recording of the dash cam that is installed on the ego vehicle's dashboard. All data streams are recorded simultaneously on one single ROS system, to avoid any synchronization issues with the data set.

Analysing this demo data set with TNO's automated scenario detection algorithms revealed 146 detections of a cut-in for approximately 18 hours of high way driving. Figure 5 shows the probability-density-function for 2 characteristic parameters (as defined in Figure 4) based on the identification of 146 cut-ins:
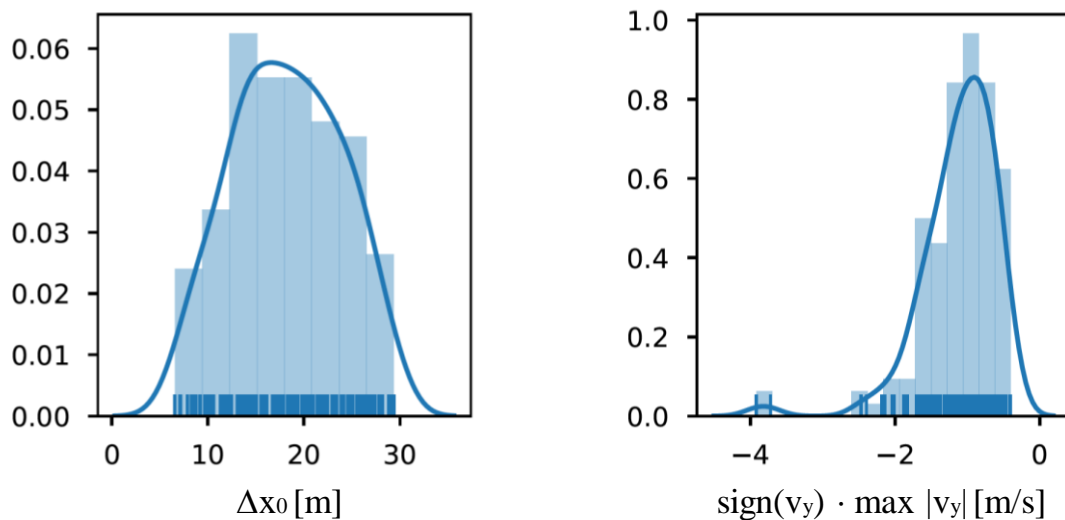

Figure 5: Probability-density-functions (PDF) for two descriptive parameters Δx_0 and v_y that characterize a cut-in scenario

The two parameters Δx_0 and $\max |v_y|$ are selected as most characteristic for a cut-in scenario. The parameter Δx_0 shows the distance that a target vehicle keeps before changing lane in front of the ego vehicle. The smaller Δx_0, the more critical a cut-in scenario is expected to be; although physically possible, a distance Δx_0 close to 0 [m] is not expected to be feasible. The criticality not only depends on the value for Δx_0 but also on the speed difference between the two vehicles in longitudinal direction and the absolute speed of the target. The PDF shows typical values for Δx_0 between 6.5m and 30m, with a maximum at approximately 15m. The distribution is rather broad.

Another characteristic measure is the lateral speed with which the target vehicle performs the lane change during the cut-in manoeuvre. The higher the absolute value of v_y, the more aggressive the cut-in will appear. The value of v_y usually varies in a sinusoidal-like way during a cut-in. As a characteristic value, we have taken the maximum value of v_y during the cut-in. The distribution of $\max |v_y|$ peaks at approximately -1 [m/s], which is taken as the nominal value (based on 146 left-to-right cut-ins). A small peek is seen around -4 [m/s]. This is a rather large and very aggressive value. In case many more data would have been analysed, we would expect a smooth distribution of $\max |v_y|$ also with values in the range of -3 and -4 m/s; based on the current information, values lower than -4 m/s would be considered corner cases. Whether or not this would lead to a critical situation depends on the combination of all parameters, e.g. the combination between Δx_0, $\max |v_y|$, and the speed difference between vehicles in longitudinal (driving) direction.

The above example is based on a data set of limited length. It however shows the strength of StreetWise to reveal what is actually happening on the road, providing indispensable input for

the assessment of newly developed connected and automated vehicle functions. The next figure shows the different modules in the StreetWise pipeline, from data logging to test case generation:
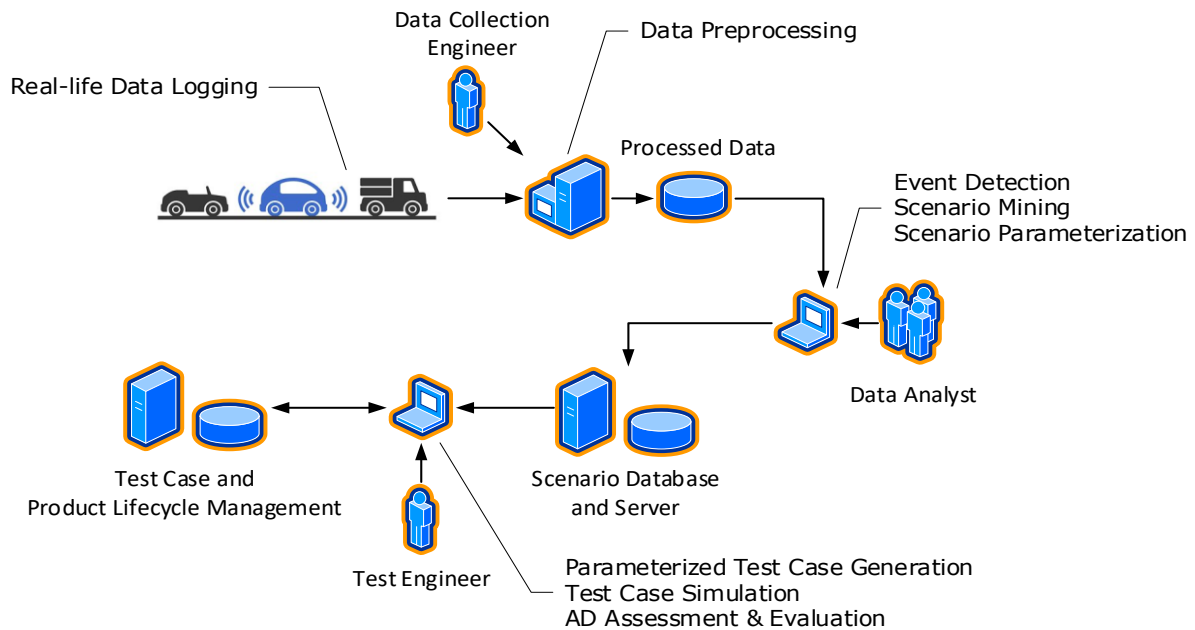

Figure 6: The StreetWise pipeline from data collection to test case generation

In the next section, we will show how the data resulting from StreetWise is already used in the specification of test cases.

5. Test case specification for platooning

Platooning of trucks is currently in a development and demonstration phase. Platooning systems on public road are still in a prototype phase classified as *partial automation* according to SAE level 2 [10]. The first truck in the platoon is driven by a human professional driver, and in the following truck(s), also a professional driver needs to be present to monitor the system and to take over control of the vehicle when needed.

Developments continue in a fast pace: from 2 truck platoons, the step is made to 3 or more trucks in a platoon. This exhibits an additional dynamic for the cooperative control system that is used to control the individual trucks in the platoon based on vehicle-to-vehicle (V2V) communication. A next step is foreseen in multi-brand cross-border platooning, where trucks of different make merge in a single platoon that is capable of running in different countries of Europe, and that continues its platooning function across the borders between countries. This type of platooning will be demonstrated in the ENSEMBLE project that received a grant from the EU within the Horizon 2020 framework programme.

In addition to simulations (software in the loop, hardware in the loop), a lot of testing of platooning trucks needs to be performed on the public road. To allow trucks to be tested in a platoon on the public road, a number of test cases need to be performed multiple times on a test track, and only when passing all tests, the platoon will receive an exemption to drive on the public road with a given minimum time gap.

Safety goals are defined in a Hazard and Risk Analysis (HARA) and subsequently mapped onto different test cases. The test cases typically refer to critical situations that might occur on

the road: a vehicle blocking the road e.g. at the tail of a traffic jam, a car performing an emergency brake action in front of the platoon, a vehicle cutting in in front of the first truck of the platoon, or a vehicle cutting into the gap between platooning truck. Tests based on such scenarios that potentially lead to critical situations on the road are performed to evaluate the safety of the response of the individual vehicles in the platoon. Additionally, test cases are combined with anticipated system failures to check whether the fall back system that includes the drivers in the 2nd and 3rd truck responds appropriately. Typical test cases are given as an example:

1. Specification of the test case with a stopped vehicle in front of the platoon (Figure 7) is rather straightforward. For a platoon with a driver in the first truck, the test case is very much determined by the response of the driver.
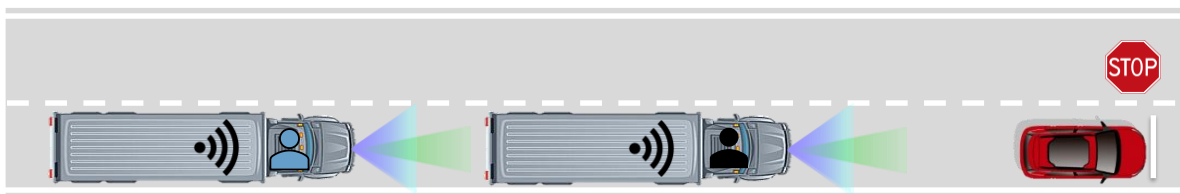

Figure 7: Test case with a stopped vehicle in front of the platoon.

2. The definition of the test case in which a vehicle performs an emergency brake in front of the platoon (Figure 8) is more difficult: parameters that need to be specified are the typical following distance that the platoon keeps in regular traffic and a typical deceleration for the emergency brake. In the AEB testing protocol of Euro NCAP, a maximum deceleration of 6 m/s^2 is used [11].
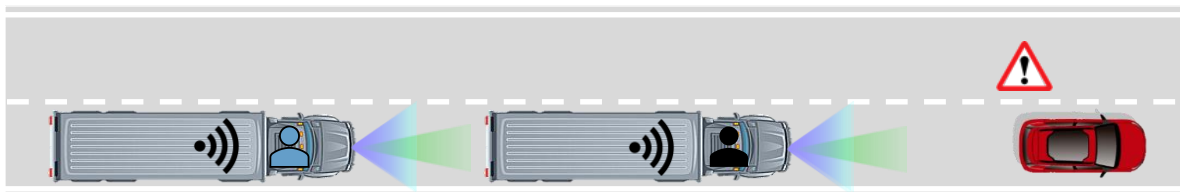

Figure 8: Test case with a braking vehicle in front of the platoon.

3. For test cases with a cutting-in vehicle, one of the most important parameters to be specified is the lateral speed with which the vehicle performs the cut-in manoeuvre. Such data is not available from accident databases.

Figure 9: Test case with a vehicle cutting in in front of the platoon.

4. In case of a platooning truck, a scenario in which a vehicle cuts into the gap between the platooning vehicles is important as well. Also in this case, the lateral speed with which the manoeuvre is performed needs to be specified.
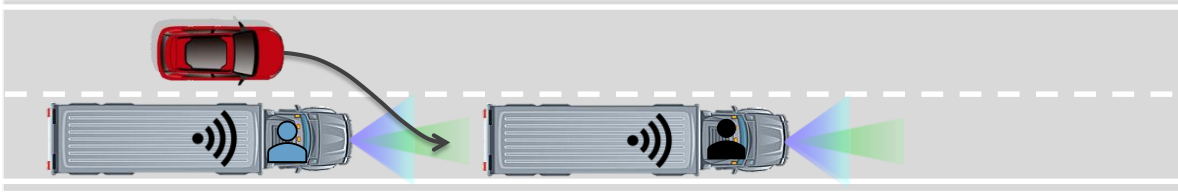
Figure 10: Test cases with a passenger car cutting in before and into the platoon.

The StreetWise approach enables the specification of parameters for generating relevant and realistic test cases. Not only will StreetWise provide typical values for the cutting-in speed (max $|v_y| = -1$ [m/s]), it also shows what can be considered a corner case with a high but still realistic cutting in speed (-4 [m/s]) or what can be considered a low speed (which is also worth testing). As shown in Section 4, also relevant combinations of parameters can be specified. A low value for Δx_0 can for instance be combined with a high value for max $|v_y|$.

In this paper, we took parameters to describe a cut-in scenario as an example. The wealth of the proposed approach is in the specification of any type of test case. Due to the vast amount of parameters, parameter combinations and parameter ranges that need to be tested, testing can no longer be limited to physical tests only. Solutions are developed for adding realistic virtual or computer simulations to the testing framework, to support a complete assessment of cooperative automated vehicle functions.

6. Discussion and conclusion

A safe introduction onto the public road of *cooperative automated driving functions*, e.g. to enable platooning, asks for many tests to be executed and evaluated to get a good insight regarding the performance and robustness of newly developed functions under real-world conditions. Part of testing needs to take place on the public road, and for systems-under-development, such public road testing campaign requires an exemption needs to be provided by the road and vehicle authorities to allow the vehicles on the road. Vehicle manufacturers need to show to the authorities that such a test campaign can be executed in a safe way under all circumstances. In such campaigns, usually an experienced test driver is monitoring the test in each vehicle in order to be able to take over full control of the vehicle in case of a failing system or the occurrence of a situation the platooning system is not designed to cope with.

In the design and generation of relevant and realistic test cases, there is a strong need to have a well-funded insight in scenarios and situations that happen on the road with which vehicles and vehicle platoons have to respond to in an appropriate way. Such scenarios not only include corner cases or critical situations, but day-to-day normal driving cases as well.

The StreetWise approach that TNO described in this paper aims to start up a continuous process of public road data acquisition and analysis according to the scheme of Figure 6 to identify the occurrence of scenarios and to determine the parameters that characterize these scenarios. A method that is capable to describe real-world driving by a sequence of scenarios is needed to reduce the number of kilometres that is used for actual testing complex cooperative automated driving functions. Since all vehicle manufacturers and suppliers as well as many automotive research organizations are driving around on the public road with a multitude of test vehicles collecting data, no additional effort needs to be spend in data collection itself.

Efforts are currently specifically focused on development of algorithms for automated annotation of this data, to identify events and scenarios and to automatically determine the

values of characteristic parameters associated with each scenario. The StreetWise toolchain is completed with modules to sample parameters in a smart way for the generation of test cases. In a consortium of OEMs and TIER1 suppliers that has been established beginning of 2018, a way of working is followed in which TNO extracts scenarios and parameters from industrially generated data, and all participants contributing to the consortium receive access to a scenario database with all resulting scenarios and parameter distributions. In this collaboration, data collected by each participants is kept confidential and consequently <u>data is not shared</u>. The analysed data, i.e. <u>scenarios</u> and parameter distribution <u>are shared</u>. This is a strong motivation for sharing the effort in data collection in which results become available through scenarios. In this way, participants have access to scenarios that are based on many more kilometres of driving than an individual participant is able to collect.

In this paper an example has been presented how StreetWise is already used to provide indispensable information on the relevance and level of realism of important scenario parameters in order to generate test cases for platooning trucks. For platooning, a distinction is made between scenarios that the lead vehicle needs to respond to and scenarios that specifically address the following trucks, e.g. a passenger car cutting into the gap between two platooning trucks. However, depending on the type of platooning, e.g. the level of automation of the first and following vehicles in the platoon, different test cases will be relevant for a complete safety assessment.

Discussions with SAE have been initiated regarding the relevance of defining specific automation levels for platooning vehicles, in addition to the current levels as described in J3016 [10].

Where the development of StreetWise was started with a focus on single vehicle automation, a next step is foreseen in extending StreetWise to incorporate the specific assessment needs associated with platooning. This specifically concerns the system-of-systems approach and the application of V2V communication.

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