ABSTRACT
Active safety systems are increasingly becoming available in trucks and passenger vehicles. Developments in the field of active safety are shifting from increasing driver comfort towards increasing occupant safety. Furthermore, this shift is seen within active safety systems: safety functions are added to existing comfort systems, rather than adding new safety systems to the vehicle. Comfort systems such as cruise control are extended via ACC to pre-crash braking systems. Testing of active safety systems must follow these developments. Whereas standardized test programs are available for passive safety systems, such test programs are hardly available yet for active safety systems. Furthermore, test programs for passive safety systems consist of only a handful of scenarios. Test programs for active safety systems, however, should consist of much more scenarios, as those systems should function well in many different situations. It is not feasible to assess the intelligent vehicle safety (IVS) system’s performance in all these scenarios by means of test-track testing. To speed up the introduction of active safety systems, there is a need for an efficient standardized test program, including alternatives to test track testing. This paper describes the vision of TNO Automotive on the developments that are expected in the field of development and evaluation of active safety systems and it explains the need for an efficient and complete test program for IVS systems, consisting of simulations, hardware-in-the-loop simulations and test track testing.

INTRODUCTION
Advanced Driver Assistance (ADA) systems are increasingly becoming available in trucks and passenger vehicles. In the last few years, developments in the field of ADA shifted from increasing driver comfort towards increasing occupant safety. Moreover, safety functions are added to comfort oriented ADA systems, rather than adding new safety systems to the vehicle. Comfort systems such as cruise control are extended via ACC to pre-crash braking systems, and will be extended to collision avoidance systems in the future. Furthermore, car-to-car (C2C) and car-to-infrastructure (C2I) communication are being integrated in intelligent vehicle safety (IVS) systems.

Although strong efforts in increasing the passive safety of vehicles have resulted in a decreasing number of fatalities in Europe, the current developments in IVS systems are needed to reduce the number of fatalities even further. However, a large penetration of IVS systems and C2C or C2I communication in the vehicle fleet is not to be expected in the next 10 years.

In the mean time, developments in the IVS systems will be focused on safety by collision mitigation and even collision avoidance. The effectiveness of the IVS systems will be increased by the use of communication. Furthermore, safety of vulnerable road users (VRUs) and the non-connected road users must be considered.

The development of IVS systems should go hand-in-hand with the development of test procedures for these systems. Without a procedure to test functionality, performance and robustness, it will not be possible to implement systems at large scale in production cars. Development and subsequent acceptance of the test procedures will require strong involvement of OEM. The test procedures should be adapted to the type of IVS system that is assessed. Development of collision mitigation and avoidance systems calls for test methods that enable testing with small time-to-collision (TTC), whereas development of IVS systems to protect VRUs, calls for the development of appropriate test objects. Furthermore, to ensure efficient testing of IVS systems that comprise different functions such as comfort and safety, test
programs are needed that allow for testing of various different functions.

TESTING OF IVS SYSTEMS

Whereas passive safety systems are assessed by standardized test programs which are accepted by OEMs, customers and governments for several decades all over the world, no widely accepted standard test program is available for active safety systems.

Standardized test programs for passive safety systems typically consist of only a handful of scenarios. In contrast, standardized test programs for IVS systems should consist of a number of scenarios in the range of 100 to 1000. This is because IVS systems should function well in many different situations and under many different conditions. However, as this is a very large number of tests, the standardized test programs should be an incentive for OEMs to consider all these situations and conditions during the IVS system's development process, in an efficient way.

It will be infeasible to assess the IVS system's performance in all these scenarios by means of test-track testing. Not only because test-track testing is expensive and time-consuming, but also because it is potentially unsafe. This is especially true when testing pre-crash systems. Furthermore, the reproducibility of the test scenarios in test-track testing is somewhat limited, which makes it difficult to compare different IVS systems in an objective way. Therefore, some alternatives to reduce the amount and complexity of tests to be performed are needed. In the next sections a complete test method for IVS systems, consisting of simulations, hardware-in-the-loop simulations and test track testing is presented.

TNO has developed a simulation and a testing environment that can be used for standardized test programs for IVS systems: PreScan [1,2] and VeHIL [3]. PreScan is a Software-in-the-Loop (SIL) environment whereas VeHIL is its Hardware-in-the-Loop (HIL) counterpart.

PRESCAN

By means of high-fidelity simulation that is based on real physics, PreScan allows for development and testing IVS systems on a desktop PC. PreScan consists of four stages (figure 1). In the first stage, the traffic scenario is built, using a database of road sections, infrastructure components and road users. This can be based on “ideal” scenario parameters, but also on logged (dGPS) data from test track driving. Also weather conditions and light circumstances can be incorporated. In the second stage, the environmental sensors of the system are modeled (or a standard sensor from the PreScan library can be used). In the third stage, a Matlab/
Simulink interface can be used to design and verify algorithms for data processing, sensor fusion, decision making and control. Alternatively existing Simulink models from CarSim or veDyna can be used. Finally, in the fourth stage, the experiment is run with ControlDesk and LabView. Typically, 1000 scenarios can be run within a couple of hours, and this process can be automated.

Once a system passes in PreScan, a subset of those 1000 scenarios can be uploaded to VeHIL where the complete IVS system is tested in a realistic hardware environment. The subset can be randomly chosen, but to increase the efficiency of the test program, a smart subset can be chosen, containing the i.e. most important or most challenging scenarios. The VeHIL tests are used to validate the PreScan simulations and thereby to validate the conclusion about the IVS system's performance.

VEHIL
VeHIL allows for evaluation various IVS systems, on a technical as well as on a functional level in a realistic and controlled environment which is partly simulated and partly real. VeHIL constitutes a traffic simulation, in which one vehicle is the real test vehicle (Vehicle Under Test - VUT) and the motions of selected other simulated vehicles are represented by wheeled mobile robots to provide environment sensor input for the VUT (figure 2).

The key principle of VeHIL as firstly described in [4], is that only relative motions of traffic participants with respect to the VUT are considered. In other words: the position, velocity and acceleration of neighboring vehicles are expressed in terms of the local VUT co-ordinate system. As a consequence, the entire traffic system is transformed to a lower velocity region. This principle is illustrated in figure 3.

The left side of this figure depicts an overtaking maneuver; the grey vehicle is the VUT and the blue vehicle the overtaking vehicle. Expressing the velocity vectors in the VUT co-ordinate frame results in the VUT standing still (with respect to its own co-ordinate frame) as shown on the right side. The resulting velocity vector of the other vehicle indicates a crabwise movement at relatively low velocity. Obviously, this crabwise movement cannot be driven by a common vehicle, which is why wheeled mobile robots (called moving bases) are used to represent other road users.

COMBINATION OF VEHIL AND TEST TRACK TESTING
Once the system has shown its good performance in VeHIL, it can be tested on a test track (figure 4) to evaluate the performance in all kinds of environmental conditions (such as weather, road and light conditions). Again, the test to be performed on the test track can be based on the results of the evaluation in PreScan. Comparing results between VeHIL and test track testing can be used to validate the VeHIL test results.

In addition to the increased efficiency (in time and cost) that can be gained by the use of simulation and HIL simulation, a second improvement compared to test track testing only is to “translate” a set of scenarios that are usually performed on test tracks to VeHIL scenarios. This results not only in higher efficiency, but also enables testing paths which are dangerous for the test driver and testing the ideal test path which is hard for human test drivers. Position and speed of the test vehicles on the test track is often measured by a dGPS system [5] or
even controlled by a steering robot connected to a dGPS system [6].

**Figure 4. Test track testing (OXTS, [4])**

The measured dGPS data can be used to define the scenarios to be performed in VeHIL. Depending on the objective of the tests, various scenarios can be developed in VeHIL. If generating dynamic sensor input for the IVS system is the objective of the test, sensor mapping is performed. If the objective of testing is to evaluate the decision algorithm, open loop tests are performed. Open loop testing means that the (relative) movement of the moving bases is not affected by the reaction of the test vehicle. If however, the objective is to assess the complete system performance, closed loop tests are performed, which means that the movement of the moving bases is affected by the intervention (e.g. braking) of the IVS system.

Due to restrictions in space of VeHIL and maximum speed of the Moving Bases, not all scenarios performed on a test track can be performed in VeHIL as it is at this moment. VeHIL is not designed to replace test track testing. It is designed as an addition to test track testing and to enable highly reproducible testing in a safe and efficient way, especially in cases where reproducibility and safety in test track testing is difficult to achieve. One of the advantages of VeHIL is that it allows very reproducible testing with respect to driven paths (which is difficult using human test drivers) and environmental conditions (such as weather and light). This makes it easy to tune the control algorithm or to benchmark various IVS systems. It is also easier in VeHIL to perform the “ideal test path” (e.g. desired speeds, lateral offsets, braking actions etc) than on a test track. Furthermore, testing in VeHIL is less time consuming and safe for man and material. Testing of near misses (to test false alarm situations) or blind spot monitoring systems for example can be quite difficult and hazardous when performed on a test track, whereas it is safe and controllable in VeHIL.

**NEAR-ZERO TTC AND VRU PROTECTION SYSTEM TESTING**

One of current developments in VeHIL is the design of non-destructive test methods for ultra low and zero TTC, aiming for evaluation of collision mitigation and collision avoidance systems. Non-destructive testing of IVS systems at (near-) zero TTC is one of the biggest challenges for the near future. The risk for undesired collision during testing is huge, and test equipment should be capable of dealing with high loads during collision.

A second development in VeHIL is the design of test objects which represent VRU's to enable testing of VRU protection systems. Most traffic fatalities are found among vulnerable road users and technically, it seems very well possible to reduce the fatality rate with intelligent vehicle systems. A good performance in protection of VRUs in case of (near) collision leads to a higher rating in EuroNCAP tests.

**ACCEPTANCE AND STANDARDIZATION**

Although most drivers are aware of the benefits of passive safety systems, their acceptation and awareness of the safety benefits of active safety systems should be increased. Standardized test programs like EuroNCAP make it easy for drivers to understand the benefit of passive safety systems. For active safety systems however, such test programs are hardly available yet. Furthermore, most drivers are not likely to pay for systems that keep other traffic participants (e.g. VRUs) safe or for systems for which a high penetration rate is needed to become effective (such as cooperative systems).

To increase the amount of IVS systems on the road, OEMs can be encouraged to introduce those systems in a larger amount of car models by legislation or EuroNCAP-like qualifications (e.g. higher rating for good performance with IVS systems). Driver's awareness of the safety benefits can also be increased by this kind of qualifications. Finally, governments need support to define minimal standards and new legislation. The development of a structured evaluation methodology, applicable for a wide range of IVS systems is a strong help in all these factors.

Several initiatives are working on developing standards describing system requirements and standard test programs. Some examples are the International Organisation for Standards, resulting in ISO standards on e.g. intelligent transport systems [2], the Crash Avoidance Metrics Partnership initiative (CAMP) and the National Highway Transport Safety Administration (NHTSA) describing confirmation test requirements for e.g. lane departure warning and forward collision warning systems. In Europe, for example, the Beyond NCAP group from EURONCAP
and European projects such as PReVENT, ASSESS and interactIVe are working on standard test programs.

The integrated project PReVENT [8] finished in 2007 and was a European automotive industry activity co-funded by the European Commission in which several preventive safety applications and technologies were developed and demonstrated. In PreVAL [9], one of the subprojects of PReVENT, an evaluation framework for preventive safety applications was developed.

ASSESS [10] is a four-year project which started mid 2009. The consortium consists of parties from the European research community and car industry and is co-funded by European Commission. It aims to enable widespread introduction of integrated vehicles safety systems by developing harmonized and standardized assessment procedures. Methods will be developed for driver behavioural aspects, pre crash sensing performance and crash performance under conditions influenced by pre-crash driver and vehicle actions.

The integrated project InteractIVe [11] which started in January 2010, is a successor of PReVENT and stands for accident avoidance by active intervention for Intelligent Vehicles. Its goal is to develop new, high performance and integrated ADAS applications, enhancing the intelligence of vehicles and promoting safer and more efficient driving. It also develops an evaluation framework including test scenarios, test methods, tools and evaluation criteria, and evaluation and impact assessment is performed for all applications built in the project.

Despite all initiatives, so far no test program is accepted widely among car manufactures or known to the public. Furthermore, the standards do not always provide sufficient information for standardized testing, nor are they applicable to future IVS systems. Therefore, effort is needed to make the standards suitable for standardized testing including rating of available IVS systems and to let them evaluate along with the developments in the IVS systems. Development and acceptance of standardized test programs also needs definition of generally accepted test scenarios and test targets (such as pedestrians and cars) as well as requirements for accurate, reproducible and efficient testing facilities. To ensure a widely accepted test program, strong cooperation is needed between OEMs, 1st tiers, governments and test facilities. A combination of HIL testing and test track testing will be most feasible, as at this moment no test facility is available that meets all test requirements.

TNO is strongly involved in Beyond NCAP, PReVENT, Interactive and ASSESS. In ASSESS a standardized program to test pre-crash braking systems will be developed in close cooperation between OEMs, 1-tiers and test facilities. This includes updating and benchmarking of the involved test facilities, and development and execution of the test program. When the project is finished, the test program should be ready-to-use for e.g. EURONCAP tests. In Interactive the performance of collision mitigation and collision avoidance systems will be tested, also based on the results from ASSESS. The systems include autonomous braking and steering in critical situations. In addition to collision avoidance and mitigation, new technologies for environmentally sensitive driving will be supported by the project. The Beyond NCAP group also spends effort on the development towards a widely accepted standardized test program for various IVS systems.

Based on the developed test program, TNO will offer a complete test program for IVS systems. This program will most likely consist of (PreScan) simulations, HIL testing in VeHIL, crash-testing and test track testing, for which a partnership will be developed.

**SUMMARY/CONCLUSIONS**

IVS systems are increasingly present on the road. As extensive testing of these systems is needed to ensure a good performance in many different traffic situations, the development of a standardized test program is important. A test program should be developed such that it is applicable to various IVS systems and such that the amount and complexity of scenarios to be tested can be decreased. This can be achieved by a smart combination of simulations (e.g. PreScan), Hardware-in-the-Loop testing (e.g. VeHIL) and full scale test track testing.

**REFERENCES**


11. http://www.interactive-project.eu

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ABBREVIATIONS

ACC
   Adaptive Cruise Control

ADA System
   Advanced Driver Assistant System

dGPS
   Differential Global Positioning System

HIL
   Hardware in the Loop

IVS System
   Intelligent Vehicle Safety system

SIL
   Simulation in the Loop

TTC
   Time-to-collision

VRU
   vulnerable road user (e.g. cyclist, pedestrian)