The issue of empirical testing of Highly Automated Vehicles

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Abstract. The study concerns the issue of empirical testing of Highly Automated Vehicles (HAVs). The driver assistance systems used in the HAVs have been listed. The principles of testing conventional vehicles have been presented and reference has been made to specific tests described in normative documents. The dissimilarity of testing the HAVs has been presented against this background.

Keywords: experimental testing of motor vehicles, experimental testing of Highly Automated Vehicles

1. Introduction
The measures taken to minimise the number of hazardous situations include the introduction of driver assistance systems, which can eliminate or reduce the risk of a hazard or collision by monitoring of, warning against, or autonomic responding to, the threats having emerged. The active safety of vehicles can be improved by e.g. using Advanced Driver Assistance Systems (ADAS) [1]. Such systems are becoming increasingly often standard production equipment of new motor vehicles. When the human driver is replaced with an automated system, the impact of driver reaction time and his/her motor skill (time of motion), which vary from person to person and depend on the current psycho-physical driver’s condition, will be eliminated; instead, the time values being constant and characteristic for the automated system will be taken into account. The use of ADAS makes a direct step to replace the human driver with a machine and thus to build the autonomous vehicle capable of controlling itself and counteracting the loss of its controllability thanks to its capability of recognising the environment and performing collision-free motion without intervention from outside [1]. Simultaneously, the monotony of passive ride in the vehicle lengthens the driver reaction time in case of a sudden hazard. Another third-level problem is the possibility that some messages sent by the vehicle may escape driver’s attention. Such a case resulted in a fatal accident with a vehicle of this type [2]. The development and increasing commercial use of highly automated motor vehicles is unavoidable. The works on such vehicles are being carried out by numerous companies, see e.g. [3, 4]. Therefore, the issue of testing the vehicles of this type has become particularly important, especially due to the fact that their specificity of driving considerably differs from that of conventional ones.

2. The specificity of highly automated vehicles
To enable the full-scale existence of autonomous vehicles, the available automatic driver assistance systems should be continuously developed and brought to compatibility with each
other for their cooperation and reciprocal supplementing to be made possible. The Highly Automated Vehicles (HAVs) must support the following basic functions:

- to raise driver’s consciousness of the situation at least by e.g. displaying information about changes in the current speed limits or an unintentional lane change;
- to provide early warning of the possibility of a hazard by emitting acoustic signals, light signals in the form of tell-tale lamps or pictorial messages displayed on LCD screens, or haptic signals coming from driver’s seat or steering wheel;
- to intervene in order to prevent an accident or to reduce the accident effects at the instant when the driver reacts too late or fails to react at all; the system should be able to stop or slow down the vehicle when it recognizes that the driver does not take any action to avoid an imminent hazard or a collision.

The adequate operation of vehicles’ active safety systems is only possible when they incorporate many sensors, which may be divided, in the most general terms, into two groups, i.e. active and passive ones [5, 6]. The more so, for the HAVs to function correctly, they must be provided with a number of such devices, e.g. [7, 8, 9]: radars [10, 11], lidars [12, 13, 14], supersonic sensors [15, 16, 17, 18, 19], satellite navigation [20, 21, 22, 23, 24], a variety of cameras [25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35], rate and directional gyroscopes [36], and accelerometers [37, 38].

Based on the sensors used, specific driver assistance systems could be built and applied, such as:

- Dedicated Short Range Communication (DSRC) [39, 40];
- Satellite navigation (GPS, GLONASS, Beidou, Galileo) [20];
- Inertial Measurement Unit (IMU) – determining the position and orientation of an object in space by measuring its acceleration and angular velocity [41, 42];
- Blind Spot Warning [43, 44, 45];
- Cross Traffic Warning [46, 47, 48];
- Lane Departure Warning [49, 50];
- Lane Keep Assist [51, 52];
- Cruise Control [53, 54];
- Adaptive Cruise Control (ACC) [55, 56];
- Cooperative Adaptive Cruise Control (CACC) [57];
- Adaptive Cruise Control with Look-ahead Anticipation [58];
- Forward Collision Warning (FCW) [59];
- Autonomous Emergency Braking (AEB) [60];
- Pedestrian Detection [61, 62];
- Collision imminent steering [63, 64];
- Do-not-pass warning [65, 66, 67, 68];
- Left Turn Assist [69, 79, 71];
- Intersection Movement Assist [72, 73, 74];
- Emergency Electronic Brake Light (EEBL) [75, 76, 77, 78];
- Traffic Sign Recognition (TSR) [79];
- Traffic Jam Chauffer (TJS) [80, 81, 82];
- Park Assist [83, 84];
- Platooning – integrated escorting [85, 86, 87];
- Raster map, vector map [88, 89].

Three separate but interconnected real-time operation phases may be distinguished in the operation of the HAVs’ systems (similarly as it is in the industrial automatic control systems) [90, 91]:

1) starting phase, i.e. transition from the steady state of standstill to the operation state of the system;
2) working phase, i.e. the phase when the system begins its “normal” operation (the control algorithms reproduce the preset values);

3) termination phase, i.e. controlled transition from the normal operation to the standstill.

The entire process runs dynamically. If the quantities that describe the dynamic state of the system change insignificantly, then the control algorithms do not undergo structural changes. On the other hand, if the process is very dynamic (where big changes take place in a short time and/or various decisions must be made in real time), the object controlled requires the control algorithm structure to be changed. This means that the changes should be effected in such a case by physical switching over between the physical information transmission channels. Preferably, the transitions between individual states should be as smooth as possible. However, this requires an automatized control algorithm with a non-linear structure to be prepared for such a system. In consequence, the functioning of the system as a whole in real operation conditions must be verified by testing it in testing-ground and road conditions.

3. Vehicle testing

In the case of conventional vehicles operating within the man-vehicle-environment (MVE) system, the most important system component is the human vehicle driver, who is the source of the inputs that are strongly coupled with the basic movement of the vehicle and whose actions are decisive for the triggering or accepting of individual situations related to the vehicle movement.

Extensive research on the running characteristics of motor vehicles has made it possible to define and adopt the recommended test types and the test results evaluation criteria. Among such tests, the steerability and stability tests cover a set of problems related to the properties that determine not only the ease of steering a vehicle but also have a direct impact on active safety issues. The said properties are described by a set of characteristics of the vehicle as a dynamic system, representing its reactions (responses) to various external and internal forces and making it possible to predict the behaviour of the driver-vehicle system during various manoeuvres. The recognition and then appropriate shaping of vehicle’s running properties helps the driver to maintain vehicle’s stability while driving, especially in critical situations. The standard tests include:

- steady-state tests on a circular track [92, 93];
- step input applied to the steering wheel [94];
- braking in a turn [95];
- quick lane change [96, 97] (double lane-change manoeuvre test representing an attempt to avoid an obstacle);
- single-period sinusoidal input applied to the steering wheel [98, 99];
- continuous sinusoidal input applied to the steering wheel [95, 99];
- impulse and random steering wheel input [95, 99, 100];
- single lane-change attempt [101].

Due to the dissimilarity of the HAVs and the specificity of their controlling, a different approach to the road testing of such vehicles is necessary. Therefore, other tests are proposed:

- test conditions according to Standard ISO 17361 [102];
- test conditions according to Standard SAE-J2808-201701 [103];
- test conditions according to Standard SAE J3045-201507 [104];
- test conditions according to Standard Regulation UN ECE 131 [105, 106];
- division of test protocols Euro NCAP (New Car Assessment Programme) [107];
- test conditions according to the Euro NCAP AEB VRU scenario [108];
- test conditions according to the Euro NCAP AEB C2C scenario [16];
- test conditions according to the Euro NCAP LSS scenario [105];
- test conditions according to Standard Regulation UN ECE 130 [109];
- Lane Departure Warning (LDW) [110];
- Lane Keep Assist (LKA) (road edge: dashed line, solid line) [110];
- Emergency Lane Keep (ELK) (road edge, oncoming, overtake) [110].

Examples of the tests have been shown in Figures 1 to 4.
Fig. 1. AEB Pedestrian, Case CPFA-50. A simulation where the moving vehicle is on a collision path with an adult pedestrian running across the path from the driver’s side. The collision with the pedestrian, in the case that the system fails to intervene, would occur in the front part of the vehicle in 50% of its width. During the test, the vehicle brakes shall not be applied manually [108].

Fig. 2. AEB Pedestrian, Case CPNC-50. A simulation where the moving vehicle is on a collision path with a child running across the path from the passenger’s side. The collision with the pedestrian, in the case that the system fails to intervene, would occur in the front part of the vehicle in 50% of its width. During the test, the vehicle brakes shall not be applied manually [108].

Fig. 3. AEB City. Only the AEB (Autonomous Emergency Braking) system is tested. Here, a single AEB CCRs (Car-to-Car Rear stationary) scenario has been taken into account, where a vehicle moving forwards hits its front part on the rear of a stationary vehicle. The test is carried out for different values of the offset between the symmetry axes of the vehicles involved. The impacting vehicle may only come to a halt when its test speed does not exceed 20 km/h [108].
Fig. 4. Lane Departure Warning (LDW). The test is performed for three road marking types: a solid line on one side, a broken line on one side, and complete lane marking [110].

4. Summary
Autonomous vehicles make one of the main goals of development of the automotive industry. With the technology development, updated or new versions of legal instruments are introduced in order to regulate and standardize the modes of operation and methods of testing of advanced driver assistance systems and autonomous vehicles. Such actions are, inter alia, to make it possible for the autonomous vehicles to move on public roads as well as to standardize the requirements such systems must meet. This also forces the testing of such systems before they are launched for commercial use. The testing of the highly automated vehicles (autonomous from a level higher than 3) is based, first of all, on examining such systems in simulation conditions and in real operation conditions on testing grounds and in urban traffic. The provision of adequate infrastructure for the tests is critical because this has an impact not only on the test results but also on the safety of the tests. During the tests in real conditions, continuous communication with the autonomous vehicle should be ensured by a DSRC (Dedicated Short Range Communication) system, which not only is responsible for uninterrupted supervision of the test but also makes it possible to transmit simulated information about e.g. traffic intensity or the operation of traffic lights to the vehicle under test.

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[108] EUROPEAN NEW CAR ASSESSMENT PROGRAMME (Euro NCAP) TEST PROTOCOL – AEB systems, Version 2.0.1, November 2017, https://cdn.euroncap.com/media/32278/euro-ncap-aeb-c2c-test-protocol-v201.pdf, access 01.02.2022.

[109] COMMISSION REGULATION (EU) No 130/2012 concerning type-approval requirements for motor vehicles with regard to vehicle access and manoeuvrability and implementing Regulation (EC) No 661/2009 of the European Parliament and of the Council concerning type-approval requirements for the general safety of motor vehicles, their trailers and systems, components and separate technical units intended therefor.

[110] SAS Test Protocol v2.0, January 2018, https://www.euroncap.com/en/for-engineers/protocols/safety-assist/, access 01.02.2022.