System of Requirements and Testing Procedures for Autonomous Driving Technologies

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Abstract. This article is dedicated to the subject of autonomous driving technologies’ testing system development for the purposes of technology certification on local market with respect to the local operational peculiarities and road safety aspects. The overview of UNECE document ‘Proposal for the Future Certification of Automated/Autonomous Driving Systems’ (ECE/TRANS/WP.29/GRVA/2019/13) is presented. Proposals for critical testing scenarios localization and complex virtual tests conduction are introduced, practical results are presented.

1. Introduction
The aim of our study is to develop a testing system for autonomous vehicles with respect to the peculiarities of road and weather-climatic conditions of the Russian Federation and Customs Union countries. The results of our study can be considered in the national certification system at type approval level, as well as in any process of developing autonomous driving technologies.

Why do we think that this subject is so important and relevant? The rapid worldwide attempts to implement autonomous driving technologies with ADAS (advanced driver assistance systems) functionality at the first stage [1] and the lack of legal regulation in Russia have led to the situation when we have a lot of modern road vehicles with ADAS on public roads. These ADAS systems (autonomous emergency braking, lane keeping, automated parking, etc.) have not been tested and may not have been adapted for use in Russian conditions [2]. Of course, it is a potential threat to national road safety.

Among our objectives we emphasize the analysis of foreign experience, localization of critical testing scenarios, making amendments to the Technical Regulations of the Customs Union (TR CU 018) [3].

It is important to mention, that testing of autonomous driving technologies is very important and can be applied to the development process and to the process of technology certification. These processes are essentially different if we are not talking about self-certification regime. Car manufacturers and their suppliers are involved in the development process [4], and testing in certification is carried out by approval authorities [5]. We make focus of our study on certification process only.

2. Testing in Certification
With the introduction of automated driving systems, the complexity and thereby the number of software-based functions will continue to increase in vehicles. When we are talking about automated and autonomous road vehicles in comparison with conventional vehicles, the potentially affected safety-areas and variances of scenarios will increase and cannot fully be assessed with a limited number of
tests that are performed on a test track or test bench. Figure 1 illustrates enormous number of test scenarios for vehicles with high SAE levels of automation [6].

![Figure 1. Number of test scenarios required for validation and verification cycles in autonomous vehicles.](image)

Physical testing only is no longer feasible, as well as ‘classical’ certification approach. The most relevant document in this field was recently published by the United Nations Economic Commission for Europe (UNECE) WP.29 on automated/autonomous and connected vehicles, and it is called ‘Proposal for the Future Certification of Automated/Autonomous Driving Systems’ [7]. The concept for the future certification of automated and autonomous driving systems is shown in figure 2. This approach consists of three components or three pillars. The first one correlates with the audit of developmental process and involves virtual testing of exotic scenarios with low statistical probability in real life – see figure 3. The second pillar involves validation of previously used mathematical models in virtual tests, as well as conduction of critical scenarios on proving ground. The third pillar deals with typical scenarios and tests on public roads.

![Figure 2. Concept for the future certification of autonomous driving systems – the three pillars.](image)
It is important to mention, that the choice of testing scenarios at each component level of the above approach will be different for each market and have to consider the peculiarities of operational conditions (weather, climate, typical road pavement, cultural and psychophysiological features, etc.).

Figure 3. Example of different test cases with respect to the pillars’ functions.

We’ve got fully-detailed statistics of road accidents in Russia from the Ministry of the Interior (MVD), and we’re trying to localize relevant Russian scenarios for the purposes of automated and autonomous road vehicles testing in certification – it is the subject of future work.

Currently, we propose using the next sequence of actions for critical testing scenarios localization and initial states for each scenario detection:

1. Real road accidents statistics analysis, applicable for local market.
2. Definition of the test’s purpose, which may include: the task of functional or operational safety monitoring; determination of operating conditions, reliability metrics, fault tolerance, performance variation between the same cars, as well as during the whole life cycle, etc.
3. Creation of test scenarios or selection and/or modifying from the existing ones (e.g. EuroNCAP, ADAC, ISO):
   a. Definition of ranges of changeable parameters of the system ‘driver—car—road—environment’ [8].
   b. The choice of evaluation criteria and their permissible values.
4. Flow simulation of all possible variations of the developed test scenarios in a virtual environment performing:
   a. Critical testing scenarios detection with respect to the test’s purpose.
5. Critical scenarios’ field tests performing:
   a. Virtual model’s parameters validation, the above cycle repetition.
6. Making resolution or performing changes in the design or control algorithms to achieve goals of testing.

3. Virtual Tests
Moscow Automobile and Road Construction State Technical University (MADI) is the first organization in Russia which has officially purchased the license for Prescan software (Siemens). This software is a physics-based simulation platform that is used in the automotive industry for development of ADAS. We have tested several software solutions from different companies, but have chosen Prescan software, because it has most detailed models for vehicles, sensors (radars, lidars, cameras, etc.), and infrastructure elements. The next important reason is that this software has an opportunity to simulate different weather conditions (rain, fog, snow, etc.), road characteristics (roughness, holes, inclinations, speed bumps, friction coefficients, etc.), lighting (day, night, glare of the sun, etc.), custom objects, and custom control algorithms. Thus, this software solution is very flexible.

Several examples of ADAS virtual testing (Advanced Emergency Braking System – AEBS) with respect to the road and weather-climatic conditions in Russia are shown below.

We simulated straight driving of a host car with initial speed of 60 km/h with a stationary object (Euro NCAP car target) on a way. It’s one of the standard Euro NCAP tests [9], but we have modified it with another environmental and road conditions [10, 11]: winter time, snow weather and wet road conditions have been used (figure 4).

![Figure 4. Visualization of virtual test conditions.](image)

The AEBS control algorithm gave a warning at 2.6s TTC (time to collision), then it applied 40% of braking at 1.6s TTC, and 100% of braking at 0.6s TTC [12]. Virtual vehicle under test was equipped with long range radar (LRR – 120m range, 9 degrees narrow beam) and short range radar (SRR – 30m range, 90 degrees wide beam). The test scenarios were as follows: 1) driving with idealized radar sensors; 2) driving with characteristics of real radars (Continental ARS510 as a LLR, and Continental SRR510 as a SRR with appropriate characteristics [13]).

Figure 5 illustrates virtual AEBS operation with idealized sensors during snowfall. Collision has occurred at driving speed of 28.05 km/h because of lower road friction coefficient only.
Figure 5. AEBS virtual test – stationary target, wet asphalt, winter time, snowfall, idealized sensors.

For the second test specific radar’s antenna characteristics (figure 6) have been used, as well as the specific characteristics of atmospheric attenuation (figure 7).

Figure 6. Radar antenna patterns.
Figure 7. Characteristics of atmospheric attenuation.

Figure 8 illustrates virtual AEBS operation with characteristics of real radars during snowfall. Collision was not avoided, collision has occurred at driving speed of 44.52 km/h. Warning and partial braking TTC values of the second test were lower (late detection and action). In the second case we see malfunction of AEBS control algorithm (the graph of deceleration in figure 8 – it suddenly stopped braking at the stage of partial braking). Perhaps, this situation has occurred because of target tracking fail. In any case, we see that the results of virtual tests are essentially sensitive to the adequacy of ADAS control algorithms and sensors characteristics.

Figure 8. AEBS virtual test – stationary target, wet asphalt, winter time, snowfall, real radars.

The information of exact ADAS control algorithms and vision recognition system characteristics is very important for virtual tests and critical scenarios detection. This type of information can be provided by car manufactures or their OEMs only. Of course this information is essentially confident, but it can be provided as a hardware or software “black boxes” for testing purposes.

4. Virtual Proving Ground
Virtual proving ground is a very important instrument in the task of complex simulations conduction. Of course it is better to have a digital copy of a real proving ground than some imagined one, because it will be possible to validate mathematical models used in simulation. One of such examples is a virtual Mcity proving ground (University of Michigan) integrated in CarSim software [14].
We have made a detailed virtual proving ground which is the copy of Dmitrovskiy automotive proving ground for automated and autonomous vehicles (FSUE ‘NAMI’). Figures 9-11 illustrate some results of our work. This virtual proving ground was designed in Prescan software and it is geodetically attached to the real proving ground in WGS-84 coordinates. Such an approach simplifies the process of virtual simulation results comparison with road tests.

Figure 9. Virtual proving ground for testing of autonomous driving technologies.

Figure 10. Virtual proving ground for testing of autonomous driving technologies.
Figure 11. Virtual proving ground for testing of autonomous driving technologies.

Our virtual proving ground consists of roads, crossings, road marking, buildings, traffic lights, road signs, guardrails, street lamps, bus stops, cars, trucks, pedestrians, etc. Complex virtual tests conduction is the subject of our future work and we’ll present it later.

5. Conclusion
The overview of UNECE document ‘Proposal for the Future Certification of Automated/Autonomous Driving Systems’ (ECE/TRANS/WP.29/GRVA/2019/13) was presented. Our vision of autonomous driving technologies’ testing system development for the purposes of technology authorization on local market with respect to the local operational peculiarities and road safety aspects was introduced.

We have proposed a method for addressing the issue of critical testing scenarios localization and initial states for each scenario detection.

Results of AEBS virtual testing with respect to the road and weather-climatic conditions in Russia were presented. The information of exact ADAS control algorithms and vision recognition system characteristics is essentially important for virtual tests.

We have introduced a detailed virtual proving ground which is the copy of Dmitrovskiy automotive proving ground for automated and autonomous vehicles (FSUE ‘NAMI’). This virtual proving ground was designed in Prescan software and it is geodetically attached to the real proving ground in WGS-84 coordinates. Such an approach simplifies the process of virtual simulation results comparison with road tests.

A comprehensive approach with the use of virtual and field tests is needed to assess the safety of autonomous road vehicles with respect to the peculiarities of road and weather-climatic conditions in Russia. AVs legal permission to access public roads should be done after comprehensive tests only.

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