Development of autonomous vehicles’ testing system

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Abstract. This article describes overview of automated and, in perspective, autonomous vehicles’ (AV) implementation risks. Set of activities, actual before the use of AVs on public roads, minimizing negative technical and social problems of AVs’ implementation is presented. Classification of vehicle’s automated control systems operating conditions is formulated. Groups of tests for AVs are developed and justified, sequence of AVs’ testing system formation is proposed.

1. Introduction
In recent years, improvement of car design is concentrated in the area of control automation. There are cars on the market with electronic driver assistance systems (DAS/ADAS), such as dynamic stability control systems, lane-keeping systems, advanced emergency braking systems (AEBS), adaptive cruise control, automatic parking and others. Some manufactures have developed cars with automatically commanded steering function technology (ASCF), available at high speed driving. The issues of complete automation of vehicle control, that is, the production of fully autonomous cars (5th SAE level) and their operation on public roads are actively discussed all over the world [1]. Thus, the following advantages of cars transition to AVs [2] can be mentioned:

- road accidents reduction;
- increase of road capacity;
- increase of average driving speed;
- traffic jams reduction;
- reduction of exhaust emissions;
- reduction of driver’s workload;
- useful free time usage by driver;
- transportation cost reduction.

Automatic control systems progress and preparation of fully AVs for use on public roads have caused the change of Vienna convention on road traffic [3]. Accepted corrections allow to control and change parameters of vehicle motion not only by driver, but also by vehicle’s automatic control systems.

At the same time, construction and control algorithms of vehicle’s automatic control systems analysis has shown, that transition to automated and, in perspective, AVs could lead to the next negative technical and social problems [2]:

- inadequate car’s behavior due to imperfection of control algorithms;
- inadequate car’s behavior in the events of failures, malfunctions, connection with infrastructure lost, after road accidents, vehicle’s parameters change (tires change, software modification);
- malfunction due to conflict of driver’s actions and automatic systems operation;
• unemployment of professional drivers;
• operation in conditions, which are not specified by car manufacturer;
• lack of cybersecurity;
• moral and ethical problems;
• contradiction with existing national legislation.
Solving of the above problems is actual and well-timed task.

2. Autonomous Vehicles’ Testing System
So that to minimize listed implementation risks, set of activities offers to be done prior getting of legal
permission for automated systems and AVs to access public roads (see Table 1). The proposed actions
relate to car manufactures, for example, in the case of service manual content, car’s compliance
verification according to national legislation aspects, as well as AVs’ testing system before the use on
public roads improvement, and process of periodic technical inspections enhancement. Fundamentally,
the testing system should cover the whole life cycle of AV, beginning from the stage of design and
ending with utilization. At the same time, methods of testing consist of simulations, proving ground
tests, public road tests and further data monitoring of automated systems in use.

Table 1. Set of activities for automated (autonomous) car’s systems implementation risks minimizing.

| Problem | Solution for risks reduction |
|---------|-----------------------------|
| 1. Inadequate behavior due to control algorithms. | Testing of functional safety (ISO 26262), as well as operational safety with simulation of typical Russian road conditions and situations. |
| 2. Inadequate behavior in use: | Testing with simulation of abnormal system operation (hazard identification and risk assessment). |
| - due to failures, malfunctions, connection with infrastructure lost; | Virtual and full-scale crash tests conduction with activated system (elements of the system) of autonomous driving. |
| - after road accident; | It is necessary to ensure: |
| - due to vehicle’s parameters change. | - monitoring during periodic technical inspections. |
| 3. Wrong or late driver’s actions. | It is necessary to develop: |
| | - requirements for the human-machine interface; |
| | - testing methods for conflict situations; |
| | - requirements for service manual content; |
| | - change of driver training process. |
| 4. Drivers’ unemployment. | Step-by-step AVs implementation. |
| 5. Operation in conditions, which are not specified by car manufacturer. | Requirements for service manual content. |
| 6. Poor cybersecurity. | Parameters of cybersecurity testing. |
| 7. Moral and ethical problems. | Development of the principles of system operation in conflict situations. |
| | Requirements for implementation of these principles in control algorithms. |
| 8. Contradiction with existing legislation. | Access to public road after design improvements or legislation changes. |

Consider a common approach to the content of automated systems, as well as AVs, testing system
before their driving on public roads. One of the main questions in testing system development is the
next – in what road situations (typical, conflict, emergency) should AVs or automatic control systems
be tested?
Research works, that were held in USA [4, 5], have allowed to formulate those road situations to which car’s automatic control systems should respond adequately, namely:

- detect and respond to speed limit changes;
- perform high speed freeway merge;
- perform low speed merge;
- park on the shoulder or transition the vehicle to a minimal risk state;
- detect and respond to dangerous oncoming traffic;
- detection of permitted and restricted zones for driving on the road, and maneuvers performing in permitted areas;
- perform car following including ‘stop and go’ and emergency braking;
- detect and respond to stopped vehicles;
- detect and respond to intended lane changes;
- detect and respond to static obstacles in roadway;
- detection of traffic light signals, road signs of stopping and giving the way;
- respond to traffic light signals, road signs of stopping and giving the way;
- navigate intersections and perform turns;
- perform driving at roundabouts;
- detection of free parking slots and parking;
- detect and respond to prescriptive and prohibitory road signs;
- detect and respond to traffic-controller’s signals;
- follow the priority rights of driving;
- respect other requirements of national traffic rules;
- follow other road requirements (temporary road signs, marking, etc.);
- detect and drive safely in road repair areas;
- react to the situation in the area of road accident;
- detect and respond to emergency vehicles;
- detect and respond to cars with activated light alarm;
- give way to pedestrians and cyclists on pedestrian crossings;
- ensure safe distance between vehicles, pedestrians, cyclists on roadside;
- detect and respond to temporary changes in traffic patterns.

This list can be broadened out with situations, actual for Russian operating conditions:

- perform overtaking on two-lane roads with oncoming traffic;
- choose safe cornering speed;
- detect and respond to dangerous defects of road pavement (roughness, ruts, etc.), as well as road areas with poor adhesion characteristics.

Actual set of road situations for automated control systems testing pattern depends on functional purpose and application conditions of tested system. The following grading of operating conditions is suggested:

- geographic location (country, region, city, etc.);
- road types (e.g., highways, one-way or dual road with oncoming traffic, parking areas, etc.);
- weather conditions (temperature range, relative humidity, possible road surface conditions, possible atmospheric phenomena, etc.);
- time of a day (day, night, time ranges);
- available speed ranges;
- other conditions (traffic type, requirements to infrastructure and so forth).

Car manufacturer in service manual handbook should provide the above listed information, and this information defines quantity and specification of conducted tests.

At present, there are some standardized methods for testing of automated control systems, namely:

- UN Regulations 131 [6]:
  - braking with stationary target;
  - braking with a moving target.
• Standard ISO 22839 [7] with requirements and test procedures for emergency braking systems:
  - braking with slow target;
  - motorcycle beyond the duplicated target begins braking;
  - duplicate target appearance in the nearest lane;
  - target drives in road lane with lateral offset;
  - duplicate target appearance in the nearest lane while cornering;
  - target above the road.
Draft of automatic steering systems’ testing procedures that is intended to be included in UN
Regulations 79 is of attentive interest [8]:
  + Functional tests:
    • FU 1 - lane keeping;
    • FU 2 - lane change process interruption;
    • FU 3 - lane change.
  + Provocative tests:
    • TR 1 - lateral acceleration limit exceeding;
    • TR 2 - road marking disappearance;
    • TR 3 - driver loss;
    • TR 4 - sensor failure;
    • TR 5 - driver's force in control process during automated minimal risk maneuver performing.
  + Emergency tests:
    • EM 1 - braking in front of moving target;
    • EM 2 - braking in front of stationary target.

It should be noted that most of the tests simulate driving on a highway during the day in dry weather, which is a cause of objective criticism.

In general, combination of possible external conditions, vehicle conditions, actions of driver and other traffic participants, and variability of traffic situations form infinite number of possible scenarios for automated (autonomous) vehicle control systems’ functional testing. Thus, nobody can guarantee 100% safety of autonomous vehicle operation, as well as operation of its driver assistance subsystems. In this case, we suppose the following sequence of necessary actions to be logically reasoned: 1) extended requirements development for product certification at type approval level; 2) requirements implementation to car manufacturer to apply the system of functional safety ensuring at all stages of product’s life cycle; 3) independent control of autonomous vehicles’ safety parameters in use.

We consider that automated (autonomous) vehicles’ testing system should include four main groups of tests:

  1) functional tests – tests in which system’s performance is checked in accordance with intended purpose in normal conditions, special attention is paid to the interaction with other vehicle systems;
  2) provocative tests – tests in which the probability of false positives is examined, as well as noise immunity, system’s behavior in the event of malfunctions, and exceeding the limits of acceptable conditions of use;
  3) emergency tests - test of system response to critical situations, not related to the functional purpose, including impact of random events assessment;
  4) interaction with a driver – tests in which system reaction is checked when driver intervenes or does not interfere with control actions, including the presence of deliberately inadequate actions.

In view of the foregoing, the following sequence of actions is proposed for AVs’ testing system formation:

• ascertaining permissible operating conditions and functionality of individual automatic control systems (performs by car manufacturer);
• choice of functional, provocative, emergency tests and interaction with a driver testing procedures for individual subsystems and/or complete autonomous vehicle with respect to permissible operating condition;
• tests conduction.
Example of proposed test procedures for advanced emergency braking system (AEBS) with operating conditions of highway driving in dry or rainy weather is shown below (see Table 2).

**Table 2. Proposed AEBS test procedures.**

| Tests                      | Method sample                      |
|----------------------------|------------------------------------|
| **Functional tests**       |                                    |
| 1. Braking in front of stationary target: | UN Reg. 131, Reg. 79 Amend. (EM2). |
| - dry road surface;        | Test procedure has not been developed. |
| - wet road surface.        |                                    |
| 2. Braking in front of moving target: | UN Reg. 131, Reg. 79 Amend. (EM1), ISO 22839. |
| - dry road surface;        | Test procedure has not been developed. |
| - wet road surface.        |                                    |
| **Provocative tests**      |                                    |
| 1. Motorcycle braking beyond the target. | ISO 22839 |
| 2. Duplicate target in the nearest lane. | ISO 22839 |
| 3. Target drives with lateral offset. | ISO 22839 |
| 4. Duplicate target in the nearest lane while cornering. | ISO 22839 |
| 5. Target above the road.  | ISO 22839 |
| 6. Car-leader overtakes stationary target. | ISO 22178 |
| **Interaction with a driver tests** |                                    |
| 1. Steer attempt of collision avoidance with target after AEBS activation. | Test procedure has not been developed. |

3. Conclusion

It is necessary to provide for set of activities to be done prior getting of legal permission for automated systems and AVs to access public roads, so that to reduce negative implementation risks. The main technical step is testing system development with respect to permissible operating conditions and automated control systems functionality. It is necessary to develop test procedures for specific road situations, taking into consideration typical weather conditions, proving grounds improvement is also of important tasks.

The following sequence of actions is proposed for AVs’ testing system formation at type approval level:

- ascertaining permissible operating conditions and functionality of individual automatic control systems (performs by car manufacturer);
- choice of functional, provocative, emergency tests and interaction with a driver testing procedures for individual subsystems and/or complete autonomous vehicle with respect to permissible operating condition;
- tests conduction.

References

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[3] Annex to report of the sixty-eighth session of the Working Party on Road Traffic Safety (Geneva) 2014 ECE/TRANS/WP.1/145
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[5] Federal Automated Vehicles Policy Accelerating the Next Revolution in Roadway Safety U.S. Department of Transportation NHTSA 2016 12507-091216-v9 p 116

[6] UNITED NATIONS: Regulation 131. Uniform provisions concerning the approval of motor vehicles with regard to the Advanced Emergency Braking Systems (AEBS)

[7] ISO 22839:2013 Intelligent transport systems – Forward vehicle collision mitigation systems – Operation, performance, and verification requirements

[8] Proposal for amendments to Regulation No 79 to include ACSF > 10 km/h. (Informal Document: ACSF-05-03) The proposal is based on document ACSF 04-20 Submitted by the experts of Germany and Japan