OPERATING EFFICIENCY OF ACTIVE SAFETY SYSTEMS IN THE CONTEXT OF THE RUSSIAN FEDERATION

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ABSTRACT

One of the most effective ways to solve the traffic safety problem is the creation of intelligent active safety systems (IASS). Almost all modern transport vehicles (TV) are equipped with such systems. The most widely used systems are: automatic emergency braking system, lane departure warning system, longitudinal wheel slip stabilization system, emergency brake assist system, tire-pressure monitoring system, and driver's condition control system. Practical application of these systems allowed reducing the number of traffic accidents and mortality of the population on the roads more than twice.

Nevertheless, all over the world, the most active measures are taken to improve the regulatory documentation with respect of IASS systems, as well as large-scale research and development is ongoing to improve the reliability and efficiency of these systems, using the latest achievements of modern science and technology. This is due to the fact that active safety systems have limited ranges of reliable operation, not covering all high-speed operating modes of vehicles. Adverse vehicle operating conditions such as dirtiness or damage of windshield, poor lighting (insufficient illumination of lanes, blinding by the light of oncoming cars), poor weather conditions (snowfall, icing, heavy fog, rain), the absence or poor marking of lanes, etc. significantly decrease the effectiveness of the IASS operation.

The present article deals with the general issues to improve the efficiency and reliability of the IASS, as well as considers the research results of advanced emergency braking system and lane departure warning system in the auto test track conditions at different speed rates of the vehicle and the simulation of adverse operating conditions.

Keywords: intelligent active safety systems, control unit, sensor, radar, video camera, traffic lane, emergency braking.
**1. INTRODUCTION**

In the current context of globalization, in the interests of optimizing resources, the coherence of policies is undertaken by advanced countries to promote vehicle automated management technologies aimed at minimizing nontariff barriers. A common global approach to form the regulatory framework for on-board intelligent active safety systems (IASS) and vehicle control automation is being developed and applied. The United Nations Economic Commission for Europe (UNECE), and in particular the World Forum for Harmonization of Vehicle Regulations (WP.29), as well as the Global Forum for Road Traffic Safety (WP.1) included in the structure of the UNECE Inland Transport Committee (ITC), which brings together representatives of countries having signed international agreements in the field of vehicle safety, including the Russian Federation, play a significant role in this issue.

A number of directive documents have been developed within the framework of the UNECE to form a common understanding of the IASS and IASS based driver assistance principles, as well as issues related to terminology, automated vehicles’ classification, and general principles of vehicles’ cybersecurity [1-5]. Information on the IASS systems, for which technical requirements are established in the UN Regulation, is presented in Table 1.

<table>
<thead>
<tr>
<th>On-board IASS</th>
<th>UN Regulation</th>
<th>Applicable scope</th>
<th>Brief description of the requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic Stability Control (ESC) system</td>
<td># 13 – Uniform provisions concerning the approval of vehicles of M, N and O categories with regard to braking</td>
<td>M2, M3, N, O</td>
<td>Comparative road tests on the stability of the vehicle with switched on and off ESC system should show the effectiveness of the system</td>
</tr>
<tr>
<td>ESC and Brake Assist System (BAS)</td>
<td># 13H – Uniform provisions concerning the approval of passenger cars with regard to braking</td>
<td>M1, N1</td>
<td>In tests with sinusoidal impact on the steering wheel, the angular velocity of the vehicle in the plane and the lateral displacement are checked</td>
</tr>
<tr>
<td>Video surveillance systems (video camera / monitor, other devices)</td>
<td># 46 – Uniform provisions concerning the approval of devices for indirect vision, and motorized vehicles with regard to the installation of these devices</td>
<td>M, N</td>
<td>Requirements for the scanning duration of the field of view, functional requirements, requirements for the arrangement of the monitor inside the vehicle</td>
</tr>
<tr>
<td>Automatic main headlight switching system</td>
<td># 48– Uniform provisions concerning the approval of a vehicle with regard to the installation of lighting and light-alarm devices</td>
<td>M, N, O</td>
<td>Requirements for the identification of oncoming and passing vehicles, at which the switching of main headlights must occur</td>
</tr>
<tr>
<td>On-board IASS</td>
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<tr>
<td>Tire-pressure monitoring system (TPMS)</td>
<td># 64 – Uniform provisions concerning the approval of the vehicles with regard to their equipment, which may include a spare wheel with a fitted tire for temporary use, tires suitable for use in the deflated condition, and/or a system for deflated tire service, and TPMS. # 141– Uniform provisions concerning the approval of the vehicle with regard to tire pressure monitoring system</td>
<td>M1</td>
<td>The efficiency of the system is checked in case of a sudden pressure drop in one of the tires (tire blowout) and a gradual pressure drop in all tires during operation</td>
</tr>
<tr>
<td>Automatically Commanded Steering Function (ACSF)</td>
<td># 79 – Uniform provisions concerning the approval of vehicles with regard to steering mechanisms</td>
<td>M, N, O</td>
<td>Requirements are introduced for individual functions of automated steering, which include driver assistance when parking, changing lane, corrective steering, and emergency steering</td>
</tr>
<tr>
<td>Adaptive Front-Lighting System (AFS)</td>
<td># 123 – Uniform provisions concerning the approval of AFS for motor vehicles</td>
<td>M, N</td>
<td>The installed photometric characteristics of the dipped-beam and high-beam lights are checked in the mode of rotary lighting with lateral displacement or change of beams in the case of bends, turns and road intersections</td>
</tr>
<tr>
<td>Lane Departure Warning System (LDWS)</td>
<td># 130 – Uniform provisions concerning the approval of motor vehicles with regard to LDWS</td>
<td>M2, M3, N2, N3</td>
<td>The system shall alert the driver when the outer part of the front wheel tire crosses a line spaced by 0.3 m from the outer edge of the marking line</td>
</tr>
<tr>
<td>Advanced Emergency Braking System (AEBS)</td>
<td># 131– Uniform provisions concerning the approval of motor vehicles with regard to the AEBS</td>
<td>M2, M3, N2, N3</td>
<td>If a moving or stationary obstacle is detected ahead of the driver, the system shall alert the driver and, if the driver has not responded, start emergency braking of the vehicle in order to reduce the speed of the collision or avoid a collision with the obstacle</td>
</tr>
</tbody>
</table>

In the European Union, the introduction of new requirements relating to the IASS is preceded by numerous studies aimed at justifying the need to apply these requirements. Meetings are held with vehicle manufacturers and the IASS components’ manufacturers.
analysis of road accidents is carried out, scientific publications are studied, etc. These activities result in the determination of the cost and benefits factor. A description of the procedures to determine this factor in respect to the IASS functions is presented in the report [1]. Subsequently, this factor is used to develop proposals on the statutory regulation of individual functions.

The assessment of reliability and efficiency of active safety systems carried out earlier by FSUE "NAMI" [6-12] has shown that:

- modern active safety systems can potentially prevent up to 57% of typical collisions possible in road and climatic conditions close to ideal;
- adaptation of active safety systems with similar functions to the road and climatic conditions of the Russian Federation is associated with the need to make significant changes in the hardware and software;
- to create new hardware with improved characteristics and capabilities, new materials and technologies are required.

FSUE "NAMI" conducts a set of studies to assess the effectiveness and reliability of modern active safety systems. This article presents the materials related to the conducted studies to assess the efficiency and reliability of the AEBS and LDWS at different speed rates of vehicles tested in simulated adverse operating conditions.

2. METHODS

Experimental studies of active safety systems (AEBS and LDWS) were carried out at the Dmitrovsky auto test track of "FSUE NAMI" in operating conditions typical for the Russian Federation.

Road tests of the AEBS were carried out using passenger cars with stationary and mobile targets at the complex of special roads and at the closed acceleration lane. A pneumatic target and M1 category passenger car were used as targets. The tests were carried out using two cars in accordance with techniques based on the provisions of UN Regulation No. 131 "Uniform provisions concerning the approval of motor vehicles with regard to the Advanced Emergency Braking Systems (AEBS)" (Appendix 130) [3], international standards ISO 15623:2013 "Intelligent transport systems. Forward vehicle collision warning systems. Performance requirements and test procedures" [4], and ISO 17361:2007 "Intelligent transport systems. Lane departure warning systems. Performance requirements and test procedures" [5].

When testing the AEBS for races with a fixed target, the road section 120 m long and 4 m wide with an asphaltic concrete surface of the average roughness was used. Before entering the test area, the object accelerated to the specified speed. A soft target was set at the end of the test area.

The sensor part of the subsystem of AEBS of the first car consisted of a combination of devices which included a video camera located next to the rear-view mirror and radar installed behind the decorative grill. On the outside, the radar was protected by a transparent plastic cover. The sensor subsystem of the AEBS on the second car consisted of a video camera and radar. The arrangement and design of the camera were similar to those of the first car.

The test area was marked with the emergency cones installed on both sides of the road. Cones were installed at a distance of 10 m from each other. The presence of cones allowed for visual control of car movement along the centerline of the target.

The rear part of car model of “Moshon Data Ltd” company was used as a soft target for testing (Figure 1).
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Figure 1 The car model of “Moshon Data Ltd” company.

To assess the effect of the adhesive properties of the roadway covering on the effectiveness of the AEBS, test area was wetted with water (Figure 2).

Figure 2 Wetting the test area by street sprinkler.

When testing a stationary target, the model was mounted on a movable support, which was a metal base with two wheels and two sliding legs. When using the model in dynamic tests (as a moving target), a towing system was used, consisting of a base plate with a coupling device, three hoses 15 meters long, supports for hoses with rollers and belts for fixing the supports. To assess the operation of the AEBS in limited visibility conditions (imitation of fog), the fumigation of the test area was produced directly behind the target. In order to create a uniform fumigation of the road, tests were performed on a closed acceleration lane with a length of 100 m (Figure 3).

Figure 3 Testing the system on a closed acceleration lane.

When testing the effectiveness of the system operation on the road with dry asphaltic concrete pavement using the car #1, for safety purposes, the main tests were carried out starting with a speed of 30 km/h. Making sure that the system was operating properly, the speed of car was increased by 20 km/h (up to 50 km/h), and then again by 10 km/h (up to 60 km/h). After
that, each time the speed was increased by 5 km/h (up to 80 km/h). At the speed of 80 km/h, the system operated normally (giving 35 warnings with subsequent automatic braking), but in the course of braking there was a collision of the car with the target at the speed of 26.1 km/h. For car and target safety purpose, the speed of subsequent runs was limited to 75 km/h (warnings with subsequent automatic braking).

Testing functional characteristics of the LDWS was carried out in accordance with the test technique in the framework of the international standard ISO 17361:2007 [5] using three commercial vehicles, namely DAF, Mercedes-Benz Sprinter, and Volkswagen Crafter equipped with systems under test (Fig. 4). During the tests, the vehicle was moving at a constant speed towards the center of the test lane. Then the vehicle shifted to the side with a certain transverse speed, crossing the lane marking. At that, in accordance with ISO 17361:2007, the warning alerts of leaving the traffic lane were recorded. We assessed the negative impact of the vehicle operating conditions, such as windshield dirtying or damage, poor lighting (insufficient illumination of lanes, blinding by the light of oncoming cars), poor weather conditions (snowfall, icing, heavy fog, rain), the absence or poor marking of lanes, etc.

3. RESULTS

3.1. Test results of AEBS

The operational integrity of the AEBS on cars #1 and #2 was tested within the speed range from 15 to 80 km/h. In the conditions of good visibility, when approaching the soft target, the system confidently (in 100% of cases) recognized the target and gave warning alerts about the collision danger. The warning stage was followed by automatic braking. The cars stopped without a collision with the target when driving from the initial speeds up to 77÷78 km/h (car #1), and up to 53÷55 km/h (car #2).

When tested with a stationary target on dry asphaltic concrete, the efficiency of the system was further tested in conditions of limited visibility range (fumigation of the target and the test area, dirtiness of the windshield in the area of the camera installation) and when blocking the sensors of the sensor subsystem (shielding of the camera and radar).

When recognizing objects on the road, the system was guided by the signals coming from each of the devices of the sensor subsystem, i.e. camera and radar. There was no priority in target recognition by any of these devices. In the case of inability to receive information from one of the devices caused by the lack of visibility ahead of the car (heavy smoke, full blockage of the camera lens), or the inability to receive the radar reflected signal, the system was not activated.

A slight deterioration in the visibility of the target and contamination of the windshield in the camera installation area did not affect the performance of systems since sensor subsystems confidently recognized the target and activated the warning signals.

Tests on the road with wet asphaltic concrete showed that the operating parameters of the systems were not adaptive to changes in the adhesive properties of the roadway covering. When wetting the road, the braking distance increased, while the distance to the target at the time of stopping the car reduced. At a speed of 70 km/h on wet asphaltic concrete car #1 collided with the target, while on a dry surface (at the same speed) stopped a meter away from the target.

In the course of testing with a moving target, with the objects’ approach velocity (relative velocity) of 40-43 km/h, the systems confidently recognized the target, and promptly reduced the vehicle speed to a value below the target velocity. The minimum distance between the objects was about 4 m.
Tests for false response, both with stationary and mobile vehicles, did not detect erroneous activation of the systems. The systems did not respond to vehicles moving in adjacent lanes, but clearly recognized stationary and moving targets located in the same lane as the test object.

3.2. Test results of LDWS

Results obtained when tested three passenger cars on the systems’ reliability are presented in Table 2.

Table 2 Operational reliability of the LDWS according to the tests of three passenger cars

<table>
<thead>
<tr>
<th>The list of road and climatic conditions</th>
<th>The reliability of the system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear weather, dry roadway covering, clean marking lines</td>
<td>+</td>
</tr>
<tr>
<td>Enabled emergency alarm, the intersection of the solid line marking</td>
<td>⊥</td>
</tr>
<tr>
<td>Solid or broken line marking is contaminated by 30-50%</td>
<td>⊥</td>
</tr>
<tr>
<td>Solid or broken line marking is contaminated by 70-90%</td>
<td>-</td>
</tr>
<tr>
<td>Solid marking line is by 15% snow-covered</td>
<td>⊥</td>
</tr>
<tr>
<td>Solid marking line is by 50% and more snow-covered</td>
<td>-</td>
</tr>
<tr>
<td>Broken line marking is by 15% snow-covered, roadway covering is wet</td>
<td>-</td>
</tr>
<tr>
<td>Solid fog</td>
<td>-</td>
</tr>
<tr>
<td>Scattered fog</td>
<td>⊥</td>
</tr>
<tr>
<td>Dipped- or high-beam headlights switched on and no oncoming headlights at night</td>
<td>⊥</td>
</tr>
<tr>
<td>Dipped-beam headlights switched on and presence of oncoming headlights at night</td>
<td>⊥</td>
</tr>
<tr>
<td>Crossing a wet solid line marking</td>
<td>⊥</td>
</tr>
<tr>
<td>Straight-line traffic on the lane at a speed of 80÷90 km/h</td>
<td>⊥</td>
</tr>
<tr>
<td>Crossing the worn broken line marking at good weather conditions</td>
<td>⊥</td>
</tr>
</tbody>
</table>

Note: "+" means that system works; "⊥" - failures in the system operation; "-" - the system is not working.

The tests confirmed the reliable operation of the LDWS in three tested passenger cars under ideal operating conditions, i.e., clear weather, dry roadway covering, and clean marking.

When simulating the 15% and more "snow cover" of the line marking, none of the LDWS on the tested passenger cars did activate. Some systems didn't activate in the following conditions: on "snowy lane" at night; while crossing the partially worn broken marking at good weather conditions; in a "scattered fog" and "solid fog"; at switched on "dipped-beam", and to a greater extent, at switched on "high beam"; at switched on "dipped-beam" and the presence of oncoming "high beam", especially at night; when crossing a wet solid line marking; when crossing the worn broken line marking; when solid line was 50% contaminated; at “enabled alarm” and the intersection of solid line marking. Tests have also shown that the effectiveness of LDWS varies significantly from manufacturer to manufacturer.
4. DISCUSSION

The research results show that modern active safety systems have limited ranges of reliable and efficient operation when driving vehicles at different speeds. Adverse vehicle operating conditions such as dirtying or damage of windshield, poor lighting (insufficient illumination of lanes, blinding by the light of oncoming cars), poor weather conditions (snowfall, icing, heavy fog, rain), the absence or poor line markings, etc. significantly decrease the effectiveness of the AEBS and LDWS [13-15].

Design and operational deficiencies, as well as adverse operating conditions can cause loss of efficiency, reliability, and false alarms in active safety systems that can lead to traffic accidents.

5. CONCLUSION

The analysis of the conducted studies show that modern active safety systems are not universal, have limited ranges of effective operation, and other serious shortcomings. At that, in the context of the operating conditions in the Russian Federation, these shortcomings are amplified.

The analysis of the problem on creating competitive active safety systems, conducted by FSUE "NAMI", as well as the results of evaluations of the effectiveness and reliability of the AEBS and the LDWS at the various vehicle speed modes and simulated adverse operating conditions indicate that:

- modern active safety systems can potentially prevent up to 57% of typical collisions out of accidents possible in road and climatic conditions close to ideal;
- adaptation of active safety systems with similar functions to the road and climatic conditions of the Russian Federation is associated with the need to make significant changes in the corresponding hardware and software;
- new hardware with improved features and capabilities requires use of new materials and technologies;
- in principle, it is possible to create a full-featured active safety system that ensures the prevention (except for collisions with oncoming obstacles) of up to 97% of potential typical collisions in the road and climatic conditions of the Russian Federation;
- implementation of the proposed active safety system with the minimum possible configuration of the IASS component base elements through the use of models and algorithms of indirect measurements (virtual sensors) and knowledge about the control object in the form of formalized descriptions of its properties, allows providing a significant improvement in almost all consumer indicators and increasing the competitiveness of such systems.

The test results indicate the need for further more in-depth studies of IASS, taking into account the Russian operating conditions.

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