Modeling the algorithm of the automatic emergency braking system with the prediction of the coefficient of tire grip

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Abstract. The problem of improving road safety is currently one of the most significant in the automotive industry. One of the promising ways to improve road safety is the development and introducing of intelligent active safety systems for automobiles. To solve the problem of improving safety, world leaders in the automotive industry are actively engaged in the development and implementation of intelligent control systems that provide control over the movement of the car and can partially intervene in driving. The article is devoted to the effectiveness of the automatic emergency braking system in accordance with the climatic and road conditions of Russia. The report discusses the problems of determining the coupling properties of the wheels of a car with a road on various surfaces, discusses the problems of predicting braking distance. Options for improving forecasting and building algorithms for the automatic emergency braking system are considered.

1. Introduction
The main reason for the occurrence of an accident is still a violation of traffic rules by drivers of vehicles. Also, an increase of accidents with the participation of people who at the time of the accident did not have the right to drive a vehicle was recorded - 3.4%. In total, 18,214 people died on Russian roads in car accidents in 2018. More detailed accident statistics for the past year can be found on the official website of the State traffic inspectorate of the Ministry of Internal Affairs of Russia (traffic police) in the section "Indicators of the state of road safety." [1] Based on the statistics, it can be concluded that the total number of accidents is reducing, but still remains at a high level and requires new solutions in terms of increasing the level of traffic safety. Let us consider in more detail the statistics of accidents and highlight some of emergency scenarios and their number that could be prevented with the help of an automatic emergency braking system and a warning about the possibility of a collision.
Table 1. Accident statistics for 2018.

| Name of indicator                        | Accident absolute | by type       |
|------------------------------------------|-------------------|---------------|
| Accidents and victims - total            | 168099            |               |
| in vehicle collisions                    | 71167             |               |
| with collisions with a standing transport| 4903              |               |
| with a collision with a pedestrian       | 48834             |               |
| hitting an obstacle                      | 11565             |               |
| with a collision with a cyclist          | 5294              |               |
| horse-drawn carriage                     | 28                |               |
| Of them                                  |                   |               |
| at pedestrian crossings                  | 13921             |               |
| in cities and towns                      | 52106             |               |
| on public roads                          | 57191             |               |

To considered collision scenarios, one can also add those that cannot be found in standard classifications. We can refer to them accidents caused by poor road conditions, late driver reaction, poor health condition, driving in bad weather conditions, etc. Taking into account for 18 thousands of people die every year, and economic damage is about 300 billion rubles, we can conclude that it is necessary to implement this system. Based on the considered statistics, we can conclude that ADAS and particularly the automatic emergency braking system, can significantly reduce the number of collisions, but its effectiveness and implementation safety remain in question.

2. The difficulties of implementation

The automatic emergency braking algorithm has to predict the braking distance of the vehicle, clearly detect and classify an obstacle and decide to brake automatically only when the driver does not have time to avoid a collision on his own, and does not apply actions for braking or emergency maneuvering. Otherwise the activation of braking prevents the driver from avoiding the collision by himself. For such scenarios, when the driver reacts to an emergency, a system such as braking assistance should work. The braking assistance system is activated, when the automatic emergency braking algorithm detects an accident of a collision, while the driver applies braking force. In case of insufficient pressure in the brake system, the brake mechanism is automatically applied to achieve a higher deceleration value of the car in order to prevent a collision [2].

Each driver has a different driving style, from calm to aggressive. In this case, drivers with an aggressive driving style may experience early warning signals about a potential collision. In addition, automatic control of the brake system should not interfere with the driver's avoidance maneuver, since improper operation of automatic emergency braking can lead to an emergency. Consequently, either the driver will ignore warnings or forcibly shut down the system. To avoid this, it is necessary to use such algorithms that will accurately assess the environment and identify emergencies. The algorithm of the automatic emergency braking system should not interfere with vehicle control.

3. Potential obstacle detection

One of the most important factors in the operation of the system is its stable functioning and the absence of false activations. One of the reasons for false triggering may be the detection of an imaginary obstacle on the way of the car’s movement by sensory equipment. In order to avoid false detection, filtering of these sensors is used. Filtration of false objects is fundamentally difficult to organize using only radar data. For this reason, cars use not one sensor, but a set of sensors. Moreover, in difficult climatic conditions, it is difficult to organize stable operation of the system using only one sensor. The most
popular and affordable solution is to use a combination of a radar sensor + front camera. This configuration is called «sensor fusion».

Processing in a separate electronic unit of the car is performed at a high level. This helps solve the problem of filtering data from the radar. It uses data about speed, angle of rotation, as well as information from other vision systems. Screening of false objects is carried out using the following algorithms:

- the dependence of the effective dispersion area (EDA) on the distance;
- low-pass filtering (by the lifetime of the object);
- tracking movement in time;
- forecasting the trajectory of the movement of objects.

Today, most automatic emergency braking systems show stable operation in a very limited range of conditions. One of the reasons for such cases is the limited list of objects that the sensor system is able to recognize with the least likelihood of false detection. One of the most effective ways to achieve high results in the field of detection is the Sensor fusion (a combination of several sensors) [3]. Sensor fusion includes a combination of several sensors. The most common solution to such recognition system is a radar sensor that works in conjunction with an object recognition camera. This option of fusion of sensors has the potential to collect additional information that allows you to detect and classify an object with high accuracy, which can reduce the likelihood of false detection of obstacles, which is an indicator of the reliability of detection of the object. In Figure 1 we can see an example of object recognition by a camera with classification and distance determination.

![Figure 1. An example of recognition of an object by the front camera.](image)

During detecting an object with a high probability of truth, control of the possibility of a collision is carried out by an algorithm for calculating the emergency braking system. It is based on the following parameters:

- position of a potentially dangerous target;
- vector of the direction of movement of the target;
- relative speed of movement;
- prediction of possible deceleration on this section of the road [4].

Next, we will examine in detail the part of the algorithm that is responsible for predicting the achievable deceleration on this section of the road.
4. System operation algorithm

Guided by existing rules, we cannot use emergency braking earlier than 3 seconds before a possible collision. Thus, the range of the system should be within the timelines shown in Figure 2.

These requirements are regulated in the following documents:

- Standard ISO 15623: 2013. This standard establishes requirements for collision avoidance systems with a vehicle in front. This system is one of the functions of the automatic emergency braking system.
- UNECE Regulation No. 131. These documents contain uniform requirements regarding automatic emergency braking systems installed on mechanical vehicles of categories M2, M3, N2, and N3. The main focus of these standards is on roads.

Thus, we see that the braking distance and the start time of the response should vary within these limits. The distance the car will go from the moment the brake system starts to compensate for speed to avoid a collision will directly depend on the deceleration that the car can develop on this section of the road.

The calculation of the time to stop the car ($t_o$) is made by adding the time intervals of the stages of the braking system and represented by formula 1.

$$t_o = \frac{1}{2} t_n + t_r + t_p + \frac{K_e V_0}{\varphi g}$$

- $t_r$ – driver reaction time, s;
- $t_p$ – response time of the brake drive, s;
- $t_n$ – time to reach deceleration value, s;
- $K_e$ – braking efficiency coefficient;
- $V_0$ – vehicle speed immediately before braking, m/s;
- $\varphi$ – coefficient of adhesion of car wheels to the road surface;
- $g$ – acceleration of gravity.

Braking schedule (jst) by time can be seen in Figure 2. This figure shows the time intervals and the process of reducing speed, depending on the achieved deceleration of the vehicle at the moment. As shown in the graph, part of the schedule takes up the portion of time allotted for the driver’s reaction. This section can vary from 0.5s to 1.5s depending on the health of the driver, his experience and age. Given modern high-speed driving modes, the car will cover a fairly large distance for this, as it might seem at first glance, a short period of time [5].

![Figure 2. The response area of the automatic emergency braking system.](image-url)
Figure 3. Calculation of stopping time with a driver.

\[ t_o = \frac{1}{2} t_n + t_{pr} + \frac{K_e V_0}{\varphi g} \]  

where \( t_p \) – driver reaction time, s; \( t_{pr} \) – response time of the brake system, s; \( t_n \) – achieving the necessary deceleration, s; \( K_e \) – braking efficiency coefficient; \( V_0 \) – vehicle speed immediately before braking, m/s; \( \varphi \) – coefficient of adhesion of car wheels to the road surface; \( g \) – acceleration of gravity.

As we can see from the graphs, the system does not require reaction time to act on the brake pedal [6].

To test the algorithm, a mathematical model of the car’s movement was created taking into account changes in the coefficient of adhesion of tires to the roadway in Simulink. We can see the external view of the created model in Figure 5. On it we see several blocks that simulate sensors used in fuzzy logic algorithms to determine the current external conditions in which the car is moving. Also created a model of the movement of the vehicle in front. In the model of movement of the vehicle in front, the initial speed, distance, the moment the braking starts and the deceleration value are set. Based on these data, the algorithm should predict at what distance to a potential obstacle it is necessary to activate the brake system taking into consideration the value of the brake deceleration that can be applied under these conditions. From the block of the braking distance forecasting algorithm, a signal is sent with a request to start braking of the model of the road surface, where the road parameters are entered (dry asphalt, wet...
asphalt, snowy road, etc.). Further, the vehicle’s movement model calculates the braking movement, according to the results of which we can observe how accurately the algorithm calculated the necessary time for the activation of the braking request.

The range of the change in the braking distance of the car, depending on the condition of the roadway, presented in the figure 6.

**Figure 5.** Appearance of the model in Simulink.

**Figure 6.** Braking distance in various road conditions.
The size of the braking distance varies depending on the coupling properties of the pair “tire-road”. A change in this coefficient can be seen in Figure 7.

![Figure 7. The dependence of the coupling properties of the pair “tire-road” on the linear speed at different thicknesses of the surface layer of water](image)

- dry asphalt, 2- 0.2 mm water layer, 3- 1.0 mm water layer, 4- 2.0 mm water layer [7].

Due to such a wide spread of the braking coefficient, depending on the size of the water layer on the road, a change in the braking distance of the car also happen in a wide range. As sources of information for predicting the coefficient of tires with the road, it is proposed to consider information:

- Ambient temperature sensor;
- Precipitation sensor;
- Current operating mode of the wiper;
- Anti-lock braking system;
- The operation of the system of ESP;
- Recognition of the current state and type of pavement using the front camera.

The values of these parameters are modeled based on the recorded values of real sensors in various conditions. A graph of the distance to the vehicle in front with automatic braking is shown in Figure 8.
Figure 8. Graph of changes in distance and speed at the moment of activation of the system of automatic emergency braking.

In the figure above, we see two graphs that display the simulation of changes in the speed of the tested cars. In the lower part, we can see two graphs of the distance change. One taking into account additional information from sensors and systems, and the other without taking into account this information, with a statically specified coefficient of tire grip. To conduct this test, the following scenario model was created:

|                     |                     |
|---------------------|---------------------|
| Temperature         | +20 °C              |
| Precipitation       | Rain                |
| Wiper Intensity     | At 2 second of simulation, the intensity decreases |
| Driver reaction     | Absent              |
| Initial distance between cars | 20 m               |
| Speed of the car in front  | 30 km/h          |
| Initial vehicle speed         | 50 km/h             |

As we can see on the top of the graph, the moment of the start of braking and speed reduction occurs a bit later, unlike the model, which does not use information about the intensity of the wipers. Based on this, the calculation of the distance to the collision is less accurate in the first case and can activate the response too early, and as described above, early system activation is one of the reasons why drivers force-shut off the automatic emergency braking system.

5. Conclusion
A modern automatic emergency braking system can reduce more than 30% of typical collisions.
The introduction of active safety systems can significantly increase the competitiveness of cars in the international market.
Considered the most common and effective combination of sensors for automatic emergency braking.
The adaptive system for calculating the coefficient of adhesion of tires to the road is able to most accurately calculate the required braking distance and the response time of the system. Mathematical modeling of the algorithm showed an improvement in braking distance calculation.
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