ACC AND ACC+ systems and their impact on improving road traffic safety

Systemy ACC i ACC+ oraz ich wpływ na poprawę bezpieczeństwa ruchu drogowego

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Abstract: The development of modern driver assistance systems, such as Adaptive Cruise Control (ACC) and its enhanced version ACC+, represents a significant step towards improving road safety. This article analyzes the operation of these systems in the context of the causes and effects of traffic accidents. Based on the reconstruction of a specific traffic incident, a detailed assessment of the impact of ACC and ACC+ on traffic safety was conducted. The study is based on the analysis of measurable technical parameters that change under varying road conditions, both with the systems activated and deactivated.The paper also discusses examples of preventive strategies for similar incidents, utilizing new technologies applied in modern vehicles. Particular attention is given to differences in vehicle behavior under various operational scenarios of ACC and ACC+ systems, with a focus on their impact on the safety of road users. This article contributes to the development of knowledge on minimizing accident risks through advanced driver assistance systems.

Keywords: *ACC; ACC+; Safety; Traffic*

Streszczenie: Rozwój nowoczesnych systemów wspomagania kierowców, takich jak adaptacyjny tempomat (ACC) oraz jego rozszerzona wersja ACC+, stanowi istotny krok w kierunku poprawy bezpieczeństwa na drogach. W artykule przeprowadzono analizę działania tych systemów w kontekście przyczyn i skutków wypadków drogowych. Na podstawie rekonstrukcji konkretnego zdarzenia drogowego przeprowadzono szczegółową ocenę wpływu ACC i ACC+ na bezpieczeństwo ruchu. Badanie opiera się na analizie wyznaczalnych parametrów technicznych, które ulegają zmianom w zmiennych warunkach drogowych, zarówno przy aktywowanych, jak i dezaktywowanych systemach. W pracy omówiono także przykładowe strategie prewencji w podobnych zdarzeniach z wykorzystaniem nowych technologii stosowanych w nowoczesnych pojazdach. Szczególną uwagę poświęcono różnicom w zachowaniu pojazdów w różnych scenariuszach działania systemów ACC i ACC+ pod kątem ich wpływu na bezpieczeństwo uczestników ruchu drogowego. Artykuł stanowi wkład w rozwój wiedzy na temat możliwości minimalizacji ryzyka wypadków dzięki zaawansowanym systemom wspomagania pracy kierowców.

Słowa kluczowe: *ACC; ACC+; Bezpieczeństwo; Ruch drogowy*

General characteristics of the accident prevention system

The ACC and ACC+ systems are designed to improve road safety. Both in Poland, in the European Union and around the world, the requirements for improving the safety of road users are constantly increasing. More and more funds are being invested in newer systems that prevent road accidents as well as supporting the improvement of road traffic safety and ensuring driving comfort for both the driver of a given vehicle and other road users. The basic systems for preventing road accidents include ABS and ASR systems.

The article presents a much more complicated ACC accident prevention system and ACC+, which is also used in autonomous vehicles.

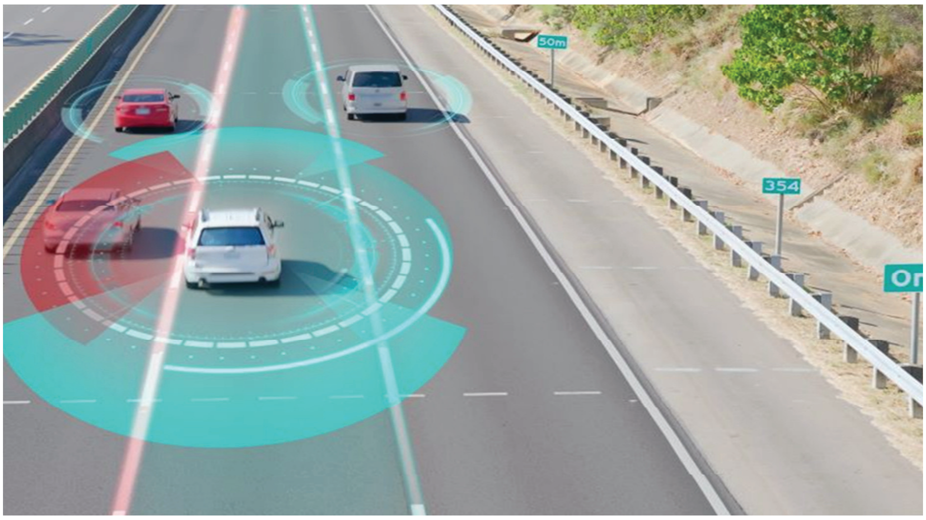
It should be noted at this point that these systems are very expensive and usually installed in premium or business class vehicles. We are currently striving to make the systems discussed more common.

The ACC and ACC+ system - Active Cruise Control and Active Cruise Control Plus [1;8] allows you to maintain a constant speed and distance from the vehicle in front, but also allows you to change the driving speed based on road conditions, such as bends or road inclination. Both ACC and ACC+ are the so-called active cruise control.

Figure **1** below shows the operating methods of both systems.

The ACC system version [1;8] (this is the earliest version of the system) uses a special sensor (radar) placed behind the radiator grille. Its range covers approximately 100 meters of road in the lane in front of the vehicle.

If too small a distance from the car in front is detected, the system reduces the car's speed to a minimum speed of 30-50 km/h. However, to fully decelerate and stop the vehicle, the driver's intervention is required, as he is informed by an alarm signal to press the brake pedal. Below the minimum speed, the cruise control turns off. Work is being carried out to



1. Principle of operation of the ACC and ACC+ systems [1;8]

replace this element of human intervention with a more reliable system that is morally acceptable and reliable in terms of measurable technical indicators, referred to as autonomy.

The ACC+ device version [1;8] is a device that allows you to decelerate as much as possible, but also to stop the car completely. In addition to the long-range long-range radar sensor installed at the front of the car (its effective operating range has been doubled compared to the first generation active cruise controls). The second generation ACC is also additionally equipped with a short-range radar sensor.

It is able to track even more than 30 moving objects at the same time (in the space from 0.2 to 30 meters in front of the vehicle).

When the vehicle in front suddenly brakes, a signal is sent to fully activate the braking system and consequently stop the car. This also happens in normal road traffic, for example when driving in a traffic jam, the cruise control immediately stops the vehicle - this is an element of autonomous operation. This was presented in the reconstruction of a road accident prepared and developed - presented in the drawings in the presented article. As can be seen in Figures **1** the ACC and ACC+ systems receive information from vehicles in front of them and the vehicle can perform programmed actions, e.g. emergency braking, decelerating or accelerating, which relieves the burden on the driver of a given vehicle. Such actions, of course, prevent and reduce the possibility of collisions or road accidents and are autonomous actions independent of humans.

Adaptive cruise control (ACC) relieves the driver's workload, especially during long journeys and in dense traffic requiring constant stop-and-go. By starting and braking automatically, the system maintains a set distance from vehicles in front of it. The analysis of a similar road incident in vehicles with and without ACC and ACC+ safety systems is presented in the next part of the work.

Characteristics of a road incident with and without ACC and ACC + safety systems

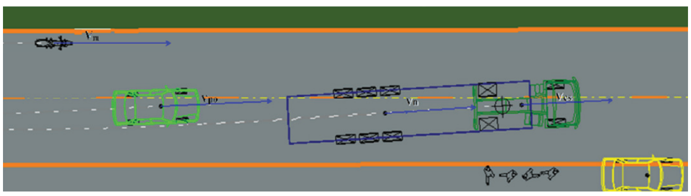
The analyzed road incident involved four vehicles (Volvo truck with a semi-trailer, Skoda Octavia vehicle, Yamaha motorcycle and Skoda Superb vehicle) [21].

None of the vehicles described were factory-installed from the systems discussed.

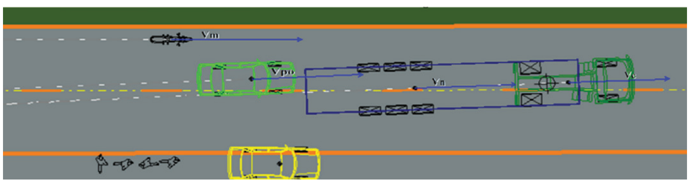
Data obtained from the manufacturers of the vehicles in question based on their VIN numbers were used to describe the technical data of all vehicles involved in the road incident. By performing a thorough inspection of the vehicles involved in the road incident, including the scene of the incident itself, taking into account the location of the area, the traffic intensity at a given time of day, the condition of the road surface and the weather at the time of the incident, as well as the height, width and length of all vehicles, it can be concluded that the incident road traffic of vehicles not equipped with ACC or ACC + safety systems occurred. It should be added that the incident could not have occurred if the vehicles were equipped with appropriate safety systems, including the described ACC and ACC+ systems, which was justified in the case study.

The reconstruction of the road accident is presented below in the V-Sim 4.0.22 program [20], with the systems presented in the article. And without these systems. It should be added that the Skoda Octavia vehicle was broken down and was located on the rightmost lane of the road. Four people were moving around the Skoda vehicle illegally.

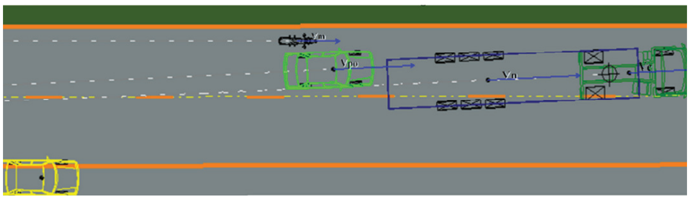
After performing the reconstructions of the events presented below, the authors presented: and analyzed in the form of mathematical models how vehicles with the safety systems presented in this work can move safely.



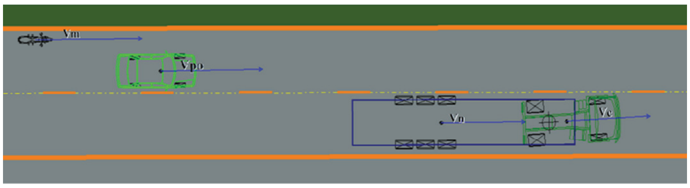
2. Reconstruction of the event in the initial phase. Own study based on [4;5;18;20]



3. Reconstruction of a road accident in the final phase just before impact. Own work based on [1;2;3;5;10;20]



4. Reconstruction of a road accident in the final phase just before impact. Own work based on [1;2;3;5;10;20]



5. Reconstruction of the event in the initial phase. Own work based on [1;2;5;6;8;19;20]

Vehicles driving without ACC and ACC+ systems - graphic case analysis

Figure **2** shows a road incident. This is the first phase in which drivers of vehicles without safety systems, by not adjusting the appropriate speed on the road to the prevailing conditions, led to a road accident.

Vehicle speed vectors are marked in Figure **2**.

The vectors described in the figures are presented below:

V_m – motorcycle speed vector;
V_{po} – speed vector of a passenger vehicle;
V_{cs} – speed vector of the tractor unit;
V_n – trailer speed vector

Figure **3** shows a road incident. This is the middle phase in which drivers of vehicles without safety systems, not adjusting the appropriate speed on the road to the prevailing conditions, led to a road accident.

Vehicle speed vectors are marked in Figure **3**.

Figure **4** shows a road incident. This is the final phase in which drivers of vehicles without safety systems, by not adjusting the appropriate speed on the road to the prevailing conditions, led to the road accident.

Vehicle speed vectors are marked in Figure **4**.

Vehicles traveling with ACC or ACC+ systems - graphic case analysis

Figure **5** shows a road incident. This is the first phase of a road incident in which drivers of vehicles with safety systems avoid a collision by not adjusting the appropriate speed on the road.

Vehicle speed vectors are marked in Figure **5**.

Figure **6** shows a road incident. This is the middle phase of a road incident in which drivers of vehicles with safety systems avoid a collision by not adjusting the appropriate speed on the road.

Vehicle speed vectors are marked in Figure **6**.

Figure **7** shows a road incident. This is the final phase of a road incident in which drivers of vehicles with safety systems avoid a collision by not adjusting the appropriate speed on the road. This is caused by the use of the ACC or ACC+ security systems.

Vehicle speed vectors are marked in Figure **7**.

In this case, in order to accurately depict the entire event, it was necessary to take into account the sequence vectors as well as the driver's reaction time [4; 5; 18], the weather conditions prevailing at the moment of the event, the quality of the road surface, as well as the quality and warm-up of the tires.

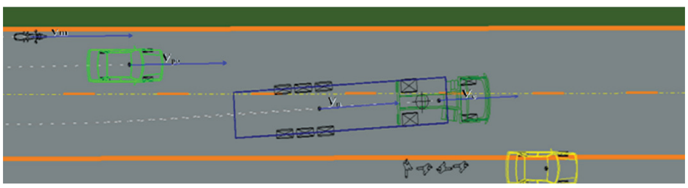
Assuming the reaction times of drivers driving vehicles involved in a road incident, it should be assumed that [4;5;18] the reaction time of a driver driving a truck is from 0.6 to 2.0 seconds. However, the reaction time of drivers of passenger cars and motorcycles after performing the calculations may range from 0.4 to 1.5 seconds.

When interpreting the entire road incident described in the article, it should be stated that the braking distance of a vehicle is the distance covered by the vehicle during actual braking. In this case, the braking distance can be called the distance the vehicle has traveled since the driver noticed an obstacle, which led to braking and stopping the car, which in this case, taking into account the ACC and ACC+ safety systems, is much shorter due to the driver's earlier reaction and we can write it as a sum

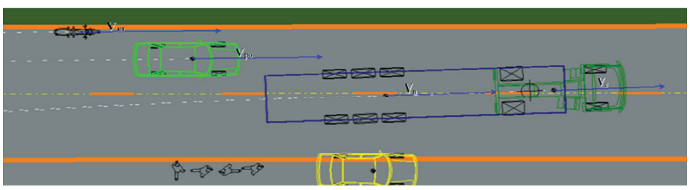
$$t_z = t_{RK1} + t_U + t_H \quad (1)$$

where:

t_{RK1} – reaction time of the passenger car and motorcycle driver (0.4…1.5 s);
t_{RK2} – reaction time of the truck driver (0.6…2.0 s);
t_U – time of activating the braking system and increasing the braking force;
t_H – full braking time, i.e. with maximum efficiency. (effectiveness in terms of time)



6. Reconstruction of the event in the middle phase. Own work based on [1;2;5;6;8;19;20]



7. Reconstruction of the road accident in the final phase - no collision with an obstacle. Own work based on [1;2;5;6;8;19;20]

To obtain an accurate answer, the total reaction time of the driver should be divided into three stages: [4;18]
- time of perception of the signal about the need to brake;
- decision-making time;
- driver's psychophysical reaction time.

The activation time of the braking system tU for modern cars when pressing the brake pedal suddenly is:
- 0.15…0.3 s in hydraulic actuation systems;
- 0.30…0.5 s in pneumatic systems;
- 0.15…0.35 s in electro-pneumatic systems.

The quantities occurring in the relationship can be presented graphically. The time t_z is the stopping time. The distance traveled by the car during this time is called the stopping distance.

After the t_{RK} time has elapsed, the driver starts pressing the brake pedal. The driver's application of force on the brake pedal does not immediately cause braking forces to appear on the wheels and delay the vehicle's movement. The beginning of the increase in braking force occurs with a delay (this is called the delay when the system has the opportunity to actuate) in relation to the movement of the brake pedal.

The length of the stopping distance sZ was calculated as the sum of two road sections:

- traveled during:

$$t_R = t_{RK} + \frac{t_u}{2} \qquad (2)$$

in which uniform motion was assumed, without braking;

Traveled in time $t_u/2 + t_H$ as the braking distance with force F_{Hmax} in uniformly retarded motion with delay α_H.

Therefore, $s_z = t_{Rvp} + s_H$

Where s_H is the length of the distance covered by the car while braking. At the same time, assuming the delayed movement of the vehicle during braking, the braking distance can be calculated

$$s_H = \frac{Vp^2}{2\alpha H} = \frac{\alpha H}{2}\,(t_H + \frac{t_u}{2})^2 \qquad (3)$$

and then the stopping distance

$$s_z = (t_{RK} + \frac{t_u}{2})\,v_p + \frac{Vp^2}{2\alpha H} = (t_{RK} + \frac{t_u}{2})\,v_p \qquad (4)$$

As you can see, it is possible to calculate the length of the braking distance based on the knowledge of the αH deceleration value. It is also possible to determine the length of the braking distance s_H by comparing the work of braking forces and the kinetic energy of the vehicle in translational motion

$$F_H S_H = \frac{Q}{2g}\,(v_p^2 - v_K^2) \qquad (5)$$

where V_p, V_K – car speed at the beginning and end of the braking process. After the transformation, an important relationship was obtained for calculating the length of the car's braking distance

$$S_H = \frac{Q(V^2p^2 - V^2k)}{2gFH} \qquad (6)$$

Given the expression saved

$$F_H = F_B = -\,m\frac{dv}{dt} = m\alpha_H \qquad (7)$$

Substituting this relationship into the relationship we get:

$$S_H = \frac{Q(V^2p - V\,^2K)}{2gm\alpha H} = \frac{V^2p - V^2K}{2\alpha H} \qquad (8)$$

If the car brakes to a stop, then V_K = 0 and

$$S_H = \frac{V^2p}{2\alpha H} \qquad (9)$$

When braking with maximum efficiency and in the most favorable conditions, in accordance with dependency

$$\alpha_H \rightarrow \alpha_{Hmax} = \mu_g. \qquad (10)$$

By substituting the above into the equations presented above, we obtain formulas to calculate the shortest possible braking distance

$$S_{Hmin} = \frac{Vp^2 - VK^2}{2g\mu} \qquad (11)$$

and

$$S_{Hmin} = \frac{Vp^2}{2g\mu} \quad gdy \quad V_K = 0 \qquad (12)$$

Taking into account the influence of rolling resistance forces during braking without wheel locking in the equation, the following was obtained

$$S_{Hmin} = \frac{Vp^2 - VK^2}{2g(\mu + f)} \qquad (13)$$

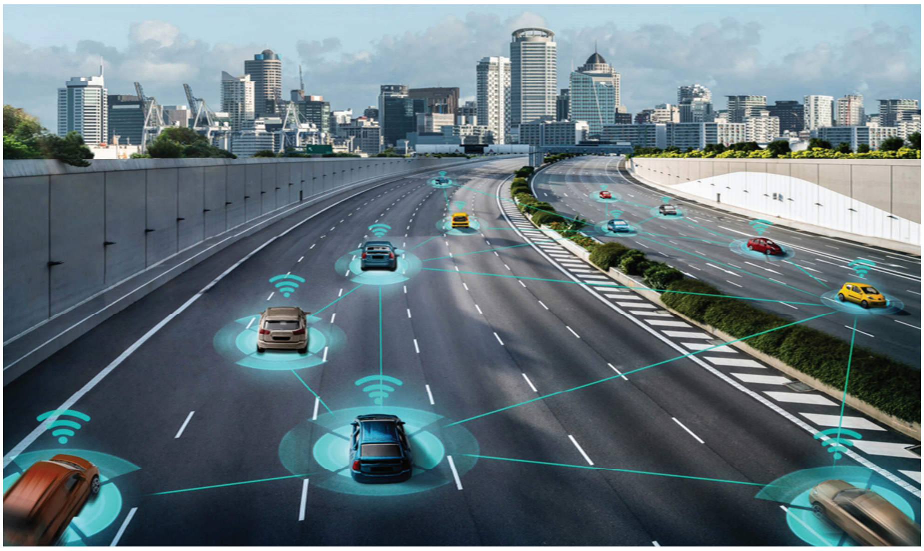
The relationship should be taken into account when braking on deformable surfaces and when driving on roads.

Therefore, after performing the calculations, the vehicles would move safer if they had appropriate safety systems, in this case ACC and ACC+. What has been demonstrated. Taking into account the technical parameters as well as making calculations, it should be stated that the road accident occurred due to vehicles traveling at excessive speed, lack of appropriate reaction of drivers (in due time), as well as the lack of appropriate safety systems.

Conclusions

The presented safety systems for autonomous vehicles, ACC and ACC+, enable drivers using vehicles equipped with these systems to react faster in various road situations [2; 4; 13; 15; 19]. Failure to implement this type of autonomous systems in the era of developing AI around the world leads to the persistence of threats resulting from human unreliability, which is caused by fatigue, lack of precision, lack of attention, or other human imperfections causing errors. In the era of increasing the number of vehicles on the roads and the development of artificial intelligence (systems operating based on algorithms and measuring devices - sensors), the presented safety systems should be implemented widely, because they contribute to increasing the safety of people traveling on the roads [1;8].

Based on the presented analyses, which show that security systems in autonomous vehicles affect the reliability of vehicles by improving measurable technical parameters, it can be stated that the basis of the process is its understanding and correct modeling of important factors that are used for its mathematical description and modeling that allows obtaining important results that can be the basis for process assessment. As a result, they have a major impact on the movement of these vehicles on roads, as shown in Figure **8**.◀



8. Autonomous vehicles with ACC safety systems installed and ACC+

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