Conflicts of Automated Driving With Conventional Traffic Infrastructure

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The project has been supported by the European Union, cofinanced by the European Social Fund. EFOP-3.6.2-16-2017-00002. The research reported in this paper and carried out at the Budapest University of Technology and Economics was supported by the “TKP2020, Institutional Excellence Program” of the National Research Development and Innovation Office in the field of Artificial Intelligence (BME IE-MI-FM TKP2020).

ABSTRACT Road traffic signals and traffic infrastructure have a significant impact on the behaviour of highly automated or autonomous vehicles. However, the increase in automation does not always mean an advantage. Generally, highly automated vehicles strictly follow the traffic rules resulting in near-accident situations, although their goal is to avoid and reduce them. Malfunctions of the automated functions might cause surprising interventions while the vehicle is in motion, drivers cannot react in time and well. This paper highlights the potential danger and uncertainty of highly automated or autonomous vehicles in the context of the current conventional traffic infrastructure system. In the future, special consideration shall be given to the vehicle industry and traffic regulation makers on how the infrastructure should be adapted to automated vehicle functions to have a seamless shift towards automated driving. The paper sums up many problematic situations with two critical problems with sensitivity analysis. The first situation: the speed assist system (based on speed limit sign recognition) conflicts with the traffic infrastructure. The second situation is shown: the ACC (Adaptive Cruise Control) and LKA (Lane Assist) contradicts with the traffic infrastructure. These critical situations were investigated by using an high-fidelity automotive simulation software as proof of concept and were examined by accident reconstruction analysis software.

INDEX TERMS Critical traffic situations, highly automated vehicles, autonomous driving, traffic infrastructure.

I. INTRODUCTION

The vehicles with various driving assist functions have spread rapidly over the years. The ambitious goal is to achieve fully autonomous transportation in the next 20-30 years, but many challenges still need to be defeated. Highly automated, autonomous vehicles and driver-assist functions are needed to reduce the number of accidents, air, and noise pollution. Accidents are still present and cause a serious threat to people in the cities. The most recent data show that more than 1.2 million people die worldwide because of injuries from road accidents. In Europe, a target to reduce the number of road fatalities in 2010 to 50 % until 2020 [34], [37]. Traffic jams are another problem in big cities around the world, and this will be a growing problem, as the number of vehicles will increase. According to some forecasts, number of the cars will rise from the current 1.1 billion cars to 2 billion over the next 15 years. Besides, self-driving vehicles can play a major role in controlling this process.

Manufacturers have begun to develop these vehicles primarily for the convenience and safety needs of customers. The AVs (autonomous vehicles) intensifying passenger expectations require new mobility services, and it will be able to reduce traffic jams. The car-sharing based on autonomous transportation (taxi, shared-taxi, feeder pod, fix route pod) becomes popular; it could curb the increase in the number of private cars. However, the AVs impact on traffic jams needs to be examined over several seasons, as their effect can be positive in the end but can be worsen the situation in the short run. The operation of the future transportation system will be rather complicated as all participants are connected [6]. The sensors’ information (LiDAR) help to get better and safer connected transportation [20]. But some researches deal with the issue that is complying with AV rules (influenced by the traffic signs, signals and infrastructure) do not always benefit safe transport on the public roads [26].

Some researchers said, at potential infrastructural changes to a road section for easier future integration of autonomous vehicles. Moreover, the development of infrastructure can be said to be one of the essential foundations for the increase
of self-driving vehicles. The case of different specification acceleration lanes or different kinds of traffic signs is a perfect example of the fact that in the future, due to the rise of self-driving vehicles, new aspects will have to be taken into account in road planning. For instance, improve how much the efficiency of classifying of an autonomous vehicle by converting the acceleration lane [31], respectively, this change is also beneficial for incoming traffic. In summary, it can be said that with transport micro-simulations - such as the current example - it can efficiently and on a small budget find opportunities for changes in the infrastructure with which it can be accelerated the spread of self-driving vehicles [28].

The structure of paper: Chapter 1 is the introduction. Chapter 2 presents the conflicts of automated driving problems. Chapter 3 shows the analysis of situations. Chapter 4 includes parameters and settings of the critical situations in simulation software. The parameters are based on the sensitivity test theory. Also, at the end of the paper, Chapter 5 presents the results of the simulations.

II. CONFLICTS OF AUTOMATED DRIVING

The development of assistant functions in vehicles serves several purposes, the most important of which is to reduce the burden on the environment or the driver and to increase road safety. Vehicle automation is usually classified into different levels, which tell us how much a driver is taken out of the control process, and how much they help the driver [32].

One problem is achieving a fully autonomous future will not only depend on the development of car manufacturers. However, it will also require significant changes in legislation and infrastructure. It can be said that a completely self-driving future is far away, but there are features in the vehicles that anticipate an autonomous future. However, ADAS (Advanced Driver Assistance System) systems are already built-in most of the new vehicles; these are still in the development stage. It means that these are not perfect yet, can make mistakes in many traffic situations, and therefore need continuous improvement. The various advanced driver assistance systems are also referred to as ADAS. From the name, it can be clearly concluded that the systems indicated by this term are mainly used to support the driver. Such systems are, for example, anti-lock braking systems (ABS), traction control (ESC), traction control (ASR), Adaptive Cruise Control (ACC), Speed Assist System (SAS) [5].

The highly automated and autonomous vehicles without a human driver will usually decrease the risk of accidents. Highly automated vehicles should help human drivers, and autonomous vehicles should completely replace drivers. Systems (traffic sign recognition, pedestrian recognition) must be able to perceive and sometimes replace relevant human’s parameters, such as perception, visibility, and auditory [19]. The Kalman filter applied to the sensors can be a good choice for making the perfect perception in a highly automated or autonomous vehicle [18]. But sometimes the automated vehicles excessive rule-compliance causes an accident. Therefore, it is necessary to find out what is the correct rate for changing the infrastructure and traffic regulations before the automated cars appear on the roads. The connected vehicles, which mean they are communicated to each other (V2V) or with everything (V2X), help to make safer travel [36].

The lane assistant system is that the vehicle scans the road in front of it with cameras and can detect objects, vehicles from the analysis of the video image. The simpler systems do nothing to intervene, just alert the driver by audible and visible signals or by vibrating the steering wheel that the vehicle is about to leave its lane without a turn signal. However, more advanced solutions do not merely warn the driver to leave the lane, but actively intervene to keep the car in the lane he is currently using. Vehicles equipped with active lane keeping electronics use small steering movements to prevent the vehicle from inadvertently leaving it is a lane [29].

The automatic emergency braking system now assesses the road ahead not only with the help of cameras but also with the help of RADARs. If the vehicle is in the region of another car or even detects a pedestrian in front of it, it will first warn the driver with an acoustic signal, steering wheel vibration; if it is not used, it will stop the car to avoid an accident. That it is beneficial and has saved many lives already, however in some situations, these systems can confuse the others. I would like to present an example of this that I have experienced in real life as well.

The paper aims to investigate the behaviour of such systems in a given traffic situation and to set up a system of requirements for real vehicle measurements based on the investigations. The article will be presented examples and simulations of critical traffic situations. Personal experiences and mathematical methods will be used for analysis and proof. The cases are for the knowledge of the behaviour of human traffic participants since this ability is crucial in avoiding accidents. The kilometers of driving experiences have been taken with vehicles equipped with the newest driver assistance systems, and it has been repeatedly experienced the advantages and disadvantages of these systems [4], [33].

Two scenarios were chosen for the critic situations illustration. The main point of view is conflicts of highly automated and traffic infrastructure. The scenarios show that people need to pay attention and think about infrastructure changing. Because these situations are hazardous for other participants on the road, sometimes, highly automated vehicles can cause accidents because of excessive rule-compliance.

The other conflict that should be mentioned in the legislation that the modernization of the infrastructure, the system of rules, will also undergo significant changes. With the appeal of self-driving vehicles, the question increasingly arises as, who is responsible in the event of an accident involving such a vehicle. Creating a set of rules is a very complex issue and likely to change several times as it gains experience with these vehicles. Legal issues related to autonomous vehicles are becoming critical with the development of technology. Their proliferation raises legal problems, for which legislators and
car companies are also looking for solutions [2]. Of course, it needs to pay attention to the ethical problems because of the machines. Reference [3] another problem may be the programming of autonomous vehicles for traffic law rules. Some researchers have already begun to develop models for this possibility [15]. The laws need to be changed for autonomous vehicles [25], [38].

One of the significant research and development topics in the automotive industry today is the automation of vehicles and the creation of various assistant systems. However, due to the novelty of the development, legislation, and testing processes for such systems are rudimentary. Although there are standards that include test conditions for some assistant systems [11]–[13]. These systems do not cover many critical traffic situations. Emerging features require the development of further standards and test situations [5]. The paper aims to consider and analyze the traffic situation suitable for the testing of assistant systems and its conditions in a simulation environment. These facilitate the conceptual implementation of a series of list-like traffic situations that, throughout the process, determine the applicability of an assistant system to traffic based on the performance in the situations. The best way to find the weaknesses of the highly automated vehicles is the sensitivity analysis.

According to the above, the main contribution of the paper is the justification of the conflicts of automated driving with conventional traffic infrastructure by using simulation method. The revealed issues need to be handled in the future in order to make the shift smooth from conventional traffic to automated driving.

III. CRITICAL SITUATION ANALYSIS
The first critical situation is presented; the speed assist system (based on speed limit traffic sign recognition) conflicts with the traffic infrastructure (Fig. 1).

The second critical situation is shown, the ACC (Adaptive Cruise Control) and LKA (Lane Keeping Assist) conflicts with the traffic infrastructure (Fig. 2).

A. SITUATION 1
The investigated traffic situation is based on the inspiration of a real road section. This place is located in Budapest near the Szent Gellért square. The earlier driving experience chose the critical situation. The selected road section took into account the infrastructure, the terrain of the road, and the vertical and horizontal traffic signs. (Fig. 3) The section is a two-lane asphalt road where traffic flows in the same direction on both lanes. The road section is crossed at a particular location by a pedestrian crossing without any other intersection road and traffic lights. Initially, the road is subject to a speed limit of 50 km/h for suburban areas, but there is a limit of 30 km/h for the 35 m section in front of the pedestrian crossing. Besides, on the restricted section, a solid line separates the lanes originally separated by a broken line. In this case, the aim is to investigate situations in which two successive or catch up vehicles attempt to cross the road with different starting conditions. Traffic situations where the performance limits of different ADAS systems can be defined ([24]). During the description of the situations, numbers, for ease of distinctness and conciseness, refers to the vehicles. The leader vehicle assigned to the vehicle at the front. In this way, the vehicle that follows or arrives behind vehicle number 1 is indicated by following vehicle.

When simulating the situations and scenarios, it is expected that the visibility and road quality on the place is excellent, as well as only the driver and the various assistant systems controlling the vehicle. The two vehicles were in the same lane, and by default, it assumed that they both have driver support systems. The vehicles have adaptive cruising and brake assistant enabled, where the ACC capable of stopping and restarting the motion of the vehicle while the ABS hold the tires from blocking. In the examined situations, the reaction times of the autonomous vehicles are significant. Because it
needs a shorter reaction time than the human one, but there is some technological limitation [39].

In the sensitivity analysis, one parameter changes at a time. The safe distance between two vehicles (braking distance) can be interpreted in several ways. This safe range is the distance from the appearance of the need for braking to the distance traveled to a complete stop. However, this distance is such a significant tracking distance that it would be difficult to always achieve in real traffic. The other extreme is when the need for braking arises; it needs to consider the speed and possible deceleration of the object, causing the braking. In which case, the distance traveled in time \( T_1 \) is significantly reduced. Thus, it is taken almost only the distance traveled during the detection and actuation time as the distance of the tracking term, in which case no detection time is left in reserve [14], [27], (Fig. 4).

It can be seen that there were situations where the first case, and there were cases, especially in urban transport, when the second case is more suitable. An absolute safety distance can be more realistic in cases where the vehicle approaches objects that are perceived to be immobile by default, i.e.; it is likely that their spatial position will not change. It is a similar case when the assumed route of an object intersects the path of the vehicle transversely, which, like immobile objects, require the vehicle to stop at a given point. Examples include pedestrian crossings and intersections too. Based on Figure Fig. 4, the absolute safety distance is derived from the following sub-distances: (Ignoring the deceleration during time \( T_1 \), simplified by 0)

\[
\begin{align*}
  s_0 &= v_0 \cdot T_0 \\
  s_1 &= v_0 \cdot T_1 \\
  s_2 &= v_0 \cdot T_2 - \frac{x_j \cdot T_2^3}{6} \quad \mid x_j = \frac{\Delta a_j}{T_2} \\
  s_3 &= \left( v_0 - \frac{a_j T_2}{2} \right) \cdot T_3 - \frac{a_j T_2^3}{2} \quad \mid T_3 = \frac{v_0 - \frac{a_j T_2^2}{2}}{a_j} \\
  s_b &= 1.5 [m]
\end{align*}
\]

where,
- \( v_0 \) = Vehicle speed when demand for braking appears
- \( x_j \) = Deceleration of the vehicle
- \( s_b \) = Safety distance between the vehicle and the object after stopping

Adding up the distances assuming an initial deceleration of 0, after the equation and simplification:

\[
\begin{align*}
  s_{ab} &= s_b + v_0 \cdot \left( T_0 + T_1 + \frac{T_2}{2} \right) - \frac{a_j \cdot T_2^2}{24} + \frac{v_0^2}{2 \cdot a_j} \\
  s_v &= \left( s_b + v_0 \cdot \left( T_0 + T_1 + \frac{T_2}{2} \right) - \frac{a_j \cdot T_2^2}{24} + \frac{v_0^2}{2 \cdot a_j} \right) \\
  &- \left( \frac{v_0 \cdot T_{2,0}}{2} - \frac{a_0 \cdot T_{2,0}^2}{24} + \frac{v_0^2}{2 \cdot a_0} \right)
\end{align*}
\]

where,
- \( v_0 \) = Detected object speed
- \( a_0 \) = Detected object deceleration
- \( T_{2,0} = T_2 \) time interval starting moment of time

However, it should be noted that the response time of automated systems is much more favorable than human response time. The calculation frequency of the decision electronics of a general motor vehicle is between 1 and 10 Hz, which means that at best, the vehicle can emit a new control signal every 0.1 seconds based on the signals from the sensors. With this in mind, periods \( T_0 \) and \( T_1 \) almost entirely disappear. For further calculations, denoting the response time and brake response time of the automatic system by \( T'_0 \) is taken as 0.2 seconds. Thus, the tracking distance equation for the automated system changes to:

\[
\begin{align*}
  s_{v}' &= \left( s_b + v_0 \cdot \left( T'_0 + \frac{T_2}{2} \right) - \frac{a_j \cdot T_2^2}{24} + \frac{v_0^2}{2 \cdot a_j} \right) \\
  &- \left( \frac{v_0 \cdot T_{2,0}}{2} - \frac{a_0 \cdot T_{2,0}^2}{24} + \frac{v_0^2}{2 \cdot a_0} \right)
\end{align*}
\]

For an average vehicle, the maximum deceleration depends on the dynamic gravitational force acting on the axles of the vehicle and the maximum coefficient of grip that can be interpreted between the vehicle-wheel contacts. It also plays a role in the axle load due to the downforce caused by the air resistance of the vehicle, especially at higher speeds. The wheels do not lock with a higher braking force. The designed deceleration achievable by passenger car braking systems is around 10 m/s², but this is only an ideal value that can, therefore, only be achieved under ideal conditions. Approach from another point of view, in order for a vehicle to participate in traffic in Hungary, it must meet the relevant requirements of UNECE Regulation No. 13, which is the subject of the “Uniform provisions concerning the approval of vehicles of categories M, N and O about braking.” A condition under this is that the vehicle must achieve deceleration of 5.8 m/s² at a pedal force of 500 N. Thus, for the two extreme cases, the maximum deceleration of a passenger car in traffic can be estimated to be between 5.8-10 m/s². If the braking time and the maximum deceleration are taken to be the same for the two bodies, the tracking distance will only depend on the speed of the vehicle and the detected object. In this case,
this deceleration can be taken as an average of 7.9 m/s².

With the assumptions, the equation is modified as follows.

\[ s_v = \left( s_b + v_0 \cdot T_0 + \frac{T_2 \cdot (v_0 - v_0)}{2} + \frac{v_0^2 - v_0^2}{2 \cdot a} \right) \]  



(9)

It can be seen from the obtained equation that in this way to get a tracking distance that can be applied to moving objects, which depends not only on the own vehicle but also on the detected object. The primary control of the ACC and emergency brake system of vehicles in traffic can be easily implemented based on the tracking distance error resulting from the difference between the above equation and the actual distance.

From the equation obtained in this way, it can be received a braking distance that can be applied to moving objects, which depends not only on one’s vehicle but also on the detected object. The speed assist systems with a traffic sign recognition, ACC, and emergency brake systems of vehicles in traffic can already be controlled based on this equation and the tracking distance error due to the difference between the actual distance. From the tests, it is worthwhile to know these formulas, because in this way an answer limit distance can be estimated, before reaching which the test vehicle must already react to the detected object to avoid a collision.

**B. SITUATION 2**

One of the significant advantages of autonomous vehicles is that they can react much faster than people in some situations can improve traffic in the end. A perfect example of this is the ACC test. However, there are traffic situations where human drivers currently make decisions differently than highly automated vehicles. That is why the acceleration lane is selected for attention as a critical traffic situation. When the test case is selected, it needs pay attention to the traffic, as people will encounter a dangerous situation in such a section, which currently affects only a few cars but may spread to. The place is dangerous in several ways, and there have been accidents on similarly designed roads. Conflicts start when the vehicles begin to change lanes. The lane changing is an easy process for a completely ordinary vehicle that does not have any driving assistance system. However, this can be a problem for vehicles with lane departure warning or automatic emergency braking (Fig. 5).

For comparative and sufficient results, calculations were performed in two simulation programs. The simulation contains two vehicles on a traffic road that were traveling one behind the other at an initial distance of 13 m. After 80 m from the starting point, the road section widens into a two-lane road, thus enabling parallel traffic. The front car indicates the intention to change lane and starts lane-changing it to the outside traffic lane. The tracking vehicle is a highly automated vehicle equipped with ADAS systems. The highly automated vehicle detects a lane change in front of him. Performs acceleration to overtake at a higher speed in the inner lane. The car’s lane keeping system is active, so the vehicle tries to stay in the middle of the lane or keep the car between the two lines. The following car moves to the right in the direction of the turning lane due to the curve of the line marking the edge of the road. In this case, the lane keeping assist/system senses that it is started to drift to the right side of the lane, and it is tried to avoid this, it can be interfered with the steering. The overtaking maneuver, according to the driver’s calculations, starts when only a small part of the vehicle in front of it is in the inner traffic lane, so the lane change is almost complete, and the overtake can be achieved with a small steering motion. Because ADAS systems were active and have an emergency braking assistant, it predestines a collision based on information from RADAR and the current vehicle speed. Thus activating the emergency braking system, thus impeding the driver’s overtaking maneuver, which is a real traffic situation - an in the case of the following vehicle - a potential source of accident, as the expected trajectory of the vehicle performing the overtaking maneuver causes a movement utterly opposite to the braking.

The cameras and RADARs of the automatic emergency braking system detect that another vehicle is on the path of our vehicle (even if only slightly), and it is straightforward for the car to perform emergency braking. In this situation, the driver behind the “leader vehicle” has very short time to react to the emergency brake even at the right following distance, and it could quickly end in an accident if his car is not equipped with the automatic emergency brake system shown earlier. At the examined location is shown, a car with a lane keeping or an automatic emergency braking system may face the following problems if the leader vehicle plans to continue driving in a straight line.

The following vehicle, at 50 km/h in the straight lane, sees the vehicle planning to turn right, slowing down in front of it. However, from a distance of 35-40 m, he still estimates that it will be able to fit the vehicle changing lane as it expects the vehicle in front of it will stop in the lane designated for right-hand turns. It soon gets close to the following vehicle, the lane-changing vehicle, which is also detected by the highly automated vehicle’s automatic emergency braking system. The following vehicle will make emergency braking soon after, as it will find it challenging to get around the vehicle in front of it. A collision can be avoided if the following vehicle is traveling at a speed of 50 km/h. In this case, the emergency braking system is still able to avoid...
the collision. It can be seen on Fig. 5 that the RADARs and cameras of the vehicle detected the vehicle in front of it. The following vehicle braked in an emergency when approaching \( x \) \( m \). However, all this would have ended in an accident if there were no driver assistance assist systems in it. However, it can also create a new emergency with emergency braking. Without the systems above, the next stopping distance must be taken into account:

\[
m \cdot \mu \cdot g \cdot s = \frac{1}{2} \cdot m \cdot v^2 - \frac{1}{2} \cdot m \cdot v_{crash}^2 \quad (10)
\]

\[
s = \frac{v^2}{2a} \quad (11)
\]

- \( v \): speed (in \( m/s \))
- \( a \): deceleration (in \( m/s^2 \))
- \( m \): mass (\( m \))
- \( v_{crash} \): crash speed \( m/s \)
- \( s \): distance (\( m \))
- \( \mu \): adhesion factor

On the left side of the equation is work, and on the right side are the kinetic energies. It will be equal because the friction work will “secure” the deceleration. If there is no collision, the value of \( v_{crash} \) is 0; the total kinetic energy is converted into heat during friction. The “work” in the formula for friction work is practically the maximum mean deceleration available, where “work” is the grip factor, i.e., the parameter describing the road conditions. The deceleration is denoted by “\( a \),” and it is value is chosen to be \( 7.5 \, m/s^2 \), which is also used in the simulation. This value corresponds to the deceleration of a vehicle with good braking system and tire condition on a better quality road. So from the above equation (assuming a stop), it can be express the length of the road needed to stop, which is:

\[
s_f = \frac{v^2}{2a} = \left( \frac{50}{3.6} \right)^2 \frac{2 \cdot 7.5}{2} = 12,86m \quad (12)
\]

So under ideal conditions, the following vehicle can stop below roughly 13 \( m \). At that time, however, the reaction time was not yet taken into account! In reality, when it can be seen as an obstacle, it does not start to slow down right away. The human body needs time to grasp what is happening and then take action. The time between perception and the actual action is called the reaction time, which averages around 0.8 seconds. Besides, it takes time for the vehicle to develop the maximum braking force. This time is called the braking time, and in a modern vehicle today, it is approx. 0.2 seconds. Of course, at these values, someone can be faster or slower, and even the cars are different, but for the sake of simplicity, now combined, it can be said that the reaction time is around 1 second. At 50 \( km/h \), the \( f_r \) means 13.88 \( m \) in 1 second before braking. Thus, for the stopping distance, the reaction time and the total stopping distance must be added, which in this case is 12.86 \( m \) + 13.88 \( m \) = 26.74 \( m \). In the test case, this means that the following vehicle would collide with the vehicles in front of it.

For the accuracy, the driver assistance system can stop the vehicle within 15,536 \( m \) - with a distance of 12.86 \( m + 2.776 \) \( m \) during a braking time of 0.2 \( s \). In addition, that means it can be avoided an accident. The only problem with this is that there may be traffic from behind with a minimum tracking distance.

C. SIMULATION SOFTWARE

Two simulation software is used for the illustration of the conflicts of automated driving and traffic infrastructure. This software is the PreScan and Virtual CRASH. The PreScan is used for the base of the measurement because the software is made for ADAS functions simulation. The Virtual CRASH is used for the analysis of the conflict situations because this software is made for accident reconstructions.

1) PreScan 8.4.0

PreScan is a physics-based simulation platform that is used in the automotive industry for the development of Advanced Driver Assistance Systems. It is based on sensor technologies such as RADAR, LiDAR, camera, and GNSS ( [10]). It can provide the development of driving assistance systems and intelligent vehicle systems. Especially useful in the early stages of development of various helps to compare and to test the operation and robustness of algorithms ( [9]). Any traffic situation can be modeled and can be used for accident reconstruction and analysis.

Another advantage is the cooperation with MATLAB, Simulink software. These programs are widespread in the industry and have a huge toolbox. In the three-dimensional visualization, it can be followed what happens during the simulation run, which makes it easier to identify problems. PreScan is made up of several main modules. The different parts controlled by the PreScan simulation engine (SimCore) are the simulation of sensors, visualization environment, combined dynamic, and control simulation.

The customizability of road segments allows at least approximate modeling of the desired road networks. The damage and tear of the paintings and the properties of the lines can also be changed. Instead of building the road network, it is possible to import an Open Street Map file. Then the road network is made with real coordinates, only the Z altitude information corresponding to the coordinate is not imported, and subsequent correction of the nodes can be necessary. The program also supports the use of OpenDRIVE networks [1].

Once the road network is built, movement paths defined on it. It can be done by connecting the nodes defined by the roads or by drawing freely on the road. It can be assigned actors to the routes. Examples of available elements are different vehicles, trailers, people, and other moving targets that simulate the vehicle used in the real vehicle test. By default, each character will proceed on the assigned trajectory based on a speed profile defined by us. In the properties of the vehicles, the vehicle dynamics model can be defined the vehicle dynamics model for them, what details are displayed during the visualization, and here it is selected whether it is provided.
them with some control logic in MATLAB, Simulink environment.

2) VIRTUAL CRASH 3.0
Virtual CRASH software is a multi-purpose application used primarily for vehicle accident reconstruction ([22]). With the newest updates, also it can be used for highly automated, autonomous vehicles tests and accidents. It can be used Virtual CRASH to simulate vehicles as well as pedestrian accidents in 2D and 3D.

In the software, the developers can create documentations, draw charts, create and manipulate 3D models and environments, and create stunning and incredibly lifelike HD animations. The Virtual CRASH uses the Kudlich-Slibar rigid body pulse model and has a multipoint contact pulse momentum model. Vehicle deformation is allowed, but this is not a SMAC-based model. Virtual CRASH has two numerical integration options: one is the fast sequential integration using an Euler and Runge-Kutta method, and the second one is full integration using a complex $n \times n$ matrix with a Euler and Runge-Kutta method [23].

The VC has been validated; the physical model is the subject of several studies. Virtual CRASH performance was compared with standard references such as RICSAC (Research Input for Computer Simulation of Automobile Collisions) [30] and JARI (Japan Automobile Research Institute) [8], as well as other batch experiments, and found to reproduce experimental results in excellent agreement.

EES (Energy Equivalent Speed) values were used from the accident analysis software Virtual CRASH. In particular, the EES, i.e., the vehicle speed equal to the energy consumed to cause the vehicle deformation. The energy equal speed value can be calculated from work done during the vehicle body deformation, and this work is estimated from the deformation size [35].

**IV. SETTINGS OF SIMULATION**

**A. SITUATION 1**
For proper evaluation of assistant systems, it is expected that each of the aggravating factors mentioned above is encountered during the measurements that constitute the validation of the system and respond to them accordingly. The baseline situation and suggestion were first analysed in PreScan, which served as proof of concept. It has proven that excessive compliance with a highly automated vehicle is dangerous. (Fig. 6)

The parameters of the sensitivity analysis in different scenarios were:

1. The first vehicle was the rule-following highly automated vehicle - slows down to 30 km/h and waiting for cross-walking people. The second vehicle went 50 km/h with different reaction times and decelerations.

2. The first vehicle was the rule-following highly automated vehicle (slows down to 30 km/h and waiting for cross-walking people. The second vehicle went 55 km/h with different reaction times and decelerations.

3. The first vehicle was the rule-following highly automated vehicle (slows down to 30 km/h and waiting for cross-walking people. The second vehicle went 60 km/h with different reaction times and decelerations.

4. The first vehicle was the rule-following highly automated vehicle (slows down to 30 km/h and waiting for cross-walking people. The second vehicle went 65 km/h with different reaction times and decelerations.

5. The first vehicle was the rule-following highly automated vehicle (slows down to 30 km/h and waiting for cross-walking people. The second vehicle went 70 km/h with different reaction times and decelerations.

One parameter changes at a time in the sensitivity analysis. **Data required for evaluation:**
- Leader car actual and demand velocities are constant
- Leader car deceleration data was constant
- Follower car actual and demand velocity
- Follower car deceleration data
- Follower car’s human driver reaction time

**Output data about the measurements:**
- Leader car EES value
- Follower car braking distance
- Follower car EES value
- Follower car and Leader car accident data

The target of the measurements demonstrates that everything in the simulation works as expected. The vehicles were capable of changing speeds, turning. Therefore, the controls do their thing at a basic level.

**Expectation:** Vehicles remain within their lanes throughout the simulation. The leader vehicle follows the specified driving cycle. The follower vehicle, in turn, follows the leader vehicle according to it is control without permanently traveling within the calculated tracking distance. No collision.

**B. SITUATION 2**
The base situation was first analysed in PreScan, which served as proof of concept. Draws attention to the fact that excessive compliance with highly automated vehicle can be dangerous. It would need to think about how to change the infrastructure for automated vehicles in the future. (Fig. 7)
The parameters of the sensitivity analysis in different scenarios were:

1. The first vehicle was the rule-following highly automated vehicle - slows down to 50 km/h and change the lane. The second vehicle went 60 km/h with different reaction times and decelerations, uses ACC.

2. The first vehicle was the rule-following highly automated vehicle - slows down to 50 km/h and change the lane. The second vehicle went 65 km/h with different reaction times and decelerations, use ACC.

3. The first vehicle was the rule-following highly automated vehicle - slows down to 50 km/h and change the lane. The second vehicle went 70 km/h with different reaction times and decelerations, use ACC.

4. The first vehicle was the rule-following highly automated vehicle - slows down to 50 km/h and change the lane. The second vehicle went 75 km/h with different reaction times and decelerations, use ACC.

5. The first vehicle was the rule-following highly automated vehicle - slows down to 50 km/h and change the lane. The second vehicle went 80 km/h with different reaction times and decelerations, use ACC.

One parameter in one time was changed in the sensitivity analysis.

Data required for evaluation:
- Leader car actual and demand velocities were constant
- Leader car deceleration data was constant
- Follower car actual and demand velocity
- Follower car deceleration data
- Follower car’s human driver reaction time

Output data about the measurements:
- Leader car EES value
- Follower car braking distance
- Follower car EES value
- Follower car and Leader car accident data

V. RESULTS OF SIMULATION
The results and the evaluations were summarized in tables and diagrams. All measurement results can be found in the Appendix. (Table 7), (Table 8), (Table 9), (Table 10). In the tables, the dangerous situations and accidents were marked with a “checkmark” (√). Vacancies mean no accidents have occurred.

A. SITUATION 1
1) FIRST SITUATION - 1. SCENARIO
The primary case of this scenario is that the vehicle in front (a highly automated, rule-following vehicle) decelerates due to the speed limit sign. A vehicle with a human driver behind it does not slow down at the speed limit sign. The article shows how dangerous this situation is, and the results confirm the statement. A sensitivity analysis was performed to demonstrate this.

All measurement results can be found in the Appendix. (Table 7), (Table 8) From these, only three deceleration values were presented in more detail. The baseline diagrams explained in PreScan were shown in the following figures. (Fig. 8) (Fig. 9).

The collision results obtained for the three deceleration values were shown in the following tables. Table 1 of the situation shows that no accidents occur at low speeds,
TABLE 2. Situation 1. results of sensitivity analysis at Deceleration: 5 m/s².

| Dec.: 5 m/s² | Accident happened? |
|--------------|-------------------|
| Reaction     |                   |
| 0.8          | ✓                 |
| 0.7          | ✓                 |
| 0.6          | ✓                 |
| 0.5          | ✓                 |
| 0.4          | ✓                 |
| time [s]     |                   |
| 50           | ✓                 |
| 55           | ✓                 |
| 60           | ✓                 |
| 65           | ✓                 |
| 70           | ✓                 |

TABLE 3. Situation 1. results of sensitivity analysis at Deceleration: 6 m/s².

| Dec.: 6 m/s² | Accident happened? |
|--------------|-------------------|
| Reaction     |                   |
| 0.8          | ✓                 |
| 0.7          | ✓                 |
| 0.6          | ✓                 |
| 0.5          | ✓                 |
| 0.4          | ✓                 |
| time [s]     |                   |
| 50           | ✓                 |
| 55           | ✓                 |
| 60           | ✓                 |
| 65           | ✓                 |
| 70           | ✓                 |

The diagrams plotted the EES values as a function of velocity and indicated three reaction times. The results follow a trend, as expected. As the speed increased, the EES values increased with a deceleration of 4 m/s². It can be read from the diagram that with the deterioration of reaction time, more collisions occurred. The polynomials fit on the measured points (Fig. 11).

The results measured at a deceleration value of 5 m/s² show that fewer accidents have occurred, especially at low speeds (Fig. 12).

At an deceleration value of 6 m/s², the following vehicle can stop safer behind it. However, at high speeds, collisions cannot be avoided here either. It should also be noted that certain older types of vehicles were no longer capable of this or a higher deceleration value. So this deceleration value cannot guarantee the occurrence of an accident either.

The tendency can be clearly seen at these values (Figure 14), and a polynomial can be fitted to it. It remains to be understood that, despite the increase in deceleration values, the sudden braking of highly automated vehicles (with an infrastructure not designed for them) poses a danger to road users (Fig. 15).
Overall, based on the tests performed with the two simulation programs, it can be said that each situation was critical, even though no collisions occurred at speed of 50 km/h. In vain did the following vehicle stop; in any case, it came close to the vehicle in front. Despite the 30 km/h limit, the tested road section allows human drivers to drive at 50 km/h. After analysing the measurement data, it can be concluded that excessive compliance with highly automated vehicles poses a danger. Especially when the infrastructure is not properly converted to highly automated vehicles. It is therefore recommended to address this issue in the future.

B. SITUATION 2

In the second situation, the hazard situation was based on what happens when the vehicle in front changes lane, and the driver of the following automated vehicle already detects that the vehicle can be overtaken. The overtaking maneuver, according to the driver’s calculations, occurs when only a small part of the vehicle in front of it is in the inner traffic lane, so the lane change is almost complete, and evasion can be achieved with a small steering motion. Because ADAS systems were active and have an emergency braking assistant, it predestines a collision based on information from RADAR (thanks to the diagonal part). The current vehicle speed, thus activating the emergency braking system, and impeding the driver’s overtaking maneuver, which is a real traffic situation - an in the case of the following vehicle - a potential source of accident, as the anticipatory trajectory of the car performing the overtaking maneuver causes a movement opposite to the braking.

The PreScan is used for the proof of concept, but the Virtual CRASH is used for the accident analysis. (Table 8) All measurement results can be found in the Appendix. (Table 7), (Table 8) Three deceleration values were presented in more detail. In the tables were presented the results of the sensitivity analysis interesting and eye-catching results. The input and output data of the measurements can be found in the previous Chapter. The main parameter of the proof is the acceleration. This situation very dangerous and need to change the infrastructure for highly automated vehicles is the acceleration. In contrast, the starting speed of the measurement is 60 km/h because this road section has a speed limit of 60 km/h. Since the vehicle in front is moving and does not stop completely, only accelerates sharply from 60 km/h to be able to change lane in fewer accidents than in Situation 1.

The collision results obtained for the three deceleration values were shown in the following tables. Table 4 of the situation shows that no accidents happened at low speeds, but 4 m/s² deceleration value is not very high value to stop the vehicle. In contrast, the starting speed of the measurement is 60 km/h because this road section has a speed limit...
of 60 km/h. However, it can be seen from the data in the table that he was able to stop correctly at the permitted speed, although due to unexpected braking, these cases cannot be considered safe either. At speeding of more than 4 m/s², the vehicle was only able to stop with better reaction time.

At decelerations above 5 m/s², a more significant change can already be seen. In several cases, the following vehicle can stop at higher speeds due to better reaction time and higher deceleration value Table 5.

In Situation 2, based on the measured data, it can be seen that the limit value was 70 km/h. With a deceleration value of 6 m/s² and good reaction times, the following car was able to stop behind the deceleration vehicle in front of the “first” vehicle Table 6.

The diagrams plotted the EES values as a function of velocity and indicated all reaction times. The Fig. 16 diagram presents for each scenario of the accident happened or not, at reaction time and speed, with the EES values. When no accident happened, the EES value is 0 km/h; this is shown in the diagram at 60, 65, and 70 km/h when the reaction time is 0.4 s.

The diagrams plotted the EES values as a function of velocity and indicated just three reaction times. The results follow the trend, as expected. As the speed increased, the EES values increased with a deceleration of 4 m/s². It can be read from the diagram that with the degeneration of reaction time, more collisions happened. The polynomials fit visibly on the measured values (Fig. 17).

A polynomial can be fitted to the measured values at 5 m/s², indicating that accidents occur with increasing reaction times and velocities (Fig. 19).

At deceleration value of 6 m/s², the following vehicle can stop safer behind the leader car. However, at high speeds, accidents cannot be avoided here either. Here it is also true that certain older types of vehicles were no longer capable of this or a higher deceleration value. Therefore, this

![Figure 16](image16.png)

**FIGURE 16.** EES values as a function of Velocity, Deceleration: 4 m/s² - Sit. 2.

![Figure 17](image17.png)

**FIGURE 17.** EES values as a function of Velocity, Deceleration: 4 m/s² - Sit. 2.

![Figure 18](image18.png)

**FIGURE 18.** EES values as a function of Velocity, Deceleration: 5 m/s² - Sit. 2.

### TABLE 5. Situation 2. results of sensitivity analysis at Deceleration: 5 m/s².

| Dec.: 5 m/s² | Accident happened? |
|--------------|---------------------|
| Reaction     | 0.8                 | ✓ ✓ ✓ ✓ ✓ |
|              | 0.7                 | ✓ ✓ ✓ ✓ ✓ |
| time [s]     | 0.6                 | ✓ ✓ ✓ ✓ ✓ |
|              | 0.5                 | ✓ ✓ ✓ ✓ ✓ |
|              | 0.4                 | ✓ ✓ ✓ ✓ ✓ |
| Situation 2. | 60 65 70 75 80      | Vehicle speed [km/h] |

### TABLE 6. Situation 2. results of sensitivity analysis at Deceleration: 6 m/s².

| Dec.: 6 m/s² | Accident happened? |
|--------------|---------------------|
| Reaction     | 0.8                 | ✓ ✓ ✓ ✓ ✓ |
|              | 0.7                 | ✓ ✓ ✓ ✓ ✓ |
| time [s]     | 0.6                 | ✓ ✓ ✓ ✓ ✓ |
|              | 0.5                 | ✓ ✓ ✓ ✓ ✓ |
|              | 0.4                 | ✓ ✓ ✓ ✓ ✓ |
| Situation 2. | 60 65 70 75 80      | Vehicle speed [km/h] |
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The trend is also clearly visible at a deceleration value of $6 \text{ m/s}^2$. A polynomial can be fitted to it.

It can be seen from the tables that as the speed increases accidents occur. As reaction times deteriorate, it can also be understood that the number of accidents increases. An increase in deceleration values can often avoid an accident, but the other three factors have a significant impact on safe stopping. The EES values increase with the degeneration of the parameters. Which also means the severity of the accident, as can be seen in the diagram. If the accident did not occur, the situation close to the accident due to sudden braking would continue. Therefore, there is an urgent need for future measures in the field of infrastructure to help the safe movement of highly automated vehicles on the roads.

**C. REMARK OF THE SITUATION**

It is necessary to show some interesting facts about the situation. This subsection tells a few remarks of the critical situations. For example, when the segment of the critical test road is not entirely straight. The curvature of the road section can be very unfavorable for an assistant system. Based on the calculations described earlier, it can be seen that the vehicle can only react to an object if it can detect it. At higher speeds, the need for emergency braking can be as high as hundreds of meters from the detected object (Fig. 22).

The problem is the range of the vehicle’s sensor system. For long-range RADARs, this range is between 150 and 200 meters. Based on the diagram, the maximum speed can be $166.94 \text{ km/h}$ to be able to stop below 150 meters. The advanced driver assistance systems will not be able to intervene in time to brake the vehicle in time. (Of course, here it...
is not taken into account the fact that bypassing the object can avoid the accident. It can be assumed that bypassing is not possible for some reason.) Thus, in turn of the road, the detection distance can be further reduced by the curvature, as the RADARs only detect an area corresponding to a given circular sector in a certain direction, in the direction of travel.

| Velocity [km/h] | Braking time [s] | Reaction time [s] | Deceleration [m/s^2] | Brake distance [m] | Accident happened? | BES values (First v.) [km/h] |
|----------------|------------------|-------------------|----------------------|-------------------|--------------------|-----------------------------|
| 1              | 50               | 1.25              | 0.8                  | 15.02             | Yes                | 5.7                         |
| 2              | 50               | 1.25              | 0.8                  | 14.24             | No                 | 0                           |
| 3              | 50               | 1.25              | 0.8                  | 13.45             | No                 | 0                           |
| 4              | 50               | 1.25              | 0.8                  | 12.67             | No                 | 0                           |
| 5              | 50               | 1.25              | 0.8                  | 11.89             | No                 | 0                           |
| 6              | 50               | 1.15              | 0.7                  | 13.99             | Yes                | 5.5                         |
| 7              | 50               | 1.15              | 0.7                  | 13.33             | No                 | 0                           |
| 8              | 50               | 1.15              | 0.7                  | 12.67             | No                 | 0                           |
| 9              | 50               | 1.15              | 0.7                  | 12.00             | No                 | 0                           |
| 10             | 50               | 1.15              | 0.7                  | 11.34             | No                 | 0                           |
| 11             | 50               | 1.05              | 0.6                  | 12.93             | Yes                | 5.5                         |
| 12             | 50               | 1.05              | 0.6                  | 12.38             | No                 | 0                           |
| 13             | 50               | 1.05              | 0.6                  | 11.83             | No                 | 0                           |
| 14             | 50               | 1.05              | 0.6                  | 11.28             | No                 | 0                           |
| 15             | 50               | 1.05              | 0.6                  | 10.72             | No                 | 0                           |
| 16             | 50               | 0.95              | 0.5                  | 11.84             | Yes                | 5.4                         |
| 17             | 50               | 0.95              | 0.5                  | 11.39             | No                 | 0                           |
| 18             | 50               | 0.95              | 0.5                  | 10.94             | No                 | 0                           |
| 19             | 50               | 0.95              | 0.5                  | 10.49             | No                 | 0                           |
| 20             | 50               | 0.95              | 0.5                  | 10.04             | No                 | 0                           |
| 21             | 50               | 0.85              | 0.4                  | 10.72             | No                 | 0                           |
| 22             | 50               | 0.85              | 0.4                  | 10.36             | No                 | 0                           |
| 23             | 50               | 0.85              | 0.4                  | 10.00             | No                 | 0                           |
| 24             | 50               | 0.85              | 0.4                  | 9.64              | No                 | 0                           |
| 25             | 50               | 0.85              | 0.4                  | 9.28              | No                 | 0                           |
| 26             | 55               | 1.25              | 0.8                  | 10.73             | Yes                | 7.8                         |
| 27             | 55               | 1.25              | 0.8                  | 10.73             | Yes                | 4.1                         |
| 28             | 55               | 1.25              | 0.8                  | 10.73             | Yes                | 0                           |
| 29             | 55               | 1.25              | 0.8                  | 10.73             | Yes                | 0                           |
| 30             | 55               | 1.25              | 0.8                  | 10.73             | Yes                | 0                           |
| 31             | 55               | 1.15              | 0.7                  | 10.73             | Yes                | 7                           |
| 32             | 55               | 1.15              | 0.7                  | 10.73             | Yes                | 3.7                         |
| 33             | 55               | 1.15              | 0.7                  | 10.73             | Yes                | 0                           |
| 34             | 55               | 1.15              | 0.7                  | 10.73             | Yes                | 0                           |
| 35             | 55               | 1.15              | 0.7                  | 10.73             | Yes                | 0                           |
| 36             | 55               | 1.05              | 0.6                  | 10.73             | Yes                | 7                           |
| 37             | 55               | 1.05              | 0.6                  | 10.73             | Yes                | 2.7                         |
| 38             | 55               | 1.05              | 0.6                  | 10.73             | Yes                | 0                           |
| 39             | 55               | 1.05              | 0.6                  | 10.73             | Yes                | 0                           |
| 40             | 55               | 1.05              | 0.6                  | 10.73             | Yes                | 0                           |
| 41             | 55               | 0.95              | 0.5                  | 10.73             | Yes                | 6.6                         |
| 42             | 55               | 0.95              | 0.5                  | 10.73             | Yes                | 0                           |
| 43             | 55               | 0.95              | 0.5                  | 10.73             | Yes                | 0                           |
| 44             | 55               | 0.95              | 0.5                  | 10.73             | Yes                | 0                           |
| 45             | 55               | 0.95              | 0.5                  | 10.73             | Yes                | 0                           |
| 46             | 55               | 0.85              | 0.4                  | 10.73             | Yes                | 6.6                         |
| 47             | 55               | 0.85              | 0.4                  | 10.73             | Yes                | 0                           |
| 48             | 55               | 0.85              | 0.4                  | 10.73             | Yes                | 0                           |
| 49             | 55               | 0.85              | 0.4                  | 10.73             | Yes                | 0                           |
| 50             | 55               | 0.85              | 0.4                  | 10.73             | Yes                | 0                           |
| 51             | 60               | 1.25              | 0.8                  | 10.73             | Yes                | 10.3                        |
| 52             | 60               | 1.25              | 0.8                  | 10.73             | Yes                | 5.5                         |
| 53             | 60               | 1.25              | 0.8                  | 10.73             | Yes                | 4.8                         |
| 54             | 60               | 1.25              | 0.8                  | 10.73             | Yes                | 7.5                         |
| 55             | 60               | 1.25              | 0.8                  | 10.73             | Yes                | 6.2                         |
| 56             | 60               | 1.15              | 0.7                  | 10.73             | Yes                | 9                           |
| 57             | 60               | 1.15              | 0.7                  | 10.73             | Yes                | 4.6                         |
| 58             | 60               | 1.15              | 0.7                  | 10.73             | Yes                | 2.6                         |
| 59             | 60               | 1.15              | 0.7                  | 10.73             | Yes                | 0                           |
| 60             | 60               | 1.15              | 0.7                  | 10.73             | Yes                | 0                           |
| 61             | 60               | 1.05              | 0.6                  | 10.73             | Yes                | 7.9                         |
| 62             | 60               | 1.05              | 0.6                  | 10.73             | Yes                | 4.1                         |
| 63             | 60               | 1.05              | 0.6                  | 10.73             | Yes                | 0                           |
| 64             | 60               | 1.05              | 0.6                  | 10.73             | Yes                | 0                           |
| 65             | 60               | 1.05              | 0.6                  | 10.73             | Yes                | 0                           |
of the vehicle. In a similar approach, altitude change can also have a range-reducing effect. The study of driver behavior can be of great help in the development of RADAR’s determination of detection distance [16] (Fig. 23). Another challenge is for the vehicle to respond only to objects that cross the planned route. It is expected to ignore traffic in other lanes and ignore pedestrians and vehicles standing on the side of the road. Because in this case, the vehicle would inadvertently detect an emergency, which would cause extreme reactions in the system.

| Velocity [km/h] | Braking time [s] | Reaction time [s] | Deceleration [m/s²] | Brake distance [m] | Accident happened? | EES values (First v.) |
|----------------|------------------|-------------------|---------------------|-------------------|-------------------|---------------------|
| 66             | 0.95             | 0.5               | 3                   | 14.48             | Yes               | 8.2                 |
| 67             | 0.95             | 0.5               | 4                   | 14.03             | Yes               | 3.8                 |
| 68             | 0.95             | 0.5               | 5                   | 13.58             | No                | 0                   |
| 69             | 0.95             | 0.5               | 6                   | 13.13             | No                | 0                   |
| 70             | 0.95             | 0.5               | 7                   | 12.67             | No                | 0                   |
| 71             | 0.85             | 0.4               | 3                   | 13.08             | Yes               | 7.6                 |
| 72             | 0.85             | 0.4               | 4                   | 12.72             | Yes               | 3.9                 |
| 73             | 0.85             | 0.4               | 5                   | 12.36             | No                | 0                   |
| 74             | 0.85             | 0.4               | 6                   | 12.00             | No                | 0                   |
| 75             | 0.85             | 0.4               | 7                   | 11.64             | No                | 0                   |
| 76             | 1.25             | 0.8               | 3                   | 20.23             | Yes               | 13.8                |
| 77             | 1.25             | 0.8               | 4                   | 19.44             | Yes               | 12                  |
| 78             | 1.25             | 0.8               | 5                   | 18.66             | Yes               | 13.1                |
| 79             | 1.25             | 0.8               | 6                   | 17.88             | Yes               | 14                  |
| 80             | 1.25             | 0.8               | 7                   | 17.10             | Yes               | 13.4                |
| 81             | 1.15             | 0.7               | 3                   | 18.78             | Yes               | 13.7                |
| 82             | 1.15             | 0.7               | 4                   | 18.12             | Yes               | 10                  |
| 83             | 1.15             | 0.7               | 5                   | 17.46             | Yes               | 10                  |
| 84             | 1.15             | 0.7               | 6                   | 16.80             | Yes               | 12.3                |
| 85             | 1.15             | 0.7               | 7                   | 16.14             | Yes               | 11.7                |
| 86             | 1.05             | 0.6               | 3                   | 17.30             | Yes               | 13.7                |
| 87             | 1.05             | 0.6               | 4                   | 16.75             | Yes               | 9                   |
| 88             | 1.05             | 0.6               | 5                   | 16.20             | Yes               | 8.6                 |
| 89             | 1.05             | 0.6               | 6                   | 15.65             | Yes               | 10.5                |
| 90             | 1.05             | 0.6               | 7                   | 15.10             | Yes               | 9.3                 |
| 91             | 0.95             | 0.5               | 3                   | 15.80             | Yes               | 10.3                |
| 92             | 0.95             | 0.5               | 4                   | 15.35             | Yes               | 7.9                 |
| 93             | 0.95             | 0.5               | 5                   | 14.90             | Yes               | 6                   |
| 94             | 0.95             | 0.5               | 6                   | 14.45             | No                | 8.3                 |
| 95             | 0.95             | 0.5               | 7                   | 13.99             | Yes               | 6.3                 |
| 96             | 0.85             | 0.4               | 3                   | 14.26             | Yes               | 8.4                 |
| 97             | 0.85             | 0.4               | 4                   | 13.90             | Yes               | 6                   |
| 98             | 0.85             | 0.4               | 5                   | 13.54             | Yes               | 3.3                 |
| 99             | 0.85             | 0.4               | 6                   | 13.18             | Yes               | 4.9                 |
| 100            | 0.85             | 0.4               | 7                   | 12.82             | No                | 0                   |
| 101            | 1.25             | 0.8               | 3                   | 21.96             | Yes               | 15.6                |
| 102            | 1.25             | 0.8               | 4                   | 21.18             | Yes               | 15.5                |
| 103            | 1.25             | 0.8               | 5                   | 20.40             | Yes               | 17.4                |
| 104            | 1.25             | 0.8               | 6                   | 19.62             | Yes               | 18.1                |
| 105            | 1.25             | 0.8               | 7                   | 18.84             | Yes               | 16.7                |
| 106            | 1.15             | 0.7               | 3                   | 20.38             | Yes               | 17.1                |
| 107            | 1.15             | 0.7               | 4                   | 19.72             | Yes               | 14.9                |
| 108            | 1.15             | 0.7               | 5                   | 19.05             | Yes               | 16.4                |
| 109            | 1.15             | 0.7               | 6                   | 18.39             | Yes               | 17                  |
| 110            | 1.15             | 0.7               | 7                   | 17.73             | Yes               | 15.1                |
| 111            | 1.05             | 0.6               | 3                   | 18.76             | Yes               | 14.1                |
| 112            | 1.05             | 0.6               | 4                   | 18.21             | Yes               | 14.1                |
| 113            | 1.05             | 0.6               | 5                   | 17.66             | Yes               | 14.4                |
| 114            | 1.05             | 0.6               | 6                   | 17.11             | Yes               | 15.8                |
| 115            | 1.05             | 0.6               | 7                   | 16.56             | Yes               | 15.2                |
| 116            | 0.95             | 0.5               | 3                   | 17.12             | Yes               | 13.4                |
| 117            | 0.95             | 0.5               | 4                   | 16.67             | Yes               | 13.5                |
| 118            | 0.95             | 0.5               | 5                   | 16.22             | Yes               | 12.9                |
| 119            | 0.95             | 0.5               | 6                   | 15.76             | Yes               | 14.1                |
| 120            | 0.95             | 0.5               | 7                   | 15.31             | Yes               | 13.2                |
| 121            | 0.85             | 0.4               | 3                   | 15.44             | Yes               | 11.4                |
| 122            | 0.85             | 0.4               | 4                   | 15.08             | Yes               | 12.2                |
| 123            | 0.85             | 0.4               | 5                   | 14.72             | Yes               | 11                  |
| 124            | 0.85             | 0.4               | 6                   | 14.36             | Yes               | 12.4                |
| 125            | 0.85             | 0.4               | 7                   | 14.00             | Yes               | 11.1                |
Solving the above mentioned problems is the biggest challenge in developing object-responsive assistant systems. At the same time, it can be said that sensor fusions and the continuous development of image recognition systems can significantly help to solve these tasks, or the naturalistic driving study can help to develop ADAS in the future [17].
Thus, the assistant systems were properly evaluated; their operation must be examined taking into account aggravating factors. It is expected that their process will remain safe even when the range of sensors can only be considered reduced. It is also essential to find what infrastructure changes are needed for the systems to operate safely. Due to the use of simulation programs, it should be mentioned that despite the many measurements, the simulation

| Velocity [km/h] | Braking time [s] | Reaction time [s] | Deceleration [m/s^2] | Brake distance [m] | Accident happened? | EES values (First v.) [km/h] |
|----------------|------------------|------------------|----------------------|-------------------|-------------------|--------------------------|
| 66             | 0.95             | 0.5              | 3                    | 17.12             | Yes               | 6.6                      |
| 67             | 0.95             | 0.5              | 4                    | 16.67             | Yes               | 5.1                      |
| 68             | 0.95             | 0.5              | 5                    | 16.22             | No                | 0                        |
| 69             | 0.95             | 0.5              | 6                    | 15.76             | No                | 0                        |
| 70             | 0.95             | 0.5              | 7                    | 15.31             | No                | 0                        |
| 71             | 0.85             | 0.4              | 3                    | 15.44             | Yes               | 6.7                      |
| 72             | 0.85             | 0.4              | 4                    | 15.08             | No                | 0                        |
| 73             | 0.85             | 0.4              | 5                    | 14.72             | No                | 0                        |
| 74             | 0.85             | 0.4              | 6                    | 14.36             | No                | 0                        |
| 75             | 0.85             | 0.4              | 7                    | 14.00             | No                | 0                        |
| 76             | 1.25             | 0.8              | 3                    | 23.70             | Yes               | 13                       |
| 77             | 1.25             | 0.8              | 4                    | 22.92             | Yes               | 12.3                     |
| 78             | 1.25             | 0.8              | 5                    | 22.14             | Yes               | 11.5                     |
| 79             | 1.25             | 0.8              | 6                    | 21.35             | Yes               | 10.7                     |
| 80             | 1.25             | 0.8              | 7                    | 20.57             | Yes               | 9.9                      |
| 81             | 1.15             | 0.7              | 3                    | 21.97             | Yes               | 12.5                     |
| 82             | 1.15             | 0.7              | 4                    | 21.31             | Yes               | 11.5                     |
| 83             | 1.15             | 0.7              | 5                    | 20.65             | Yes               | 11.6                     |
| 84             | 1.15             | 0.7              | 6                    | 19.99             | Yes               | 9.6                      |
| 85             | 1.15             | 0.7              | 7                    | 19.33             | Yes               | 8.5                      |
| 86             | 1.05             | 0.6              | 3                    | 20.22             | Yes               | 12                       |
| 87             | 1.05             | 0.6              | 4                    | 19.67             | Yes               | 10.9                     |
| 88             | 1.05             | 0.6              | 5                    | 19.12             | Yes               | 9.7                      |
| 89             | 1.05             | 0.6              | 6                    | 18.57             | Yes               | 8.5                      |
| 90             | 1.05             | 0.6              | 7                    | 18.02             | Yes               | 6.8                      |
| 91             | 0.95             | 0.5              | 3                    | 18.44             | Yes               | 11.5                     |
| 92             | 0.95             | 0.5              | 4                    | 17.99             | Yes               | 10.2                     |
| 93             | 0.95             | 0.5              | 5                    | 17.54             | Yes               | 8.7                      |
| 94             | 0.95             | 0.5              | 6                    | 17.08             | Yes               | 7                        |
| 95             | 0.95             | 0.5              | 7                    | 16.63             | Yes               | 4.8                      |
| 96             | 0.85             | 0.4              | 3                    | 16.62             | Yes               | 11.1                     |
| 97             | 0.85             | 0.4              | 4                    | 16.26             | Yes               | 9.5                      |
| 98             | 0.85             | 0.4              | 5                    | 15.90             | Yes               | 7.7                      |
| 99             | 0.85             | 0.4              | 6                    | 15.54             | Yes               | 5                        |
| 100            | 0.85             | 0.4              | 7                    | 15.18             | No                | 0                        |
| 101            | 1.25             | 0.8              | 3                    | 25.43             | Yes               | 14.1                     |
| 102            | 1.25             | 0.8              | 4                    | 24.65             | Yes               | 14.9                     |
| 103            | 1.25             | 0.8              | 5                    | 23.87             | Yes               | 14.5                     |
| 104            | 1.25             | 0.8              | 6                    | 23.09             | Yes               | 14                       |
| 105            | 1.25             | 0.8              | 7                    | 22.31             | Yes               | 13.6                     |
| 106            | 1.15             | 0.7              | 3                    | 23.57             | Yes               | 13.5                     |
| 107            | 1.15             | 0.7              | 4                    | 22.91             | Yes               | 14                       |
| 108            | 1.15             | 0.7              | 5                    | 22.25             | Yes               | 13.4                     |
| 109            | 1.15             | 0.7              | 6                    | 21.59             | Yes               | 12.7                     |
| 110            | 1.15             | 0.7              | 7                    | 20.93             | Yes               | 12.1                     |
| 111            | 1.05             | 0.6              | 3                    | 21.68             | Yes               | 13.1                     |
| 112            | 1.05             | 0.6              | 4                    | 21.13             | Yes               | 13.2                     |
| 113            | 1.05             | 0.6              | 5                    | 20.58             | Yes               | 12.4                     |
| 114            | 1.05             | 0.6              | 6                    | 20.03             | Yes               | 11.5                     |
| 115            | 1.05             | 0.6              | 7                    | 19.47             | Yes               | 10.6                     |
| 116            | 0.95             | 0.5              | 3                    | 19.76             | Yes               | 9                        |
| 117            | 0.95             | 0.5              | 4                    | 19.31             | Yes               | 12.6                     |
| 118            | 0.95             | 0.5              | 5                    | 18.85             | Yes               | 11.5                     |
| 119            | 0.95             | 0.5              | 6                    | 18.40             | Yes               | 10.4                     |
| 120            | 0.95             | 0.5              | 7                    | 17.95             | Yes               | 9.1                      |
| 121            | 0.85             | 0.4              | 3                    | 17.81             | Yes               | 8.2                      |
| 122            | 0.85             | 0.4              | 4                    | 17.44             | Yes               | 11.9                     |
| 123            | 0.85             | 0.4              | 5                    | 17.08             | Yes               | 10.6                     |
| 124            | 0.85             | 0.4              | 6                    | 16.72             | Yes               | 9.1                      |
| 125            | 0.85             | 0.4              | 7                    | 16.36             | Yes               | 7.5                      |
programs might not always match the actual data. Continuous studies require comparisons between measurements with measurements in simulation software and real environment [7].

VI. CONCLUSION

Overall, based on tests performed with the two simulation programs, it can be said that all situations were critical, even though no collision occurred at lower speeds. In many cases, sudden braking results in a situation close to the accident. Though no collision occurred at lower speeds. In many cases, sudden braking results in a situation close to the accident. However, the problem needs to be addressed in the future if people want to drive safely in autonomous vehicles. The tables show that accidents happened as speed increases. It should also be noted that certain older types of vehicles were no longer capable of this or a higher deceleration value. Besides, even a proper value for reaction time does not provide safety, as not all people can react appropriately to a sudden braking vehicle in front of them.

Based on the analyzed simulations, it is concluded that autonomous vehicles do not necessarily have to be designed for existing infrastructure. Nevertheless, the infrastructure also needs significant change, which could mean building new signs, other types of lanes, or possibly overhauling. However, the problem needs to be addressed in the future if people want to drive safely in autonomous vehicles.

APPENDIX

See Tables 7–10.

ACKNOWLEDGMENT

The project has been supported by the European Union, cofinanced by the European Social Fund. EFOP-3.6.2-16-2017-00002. The research reported in this paper and carried out at the Budapest University of Technology and Economics was supported by the “TKP2020, Institutional Excellence Program” of the National Research Development and Innovation Office in the field of Artificial Intelligence (BME IE-MI-FM TKP2020).

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