THE ISSUE OF OBSERVANCE OF SAFE FOLLOWING DISTANCE BETWEEN VEHICLES IN GERMANY

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Abstract

This technical article discusses the issue of observance of safe following distance between vehicles on motorways in the Federal Republic of Germany. It contains an analysis of accident frequency on roads in Germany, with a particular focus on traffic accidents caused by the failure to observe a safe following distance behind another vehicle. Next, it describes legal requirements on the observance of a safe distance in particular countries and, in respect thereof, it presents results of an analysis of the observance of a safe following distance between vehicles on German motorways containing two and three traffic lanes per carriageway in one direction.

Keywords: Safe distance; vehicle; traffic accident; cause of an accident

Introduction

A traffic accident is usually a direct result of the failure of one or more basic interacting factors, including vehicle safety, safety of road itself and its surroundings and behaviour of road users.

One of the objectives of individual countries of the world is to prevent or at least to reduce the risk of traffic accidents and their consequences, which are linked to losses as regards health, human lives as well as economy and others. Statistics of traffic accidents show one of the most common causes of traffic accidents to be the “failure to observe a safe distance behind another vehicle”. Introducing measures related to traffic accidents arising from this particular cause can contribute to reducing traffic accidents. One of the ways forward is the exact definition of a safe following distance in legislation, setting of effective penalties for the breach thereof, and so on.

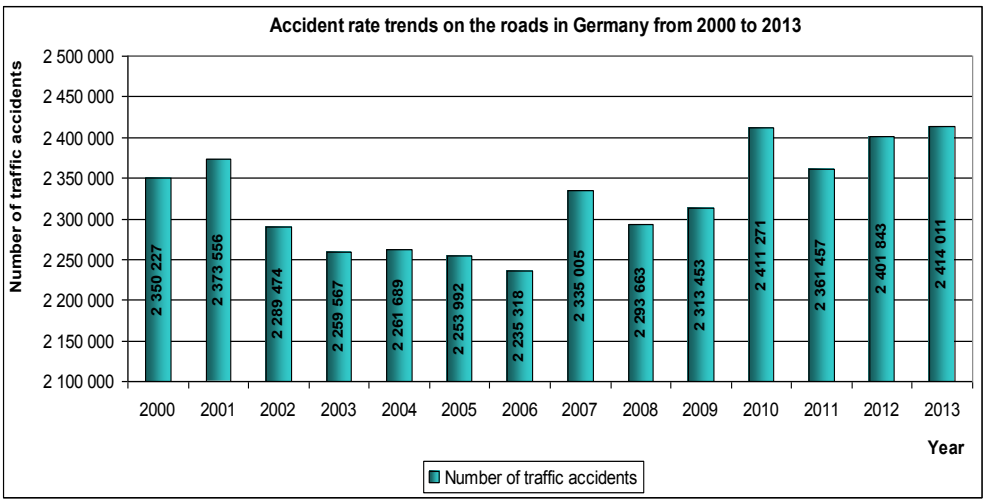
This contribution deals with the issue of a safe following distance between vehicles on roads in Germany, with a focus on the analysis of its observance on motorways with two or three traffic lanes in one direction.

Accident rate on the roads in germany

Number of traffic accidents

According to UNECE statistical data, there occurred a total of 32,554,526 traffic accidents on the roads in Germany from 2000 to 2013 (see the following chart), which represents an average of 2,325,323 traffic accidents per year. [11]

From 2001 to 2006, there was a significant drop in the number of these accidents, namely to 2,235,318 accidents. The significant decrease by more than a half could have been influenced by amendments to legislation and a number of factors, which included, for example, developing active and passive vehicle safety, increasing transport infrastructure safety, campaigns focused on increasing prevention in the field of road safety, innovations concerning driver education, increasing the number of road checks etc. By contrast, from 2007 to 2013, the number of traffic accidents increased on average with 2,414,011 traffic accidents reported in 2013. [11]



Graph 1: Accident rate trends on the roads s in Germany from 2000 to 2013 [11]

Consequences of traffic accidents

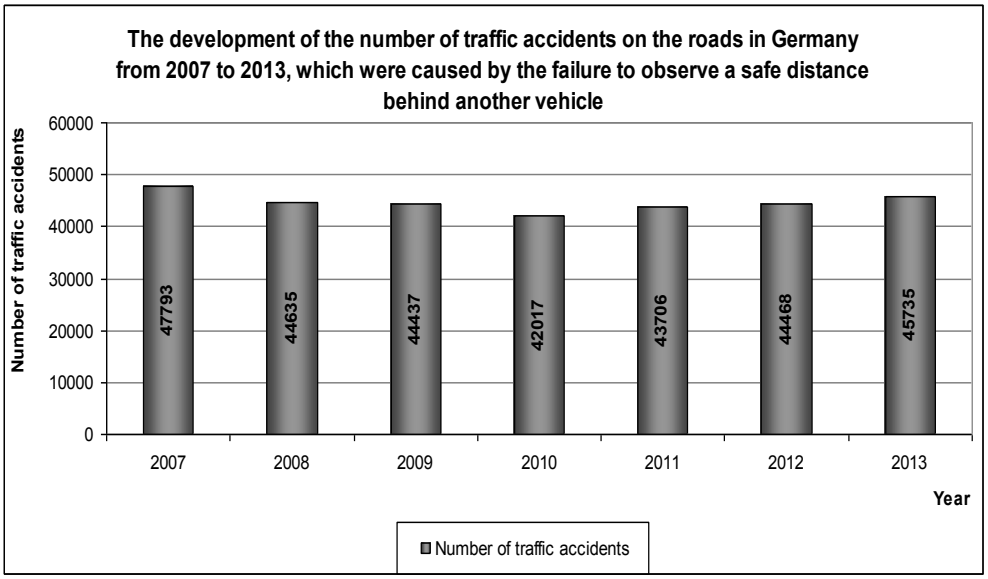
According to UNECE statistical data, the number of people killed in traffic accidents on the roads in Germany gradually decreased from 2000 to 2013 (see the following chart). In 2013, the number of people killed reached approximately 45% of the figure of 2000, namely with 3,339 people killed. A person is considered killed in a traffic accident if they died as a result of a traffic accident within 30 days. [11]

Graph 2: Trends in the number of people killed in traffic accidents on the roads in Germany from 2000 to 2013 [11]

Causes of traffic accidents

According to UNECE statistical data, 2,414,011 traffic accidents occurred in Germany in 2013, of which there were 291,105 accidents involving injury or death, while altogether 350,381 causes of the accidents were recorded by the German Statistical Office. Out of these, 55,480 accidents were caused by incorrect turning or reversing, 51,055 by failure to give right of way, 48,730 were down to speeding, 45,735 to failure to observe a safe distance behind another vehicle, and 13,327 accidents were caused by driving under the influence of alcohol, etc. [11, 3, 4]

The following chart shows the development of the number of traffic accidents on the roads in Germany from 2007 to 2013, which were caused by the failure to observe a safe distance behind another vehicle with the cause being related to traffic accidents, which resulted in injury or death.



Graph 3: The development of the number of traffic accidents on the roads in Germany from 2007 to 2013, which were caused by the failure to observe a safe distance behind another vehicle [3,4]

Methodology

Safe following distance behind another vehicle:

From a technical point of view, a safe following distance between vehicles, where two vehicles follow each other in a lane, consists of three basic components. They include the speed of each car, the maximum attainable braking rate of each vehicle and the reaction time of the driver of the second vehicle. The safe following distance behind another vehicle can be described by the following formula [2, 12]:

$$b \geq v_2 \cdot t_{r2} + \frac{v_2^2}{2 \cdot a_2} - \frac{v_1^2}{2 \cdot a_1}$$

Where:

b…….... safe following distance between two vehicles [m],

v_1……..... speed of the first vehicle [m/s],

v_2……..... speed of the second vehicle [m/s],

t_{r2}…….…….. reaction time of the driver of the second vehicle [s],

a_1…….…….. braking rate of the first vehicle [m/s^2],

a_2…….…….. braking rate of the second vehicle [m/s^2].

If both vehicles following each other have the same speed and the same maximum attainable braking rate, the safe distance between the vehicles corresponds to the reaction time of the second driver. Research has been carried out to assess driver's reaction time with the time depending on the driver's age, their mental state and a number of other factors.

The length of the safe distance is determined by the fact that upon a sudden stop of the first vehicle the vehicle travelling behind it can be safely brought to a halt. From a technical point of view, a sudden stop is to be understood as braking involving the maximum attainable deceleration regarding adhesive and design conditions until the vehicle fully stops. In the case the first vehicle is overtaken by the second one in such a way that there is no safe distance between the vehicles, the driver of the overtaken vehicle should not be forced to perform deceleration of its vehicle higher than deceleration prescribed for such vehicle by law. [2]

In terms of legislation, the driver of the vehicle travelling behind another vehicle must leave sufficient safe distance behind the first vehicle so as to be able to avoid a collision in the event of a sudden reduction in speed or sudden stop of the vehicle travelling in front. In the legislation of some countries there is a direct definition of a minimum distance behind another vehicle, which the driver must observe, otherwise they face sanctions.

The German road traffic regulation, Straßenverkehrs-Ordnung, amending the Road traffic act, Straßenverkehrsgesetz, the latest amendment of which entered into force on 1 April 2013 and was valid during following measurements, includes in its first part, in Section 4 entitled "Abstand", a definition of a safe distance between vehicles. In Clause 3 of the above Section the minimum safe distance is defined for lorries with weight exceeding 3.5 *t* or for buses, which have to observe the minimum following distance of 50 *m* behind another vehicle, when driving on motorways at a speed exceeding 50 *km/h*. [5, 6]

The primary legislation including penalties for violations of the regulations by drivers in road operations is the German list of offences, named Bußgeldkatalog. Penalties for non-observance of a safe distance behind another vehicle are graded according to gravity of the driver's offence, namely from 35 to 400 €, adding up to 4 penalty points or withdrawing the driver's licence for up to three months. The gravity of the offence is classified according to the speed of the vehicle, where the speed limits are 80 km/h and 130 km/h, and further by the degree of non-observance of a safe distance. The following table shows individual penalty categories, for which distances behind vehicles are converted to a time unit. [7]

Table 1: Conversion of the basic penalties in relation to the non-observance of a safe distance behind another vehicle [7]

Gravity	Distance [*m*]	Distance [*s*]
1	< 5/10 of half of speedometer speed	< 0,90
2	< 4/10 of half of speedometer speed	< 0,72
3	< 3/10 of half of speedometer speed	< 0,54
4	< 2/10 of half of speedometer speed	< 0,36
5	< 1/10 of half of speedometer speed	< 0,18

Measurement procedure

Measurements were carried out in Germany. The first speed measurements were carried out on the A8 motorway with two traffic lanes per carriageway, in particular in the vicinity of Exit No. 109, in the direction of Salzburg, near the village of Winkl. Next, speed measurements were carried out on the A9 motorway with three traffic lanes per carriageway, in particular in the vicinity of Exit No. 64, in the direction of Nuremberg, near the village of Au A. Aign.

All measurements were made under relatively fine weather conditions and in good visibility. When recording, the camcorder was hidden from the drivers' sight so as to pass unnoticed and not to affect their behaviour. Video recordings were taken using a digital camcorder with 1920 by 1080 pixel-resolution with 50 frames per second.

Fig. 1: *Camcorder station - measuring near the village of Winkl*

Fig. 2*: Camcorder station - measuring near the village of Au A. Aign*

Prior to the start of video recording, distances were measured using a surveying total station between motorway verge marker posts, broken markings separating the individual lanes in corresponding carriageway, or vertical traffic signs and so on. These values obtained through measurements were then fed into the video recording to be used in subsequent analysis. In order to avoid systematic distortion of values caused by vehicle height, the corresponding distance from the relevant part of the vehicle was taken from the border of the vehicle shadow.

When analyzing individual pictures, the following data about vehicle columns were recorded:

• Type of lane, in which a vehicle moves in a traffic column (values: left, right, or middle),

• Type of vehicle moving in a traffic column (values: passenger car, van, lorry up to 12 *t*, tractor with semi-trailer),

• Framing coefficient determined according to the frame rate of the video recording taken (values: 0.02),

• Time of the front of the vehicle at the beginning of the section (values: frame number of the video recording),

• Time of the rear of the vehicle at the beginning of the section (values: frame number of the video recording),

• Time of the rear of the vehicle at the end of the section (values: frame number of the video recording),

• Length of the measured section (values: distance in meters).

From these variables were consequently calculated the average speed of the vehicle and the distance between vehicles in the measured section, from which mean values of these figures were then calculated. Those vehicles were regarded as vehicles moving in a column if spacing between them was less than 110 metres. The following tables show resulting values of measurements taken, while values of the average speed and average distance between vehicles in a column may fluctuate by no more than about 5 *%*.

Results of measurement

Measurement of following distance between vehicles near the village of Winkl on 14 November 2013

The measurements were carried out from 14.55 to 16.25 hours on Wednesday, 13 November 2013, when in the area the outdoor temperature was 4.5 *°C*, with clear skies, no precipitation, light wind, and the motorway surface was dry.

Average speeds of individual vehicle types in the measured section in the right lane of the A8 motorway ranged from 83 to 109 *km/h* on the average, with the average distance behind vehicle being in the range from 45 to 52 *m*. Regarding the average vehicle speed in the section in question and the distance behind another vehicle, the shortest distance behind another vehicle in the right motorway lane was kept on average by drivers of passenger cars, namely 1.62 *s*. In contrast, the longest distance was kept by drivers of tractors with semi-trailers, namely 2.06 *s*.

Tab. 2 The measured values in the right lane of the A8 motorway near the village of Winkl in the direction of Salzburg.

Vehicle category	**Number of vehicles**	**Average vehicle speed in the given section**	**Average distance between vehicles in the given section**
Passenger cars	142	109 *km/h*	49 *m* (1.62 *s*)
Vans	46	100 *km/h*	52 *m* (1.87 *s*)
Lorries up to 12 *t*	36	83 *km/h*	45 *m* (1.95 *s*)
Tractor with semi-trailer	80	84 *km/h*	48 *m* (2.06 *s*)

In regard to observing a safe distance between vehicles, the situation in the left lane was significantly worse. Average speeds of individual vehicle types in the measured section in the left lane of the A8 motorway ranged from 115 to 119 *km/h* on the average, with the average distance behind vehicle being in the range from 38 to 39 *m*. Regarding the average vehicle speed in the section in question and the distance behind vehicle, the shortest distance behind another vehicle in the left motorway lane was kept on average by drivers of passenger cars, namely 1.18 *s*, but this value is almost identical with van drivers, who observed an average distance between vehicles of 1.19 *s*.

Tab. 3 The measured values in the left lane of the A8 motorway near the village of Winkl in the direction of Salzburg.

Vehicle category	**Number of vehicles**	**Average vehicle speed in the given section**	**Average distance between vehicles in the given section**
Passenger cars	347	119 *km/h*	39 *m* (1.18 *s*)
Vans	47	115 *km/h*	38 *m* (1.19 *s*)

Measurement of following distance between vehicles near the village of Au A. Aign on 14 November 2013

The measurements were carried out from 12.00 to 13.30 hours on Thursday, 14 November 2013, when the outdoor temperature in the area was 4.5 °*C*, cloudy with mild rainfall, light wind, and the motorway surface was slightly wet.

Average speeds of individual vehicle types in the measured section in the right lane of the A9 motorway ranged from 94 to 125 *km/h* on the average, with the average distance behind vehicle being in the range from 53 to 68 *m*. Regarding the average vehicle speed in the section in question and the distance behind another vehicle, the shortest distance behind another vehicle in the right motorway lane was kept on average by drivers of

passenger cars, namely 1.67 *s*. In contrast, the longest distance was kept by drivers of lorries up to 12 *t*, namely 2.26 *s*.

Tab. 4 The measured values in the right lane of the A9 motorway near the village of Au A. Aign in the direction of Nuremberg.

Vehicle category	**Number of vehicles**	**Average vehicle speed in the given section**	**Average distance between vehicles in the given section**
Passenger cars	23	125 *km/h*	58 *m* (1.67 *s*)
Vans	10	122 *km/h*	68 *m* (2.01 *s*)
Lorries up to 12 *t*	49	94 *km/h*	59 *m* (2.26 *s*)
Tractor with semi-trailer	111	94 *km/h*	53 *m* (2.03 *s*)

In regard to observing a safe distance between vehicles, the situation in the middle lane was significantly worse. Average speeds of individual vehicle types in the measured section in the middle lane of the A9 motorway ranged from 101 to 136 *km/h* on the average, with the average distance behind vehicle being in the range from 44 to 52 *m*. Regarding the average vehicle speed in the section in question and the distance behind another vehicle, the shortest distance behind a vehicle in the middle motorway lane was kept on average by drivers of vans, namely 1.33 *s*. In contrast, the longest distance was kept by drivers of lorries up to 12 *t*, namely 1.64 *s*.

Tab. 5 The measured values in the middle lane of the A9 motorway near the village of Au A. Aign in the direction of Nuremberg.

Vehicle category	**Number of vehicles**	**Average vehicle speed in the given section**	**Average distance between vehicles in the given section**
Passenger cars	198	136 *km/h*	52 *m* (1.38 *s*)
Vans	42	133 *km/h*	49 *m* (1.33 *s*)
Lorries up to 12 *t*	10	110 *km/h*	50 *m* (1.64 *s*)
Tractor with semi-trailer	21	101 *km/h*	44 *m* (1.57 *s*)

In regard to observing a safe distance between vehicles, the situation in the left lane was even worse. Average speeds of individual vehicle types in the measured section in the left lane of the A9 motorway ranged from 157 to 164 *km/h* on the average, with the average distance behind vehicle being in the range from 46 to 51 *m*. Regarding the average vehicle speed in the section in question and the distance behind another vehicle, the shortest distance behind another vehicle in the left motorway lane was kept on average by drivers of vans, namely 1.05 *s*. The situation was slightly better in regard to drivers of passenger cars, namely 1.12 *s*.

Tab. 6 The measured values in the left lane of the A9 motorway near the village of Au A. Aign in the direction of Nuremberg.

Vehicle category	Number of vehicles	Average vehicle speed in the given section	Average distance between vehicles in the given section
Passenger cars	295	164 *km/h*	51 *m* (1.12 *s*)
Vans	28	157 *km/h*	46 *m* (1.05 *s*)

Results of the analysis in regard to penalties and findings

It follows from the executed measurements that have been mentioned above that the driver travelling in the right traffic lane observe on average a bigger distance behind vehicle than those in other lanes. The distances observed towards vehicles travelling in front get shorter on average towards the left lane. On average, drivers of passenger cars and vans drive in the shortest distance behind vehicles.

The results of the analysis of the first measurements of the observance of following distance between vehicles on the A8 motorway near the village of Winkl show that out of 699 analyzed vehicles travelling in columns 522 vehicles had a vehicle in front of them, from which they kept a certain distance, with 133 vehicles violating the relevant regulation referred to in Table 7. The relevant regulations were most frequently and most gravely violated by drivers of passenger cars. The prescribed minimum distance behind a car was most frequently violated in the left motorway lane.

Taking into account penalties in relation to lorries of weights exceeding 3.5 *t* or buses, while riding at speeds in excess of 50 *km/h* on motorways have failed to observe the minimum following distance of 50 *m* behind another vehicle, penalties would have been awarded to a total of 48 lorries travelling in the right traffic lane.

Tab. 7 An overview of the number of violations of the regulation by drivers travelling on the A8 motorway near the village of Winkl.

Gravity	Number of violations of the regulation	Number of violations by vehicle type				Number of violations by traffic lane	
		Passenger cars	*Vans*	*Lorries up to 12 t*	*Tractor with semi-trailer*	*Right*	*Left*
1	63	53	8	1	1	16	47
2	42	38	3	0	1	5	37
3	21	18	2	1	0	1	20
4	7	5	1	0	1	1	6
5	0	0	0	0	0	0	0
∑	***133***	***114***	***14***	***2***	***3***	***23***	***110***

The results of the analysis of the second measurements of the observance of following distance between vehicles on the A9 motorway near the village of Au A. Aign show that out of 789 analyzed vehicles travelling in columns 547 vehicles had a vehicle in front of them, from which they kept a certain distance, with 138 vehicles violating the relevant regulation referred to in Table 8. The prescribed minimum distance behind a car was most frequently violated in the left motorway lane.

Taking into account penalties in relation to lorries of weights exceeding 3.5 *t* or buses, while riding at speeds in excess of 50 *km/h* on motorways have failed to observe the minimum following distance of 50 *m* behind another vehicle, penalties would have been awarded to a total of 34 lorries travelling in the right traffic lane and to 10 lorries travelling in the middle traffic lane.

Tab. 8 An overview of the number of violations of the regulation by drivers travelling on the A9 motorway near the village of Au A. Aign

Gravity	**Number of violations of the regulation**	**Number of violations by vehicle type**				**Number of violations by traffic lane**		
		Passenger cars	***Vans***	***Lorries up to 12 t***	***Tractor with semi-trailer***	***Right***	***Middle***	***Left***
1	58	45	9	1	3	4	16	38
2	48	38	6	0	4	5	16	27
3	27	19	5	0	3	3	4	20
4	5	2	2	1	0	0	4	1
5	0	0	0	0	0	0	0	0
∑	***138***	***104***	***22***	***2***	***10***	***12***	***40***	***86***

Critical situations recorded in photographs

Continuous video recording time for each measurement in a given direction was approximately 1.5 hours, of which approximately 45 minutes were analyzed in the case of the first measurement and approximately 30 minutes of the second one. Even during these periods, some frequently repeated drivers' failings were markedly shown. Captions under the following pictures describe the place of measurement, vehicle speed and its distance from the vehicle in front in metres as well as in seconds.

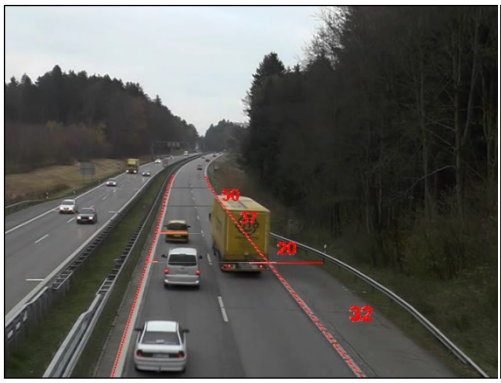


Fig. 3 *The A8 motorway near Winkl, 125 km/h, 10 m (0.30 s)*

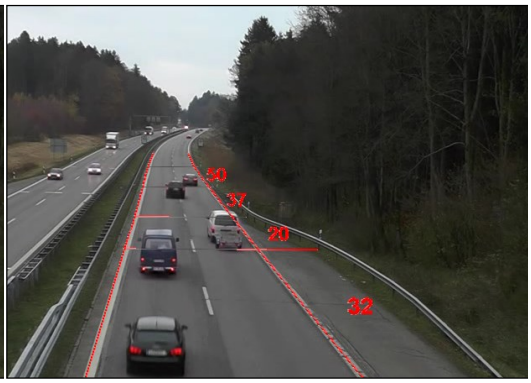


Fig. 4 *The A8 motorway near Winkl, 137 km/h, 12 m (0.32 s)*

Many of the monitored vehicle drivers failed to observe a safe distance, which, for example, should be approximately 72 *m* at 130 *km/h* (in the case of the so-called "two-second rule"). Some drivers even got near the vehicle in front of them up to a distance in the order of individual metres, as can be seen in the following pictures. At 130 *km/h*, a vehicle will cover the distance of 10 *m* in about 0.28 *s*, which is well below the mean value of the driver's standard reaction time.

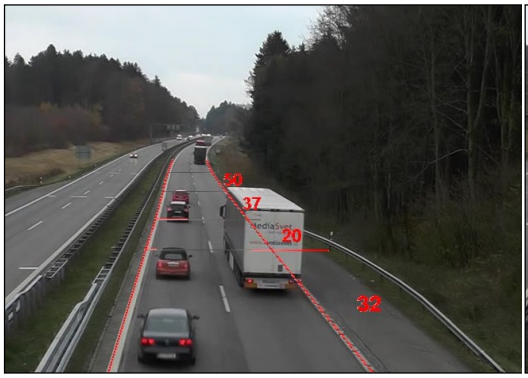


Fig. 5 *The A8 motorway near Winkl, 114 km/h, 9 m (0.28 s)*

Fig. 6 *The A9 motorway near Au A. Aign, 100 km/h, 13 m (0.46 s)*

In some cases, dangerous reduction of the following distance between vehicles could be observed, when a vehicle suddenly moved in front of another vehicle when overtaking.

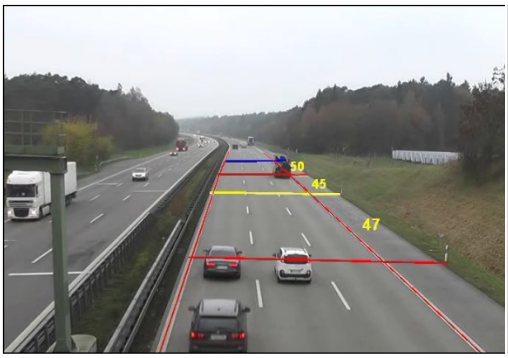


Fig. 7 *The A9 motorway near Au A. Aign, 152 km/h, 8 m (0.20 s)*

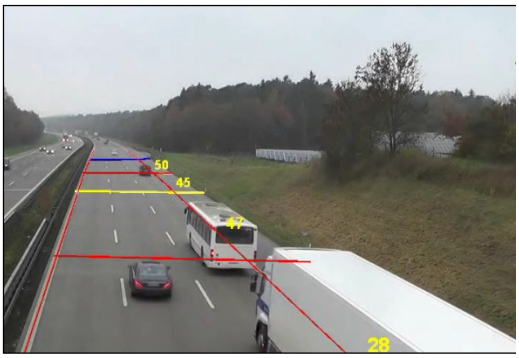


Fig. 8 *The A9 motorway near Au A. Aign, 86 km/h, 13 m (0.54 s)*

Conclusion

Next to a vehicle and traffic infrastructure, the most critical factor in the traffic system is the driver, in particular. Traffic accident statistics show that road users present the highest share of causes of road accidents. With the developments in science and technology a number of new assistance systems increasingly appear in vehicles, also designed to assist drivers when driving in columns or when critical situations arise during driving behind another vehicle. These assistance systems include brake assist, in particular adaptive cruise control, emergency brake assist, etc [1, 10]. With their help, it is possible to reduce to at least a certain extent the number of traffic accidents caused by non-observance of a safe following distance behind another vehicle.

Statistics of traffic accidents on German roads show that the “failure to observe a safe following distance behind another vehicle” is one of the most common causes of traffic accidents.

The video recordings made show that a significant proportion of drivers travelling in a column do not observe the following distance behind another vehicle, for example in the form of the “two-second rule”, but often even the minimum following distance behind another vehicle required by law, or the distance equalling the length of the usual reaction time of the driver and apparently they fail to realize the risk of such behaviour. It follows from the recordings that on average, the drivers in the right lane observe longer following distance behind another vehicle, than drivers in the middle or left lanes. It has also been shown that to a great extent it is professional drivers or career drivers that fail to observe the safe following distance behind other vehicles.

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