GDV
Unfallforschung
der Versicherer

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Distance-related behaviour on motorways

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1. Background and motivation

There were a total of 17,755 accidents involving personal injury on Germany's motorways in 2022, that is approximately 11 percent fewer than in 2019. This change is due, in particular, to the effects of the Covid-19 pandemic. In 2022, 23,190 cases of driving errors on motorways were recorded, of which 6,971 were classified as being due to an "insufficient safety distance" (accident cause 14). Such errors therefore accounted for approximately 30 percent of all registered driving errors (German Federal Statistical Office, 2023). If the period 2010 to 2022 is considered, it can be seen that this driving error has continuously increased as a proportion of total driving errors, rising from 20 to 30 percent, and has thus replaced "inappropriate speed" as the main cause of accidents.

Richter et al. (2023) were commissioned by the German Insurers Accident Research (UDV) to examine approaches to improving road traffic safety on Germany's motorways. The accident analysis they conducted showed that accidents involving personal injury were predominantly assigned to accident type 6 (accidents in longitudinal traffic), which account for 61.3 percent of total accidents. The kind of accident accounting for the largest number of accidents (45.2 percent) continues to be the 2nd kind of accident (collision with another vehicle moving ahead or waiting).

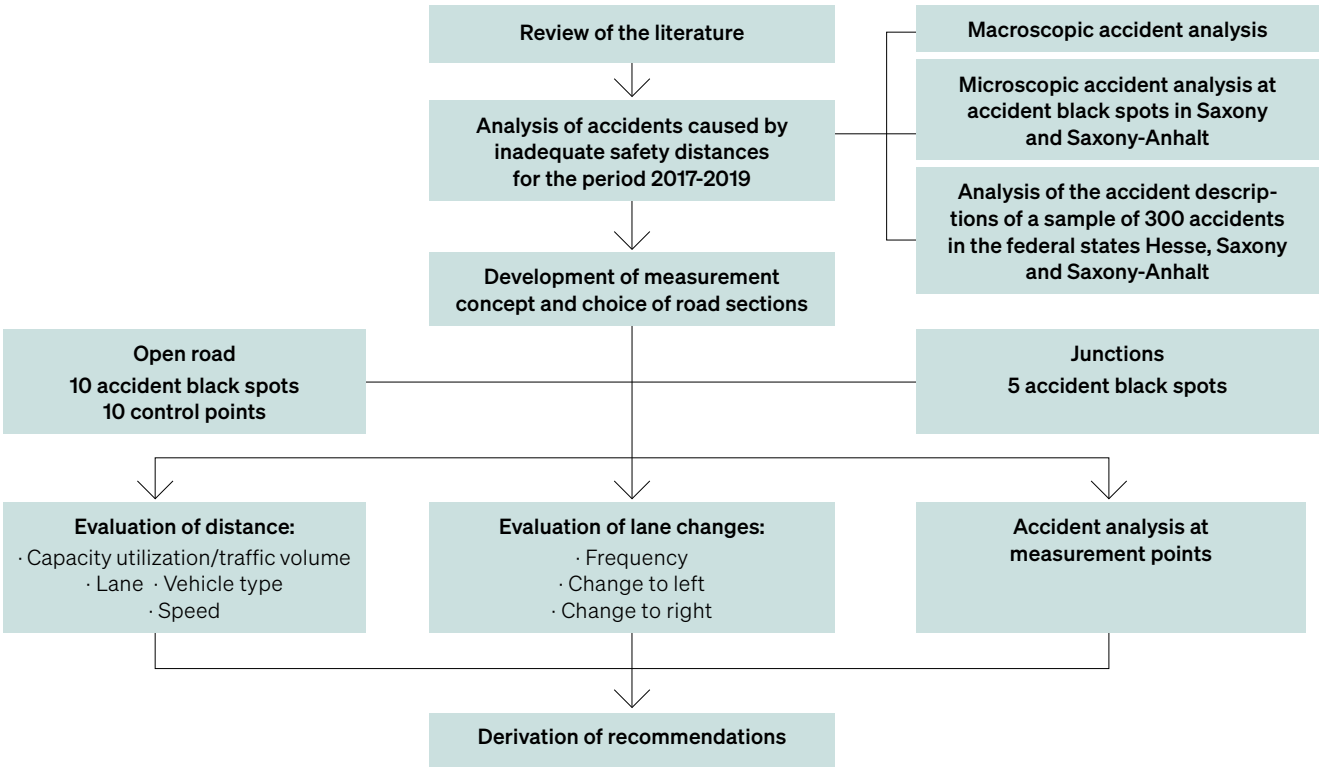
Due to the frequent occurrence of accident type 6 and the 2nd accident kind, as well as to the increase in the number of accidents due to insufficient safety distances, the UDV has launched a research project in cooperation with the Chair of Road Planning and Road Design at Dresden University of Technology. The purpose of the study was to analyse and provide a scientific description of distance-related behaviour on German motorways and to use this as a basis for deriving recommendations for improving road traffic safety on these motorways.

2. Methodology

The flow chart in Figure 1 outlines the methodological approach to the project. Following a review of the literature, the accidents with and without accident cause 14 were analysed. The analysis was performed on accident data from 2017 to 2019 from the federal states Hamburg, Hesse, North Rhine-Westphalia, Saxony and Saxony-Anhalt. Following a special request to the Federal Statistical Office, it was possible to extend this with data for the whole of Germany. Points at which to perform measurements were then chosen (accident black spots as defined in M Uko (FGSV, 2012)) and the measurement concept was developed. The measurement concept made use of drones to take video recordings at various times of day. The commercially-available program DataFromSky was used to evaluate the distances and speeds captured in the video recordings. On stretches of open road, recordings of a total of three hours per measurement point were taken at three different times of day. At motorway junctions, the recordings comprised one hour each in the areas of the junction's on-ramp and off-ramp and were made at two different times of day (four hours total). The identified distances and speeds were then analysed on the basis of various criteria. This step was followed by an analysis of identified lane changes and a separate accident analysis for the selected measurement points. The final stage in the study consisted in deriving recommendations from the results of the analysis, with the aim of improving traffic safety on motorways, in particular with regard to critical (excessively short) distances and lane changes (Koetttnitz et. al., 2023).

Methodology of the research project

Figure 1



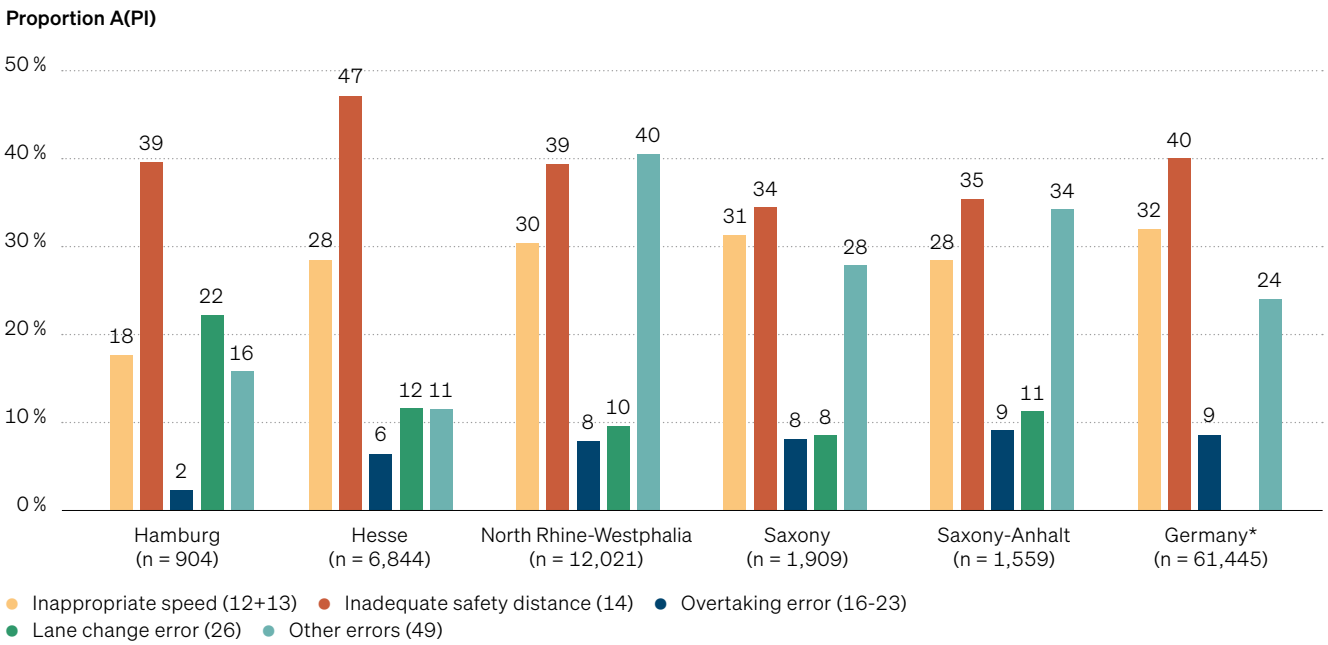
3. Accidents with insufficient safety distance

The analysis of accident causes showed that the most frequently cited accident cause for accidents involving personal injury was inadequate safety distance (accident cause 14), which accounted for between 34 and 47 percent of accidents across the examined federal states (Figure 2). The accident causes involving inappropriate speed (causes 12 and 13) occurred less frequently than cause 14 (inadequate safety distance) in all the examined federal states. Overtaking errors (accident causes 16 to 23) and lane change errors (cause 26) tended, with a few exceptions, to be cited less frequently at approximately 10 percent. In North Rhine-Westphalia, Saxony and Saxony-Anhalt, accident cause 49 (other errors made by the person in control of the vehicle) was given relatively frequently; however, in the absence of further information, this categorization does not make it possible to draw any particular conclusions about the actual cause of the accident.

The evaluation of the accidents based on accident severity shows that accidents involving personal injury with indicated accident cause 14 led to serious personal injury (16.9 percent A(SI)) less often than accidents in which this cause was not indicated (26.5 percent A(SI)). If the criteria of accident severity and road user type of the party causing the accident are combined, then it can be seen that trucks were particularly often the cause of serious traffic accidents with accident cause 14 (Figure 3).

"Insufficient safety distance" is the most frequently recorded driving error on motorways

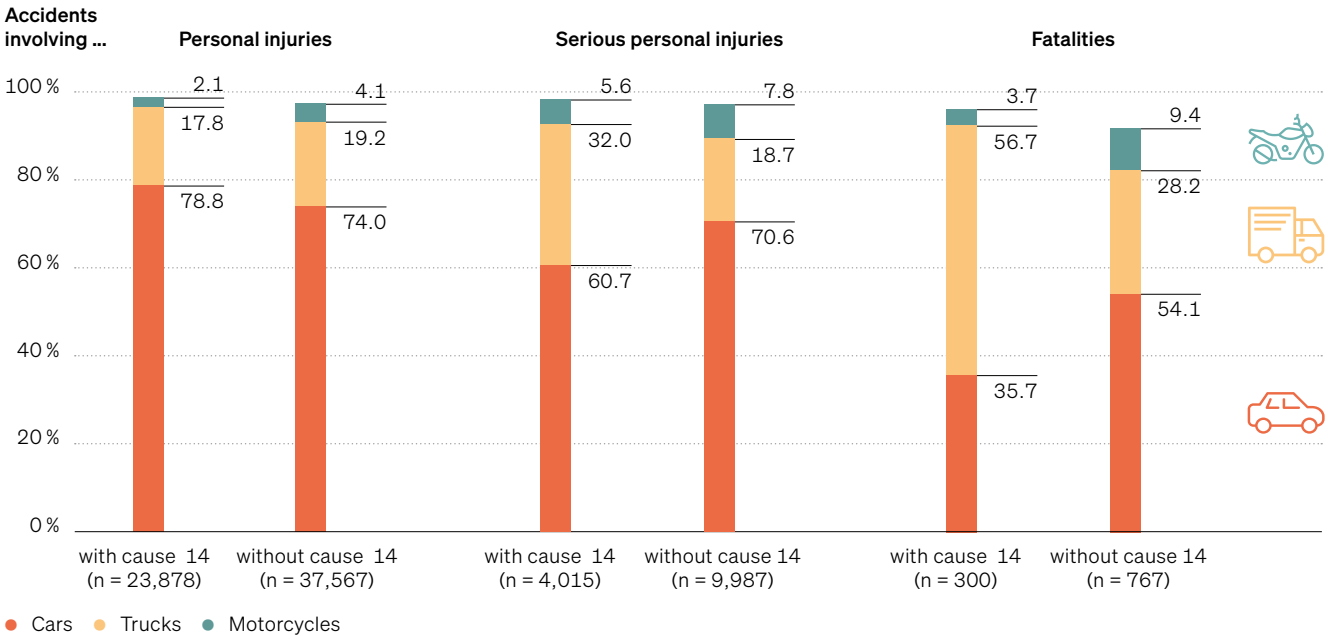
Figure 2 · Driving errors made by the party causing the accident in the case of accidents involving personal injury for the period 2017 to 2019



* The special request for additional statistical data regarding Germany as a whole yielded no information about the frequency of accident cause 26, meaning that no corresponding proportion can be given here..

Trucks are the main cause of more than half the fatal accidents with cause 14

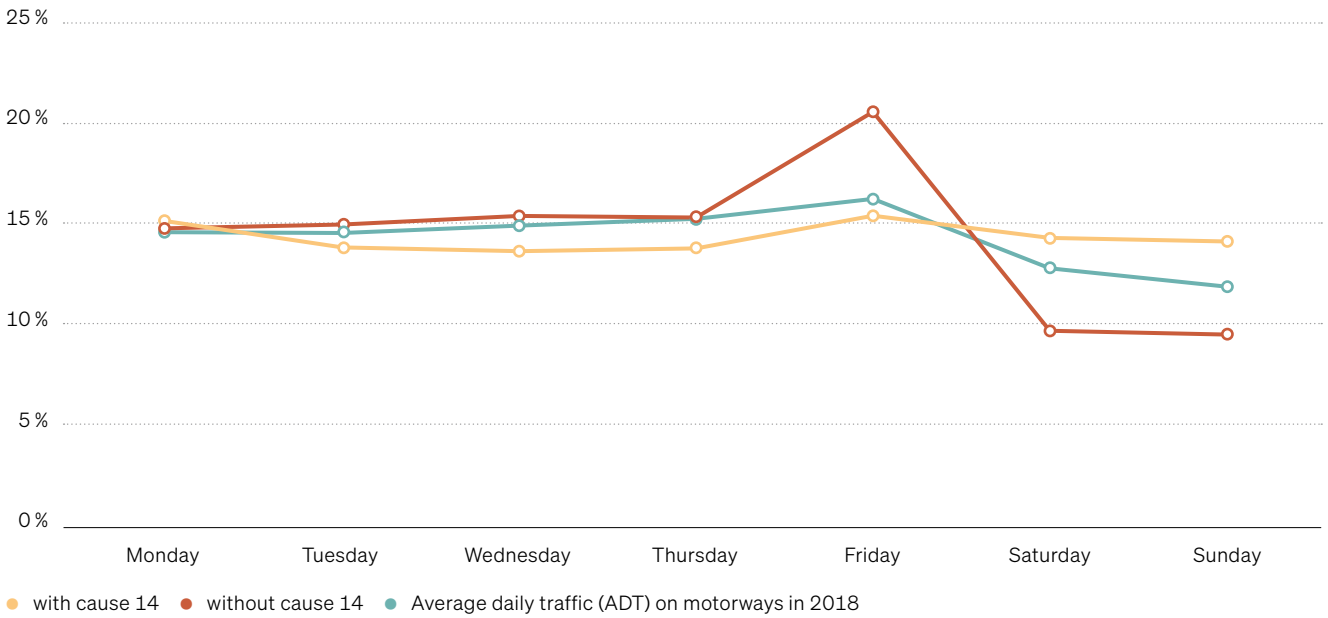
Figure 3 · Proportion of accidents with/without indication of cause 14 for the party mainly responsible for causing the accident, indicated by type of road use and accident severity for the period 2017 to 2019



The analysis of the time of the accidents shows that accidents involving inadequate safety distance occurred primarily during periods with high traffic volumes, i.e. during the morning peak period from 7 to 9 a.m. and during the afternoon from 2 to 7 p.m. A particularly large number of accidents occurred on Fridays. By contrast, accidents with cause 14 were less frequent during the night and at weekends (Figure 4).

Disproportionately large number of accidents with cause 14 on Fridays, twice as many as at the weekend

Figure 4 · Breakdown of accidents involving personal injuries in Germany on weekdays during the period 2017 to 2019



In addition, an evaluation of a sample of 300 descriptions of accidents involving personal injuries during the period 2017 to 2019 for the federal states of Hesse, Saxony and Saxony-Anhalt showed that more than 50 percent of the accidents were due to a high traffic volume or disruptions to the traffic flow at the time of the accident. 13 percent of the examined descriptions refer to inattentiveness on the part of the driver; however, only one report explicitly speaks of a distraction. According to the descriptions, nine percent of the examined accidents occurred in the context of a lane change. All the keywords recorded during the evaluation and their associated frequencies of occurrence are indicated in Table 1.

Traffic jams and braking due to the traffic situation are the prime factors responsible for accident occurrence

Table 1 · Frequency of circumstances reported in descriptions of accidents involving personal injury during the period 2017 to 2019 for the states Hesse, Saxony and Saxony-Anhalt (n=300) (descriptions may be counted in more than one category)

Subject	Circumstances	Meaning	Frequency	
			Absolute [-]	Relative [%]
State of traffic	**Jam**	There is a literal reference to a traffic jam (e.g. traffic jam, formation of jam, tailback).	95	32
	Braking due to traffic situation	Reduction of speed without any mention of “traffic jam”.	74	25
	Traffic stoppage	Rear-end collision with stationary vehicle without any mention of “traffic jam” (e.g. “comes to a stop”, “stationary because of the traffic”).	37	12
	“Slow-moving”	“Slow traffic” or “slow-moving traffic” is referred to without any mention of “traffic jam”.	17	6
	High traffic volume	“High traffic volume” is given as cause without any mention of “traffic jam”.	16	5
	Accident	Another accident occurred immediately before the considered accident.	9	3
Human	**Inattentiveness**	“Inattentiveness” or “lack of attention” are given as the cause of the accident.	38	13
	Sudden evasive action	The driver took sudden evasive action.	31	10
	Lane change	The accident is linked to a lane change which took place either before or during the accident.	28	9
	Speed	Excessive or inappropriate speed is mentioned independently of the cause of the accident.	15	5
	Rear-end collision without braking	The rear-end collision took place without any braking manoeuvre.	14	5
	Emergency braking	One of the parties involved in the accident performed emergency braking.	12	4
	Asleep at the wheel	The party that was the main cause of the accident fell asleep briefly at the wheel.	3	1
	Distraction	The term “distraction” is used.	1	0
Motorway operation and maintenance	**Roadworks**	The description states that the accident occurred close to roadworks.	27	9
Other	**Unexplained cause**	No concrete indications of the reasons for the collision, “unexplained cause” or similar is indicated.	25	8

4. Results for open road

4.1 Distance-related behaviour

The study first examined the distance-related behaviour of vehicles in the vicinity of the measurement points on stretches of open road. The results for the accident black spots were compared with those for the control points. Net time intervals between vehicles were calculated for the analysis of distances. Since the recommended minimum distance of half the speed in km/h converted into metres corresponds to a time interval of 1.8 seconds, intervals shorter than two seconds are considered to be small or critical distances in the following.

4.1.1 Distance-related behaviour by level of capacity utilization

During the first part of the analysis, the influence of the traffic situation on distance-related behaviour was examined. Because the peripheral circumstances differed at the various measurement points, for example in terms of the gradient in the direction of travel or the proportion of heavy vehicle traffic, the capacity utilization and/or level of service of the section of road was used for this analysis. The capacity utilization was calculated as the quotient of the current traffic volume and the capacity of the road section, determined on the basis of the conditions at the road section as set out in the German manual for the design of road facilities (Handbuch für die Bemessung von Straßenverkehrsanlagen – HBS). The capacity utilization was then assigned to the levels of service (LOS) which are set out in the manual for the design of road facilities and describe and evaluate the prevailing level. Table 2 provides an overview of the capacity utilization levels representative of each level of service (LOS) and of how the traffic state corresponding to each of the levels can be described.

The capacity utilization describes various traffic states

Tabelle 2 · Levels of service as per German manual for the design of road facilities (HBS, FGSV, 2015)

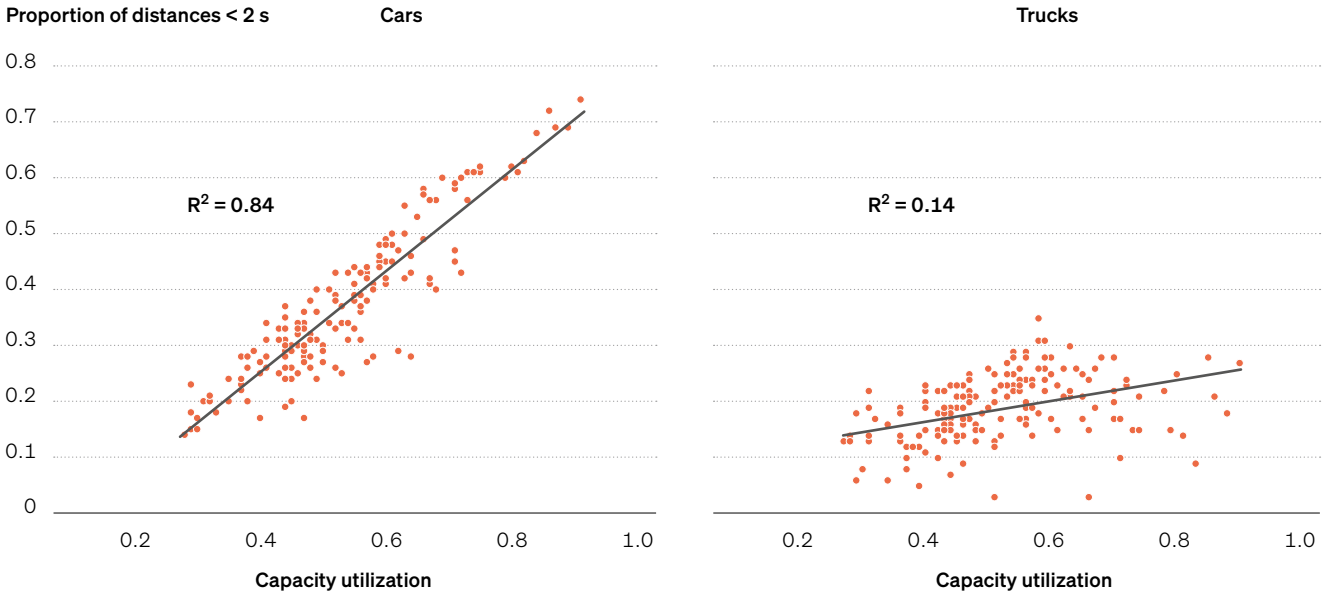
	Capacity utilization x	Description
LOS A	$x \leq 0.30$	Free choice of lane and speed, **traffic unaffected**
LOS B	$0.30 < x \leq 0.55$	Largely free choice of lane and speed, **traffic largely unaffected**
LOS C	$0.55 < x \leq 0.75$	Limited choice of lane and speed, **traffic noticeably affected**, traffic state stable
LOS D	$0.75 < x \leq 0.90$ (0.92 for TMS*)	Extremely limited choice of lane and speed, **traffic continuously affected**, traffic state still stable
LOS E	$0.90 < x \leq 1.00$	Vehicles generally confined to driving in lane, small irregularities can result in traffic jams, **traffic state unstable**
LOS F	$x > 1.00$	**Stop-and-go traffic** due to breakdown of traffic system

LOS: Level of service, * TMS: Traffic management system

The analysis of distances based on the prevailing level of service (LOS) showed that distances of less than two seconds occurred more frequently as the level of service worsened. The proportions of these short distances on both two-lane and three-lane motorway sections increased linearly with increasing capacity utilization level. Figure 5 shows how the proportions of these distances for cars and trucks changed as a function of capacity utilization. Only for cars was there a high coefficient of determination for the linear increase in these small distances with increasing capacity utilization. This indicates that the linear increase observed for all vehicle types taken together was primarily due to the distance-related behavior of car drivers.

The fuller the motorway is, the higher the proportion of critical time intervals for cars

Figure 5 · Proportions of distances of less than two seconds as a function of capacity utilization for cars and trucks on measured three-lane carriageway cross-sections



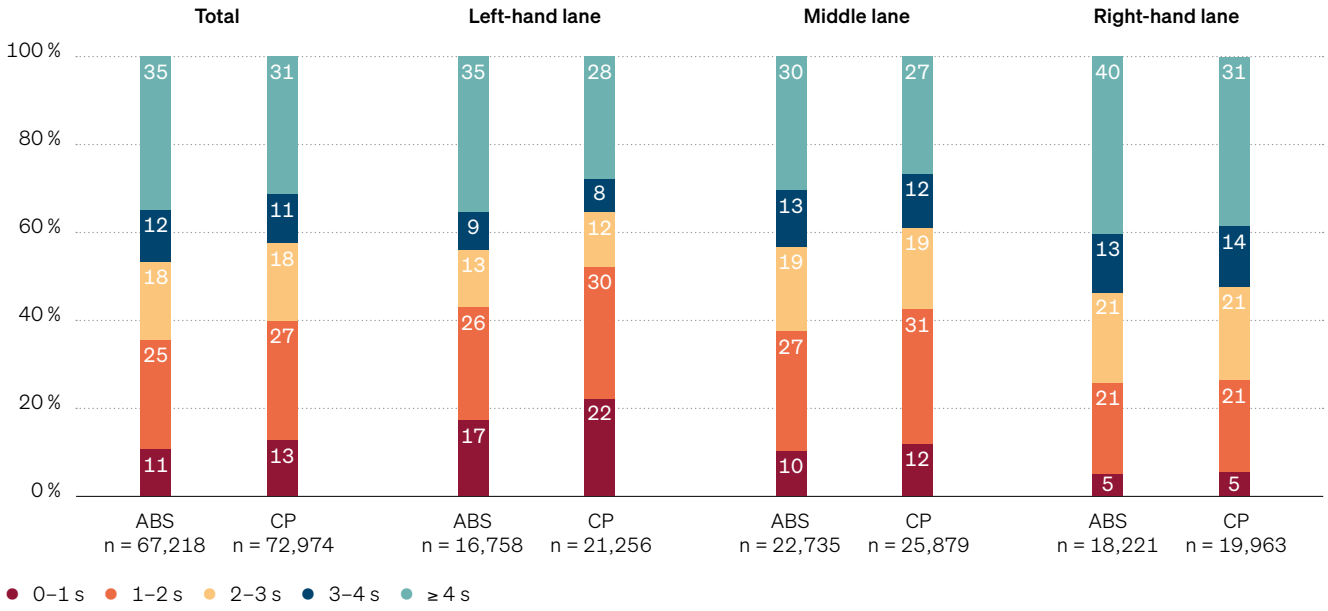
4.1.2 Distance-related behaviour by position of lane in carriageway cross-section

The analysis of distance-related behaviour as a function of the lane in which the vehicle in question was travelling shows that the proportion of critical distances increased from the right-hand to the left-hand lane. Figure 6 shows the results for the three-lane measurement points. While in the left-hand lane 43 percent of the distances at the accident black spots and 52 percent of the distances at the control points were under two seconds, the value in the right-hand lane was only 26 percent in both of these locations.

These differences were even more striking in the two-lane sections included in the study, as Figure 7 shows. In the left-hand lane, 28 percent of distances were less than one second and a further 32 percent to 36 percent were between one and two seconds. This means that a distance of less than two seconds was maintained in more than 60 percent of cases here. In the right-hand lane, this value was only 23 percent.

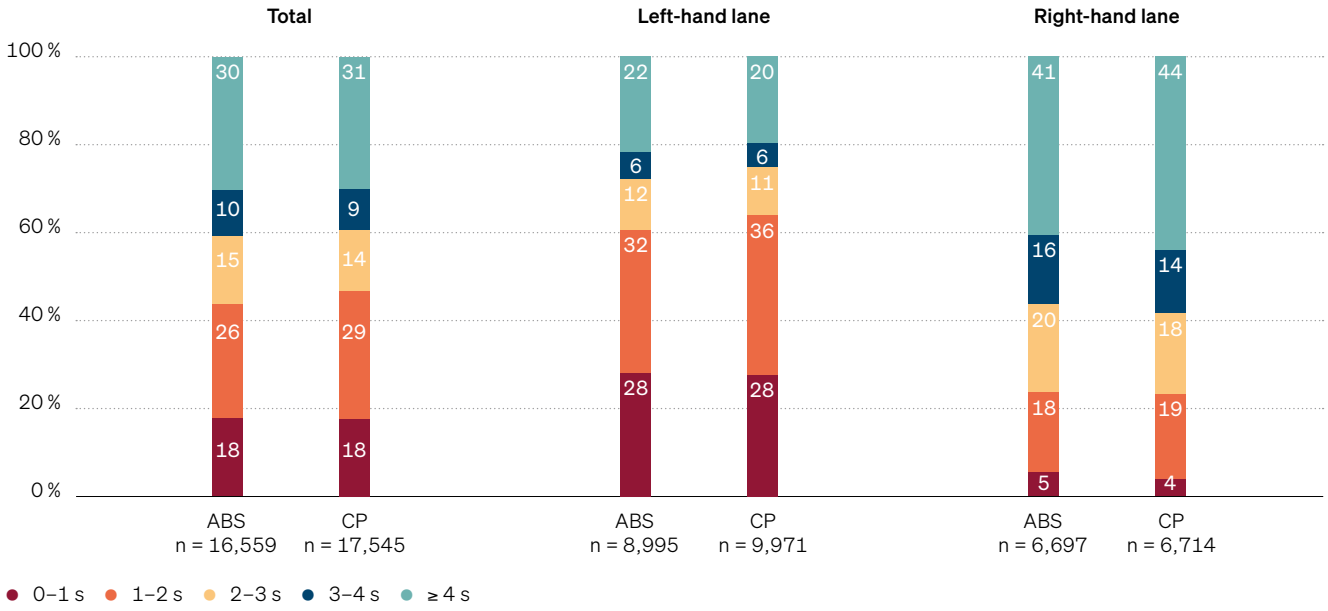
Critical time intervals are significantly more frequent in the left-hand lane

Figure 6 · Proportions of net time intervals by lane on measured **three-lane carriageway** cross-sections, subdivided into accident black spots (ABS) and control points (CP)



Extremely short time intervals in left-hand lane up to 7x more frequent than in right-hand lane

Figure 7 · Proportions of net time intervals by lane on measured **two-lane carriageway** cross-sections, subdivided into accident black spots (ABS) and control points (CP)



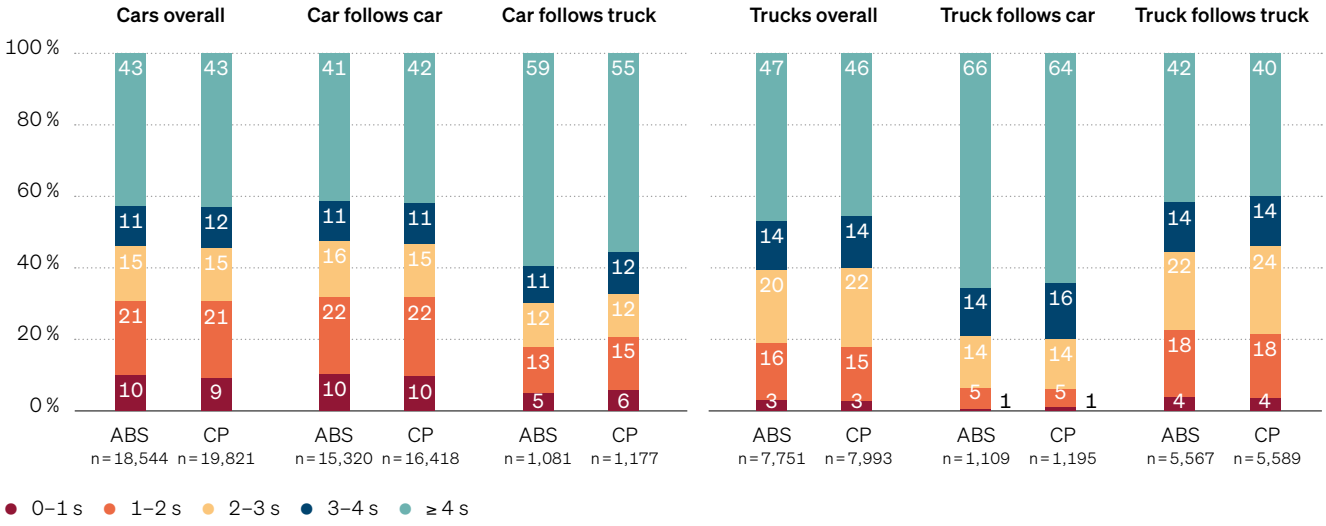
4.1.3 Distance-related behaviour by vehicle type

The analysis of distances by vehicle type shows that, generally speaking, cars drive at distances of under two seconds more often than trucks and irrespective of the type of vehicle in front of them. When one car follows another in level of service B traffic on a three-lane motorway section, then the distance between the vehicles is less than two seconds in approximately 30 percent of cases and 10 percent of

the distances are even smaller than one second (Figure 8). By contrast, when a car follows a truck under the same circumstances as above, then the distance is less than two seconds in only approximately 20 percent of cases. These proportions increase as the level of service worsens. When one truck follows another at a three-lane measurement point, then the distance is less than two seconds in just over 20 percent of cases. However, when a truck follows a car, the distances are less than two seconds in only approximately 10 percent of cases This applies to trucks irrespective of the prevailing level of service because the distance-related behaviour of trucks is not greatly affected by the LOS. At a maximum of four percent, distances of less than one second generally occur very infrequently for trucks. These values are similar at the two-lane measurement points, although the differences between the proportions are higher, as Figure 9 shows.

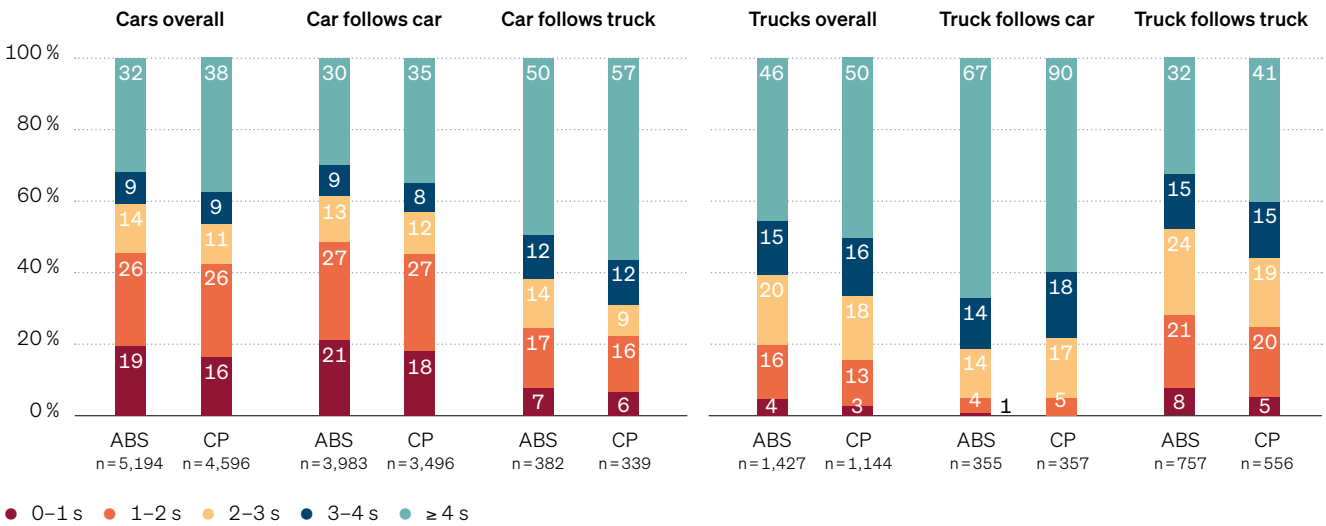
Proportionally speaking, cars drive too close behind one another

Figure 8 · Proportions of net time intervals of cars and trucks by **vehicle sequence** at LOS B (see Table 2) on measured **three-lane carriageway** cross-sections, subdivided into accident black spots (ABS) and control points (CP)



Almost 50 percent of cars drive too close behind one another on these carriageway cross-sections

Figure 9 · Proportions of net time intervals of cars and trucks by **vehicle sequence** at LOS B (see Table 2) on measured **two-lane carriageway** cross-sections, subdivided into accident black spots (ABS) and control points (CP)

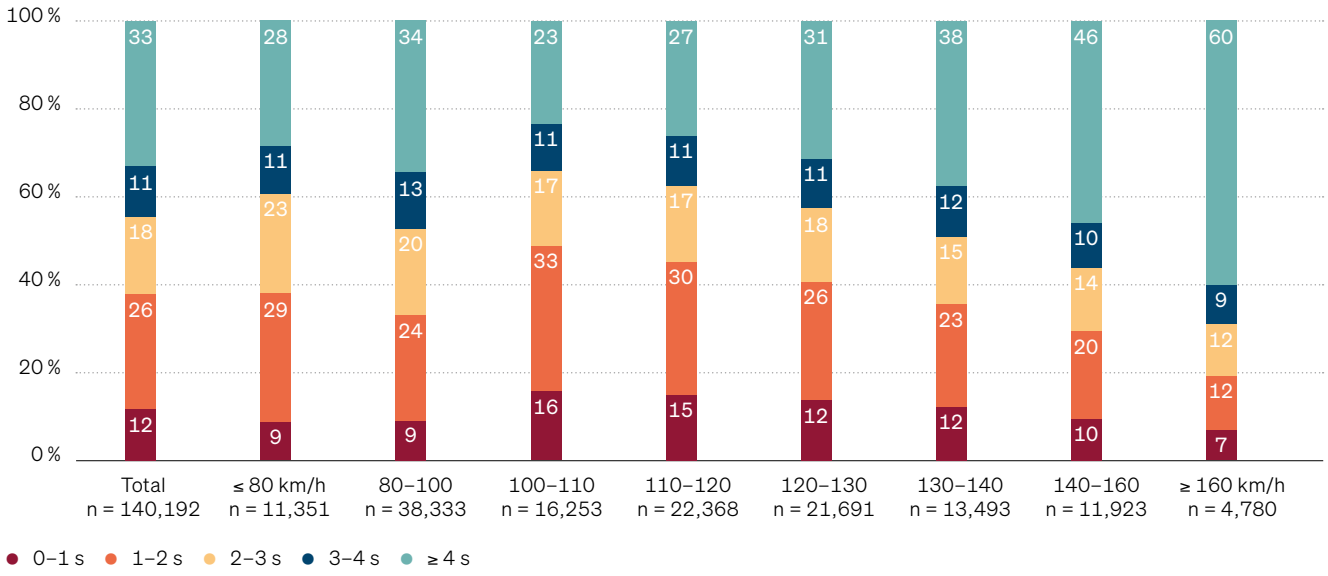


4.1.4 Distance-related behaviour by speed

In the final stage of the analysis, the distance-related behaviour was examined in the light of the vehicle speed. As presented in Figure 10, this showed that distances of less than two seconds occurred most frequently at speeds between 100 km/h and 140 km/h, accounting for 49 to 35 percent of cases. This suggests that vehicles travelling in this speed bracket are often dependent on the behaviour of the surrounding traffic and have little freedom to choose their speed. As the speed increases, the proportions of critical distances fall. At speeds of less than 100 km/h, the proportion of distances under two seconds was less than 40 percent. At speeds of more than 160 km/h, only 19 percent of distances were under two seconds; by contrast, 60 percent of the distances were greater than four seconds. This indicates that vehicles usually only travel at these high speeds when there is sufficient space available and the traffic is sparse enough to allow drivers to choose their speed freely. This is also shown by the speed breakdowns for the different levels of service (see Table 2), which indicate that the proportion of vehicles travelling at more than 130 km/h falls significantly as the level of service declines (Koettnitz et al., 2023).

The higher the driving speed, the smaller the proportion of critical time intervals

Figure 10 · Proportion of net time intervals as a function of **driving speed** [km/h] on measured three-lane carriageway cross-sections



4.2 Lane changes

During the first stage of the separate examination of lane changes at the measurement points on stretches of open road, the study looked at the frequency of occurrence of lane changes on the individual motorway sections included in the study in order to identify possible differences between the accident black spots and the control points. To this end, the number of lane changes per 100 videoed vehicles was determined. The results show that the issue of whether there were more lane changes at black spots or control points differs from measurement point to measurement point. Furthermore, the differences are mostly very small

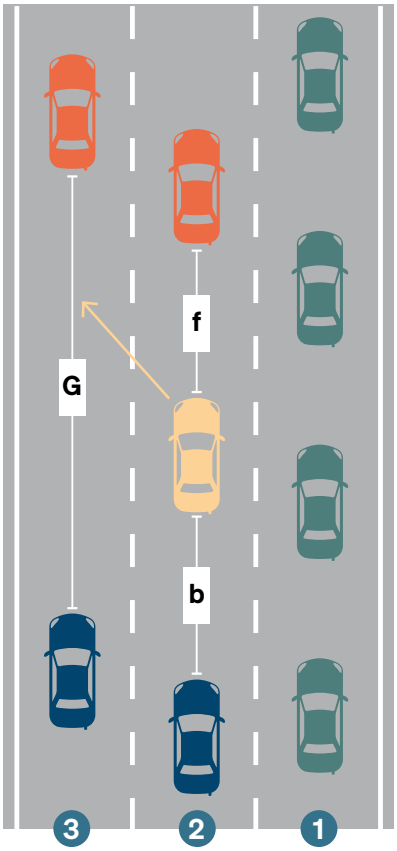
in numerical terms. At the same time, the examination showed that more lane changes occur as junctions approach than they do on sections of motorway further away from junctions.

During the next step, lane changes to the left and lane changes to the right were considered separately. By way of an example, Figure 11 shows a lane change to the left on a three-lane motorway. In the case of lane changes from the right-hand to the middle lane, 30 percent of the gaps measured were less than 100 metres. At least 80 percent of the vehicles that made a lane change to the left were being followed by a faster vehicle; in approximately 25 percent of such cases, the following vehicles were as much as 20 km/h faster.

Before moving out, some 68 percent of the cars were driving at a distance of less than 50 metres behind the car in front. 67 percent of truck drivers also drove at a distance of less than 50 metres behind the truck in front of them. 28 percent of all the observed vehicles were driving at a distance of even less than 25 metres behind the vehicle in front; in the case of truck-truck constellations, this value rose to as much as 40 percent.

Results of the analyses for “lane change to the left”

Figure 11



Lane change to the left

	Value	Observation
G	G ≤ 100 m	Used 30 % of the time when changing from lane 1 to lane 2
		When these are used, the following vehicle is faster in at least 80 % of cases, and by more than 25 km/h in at least 25 % of cases
f	f < b	Applies both before and after completion of the change to the left
	f ≤ 50 m	Occur in 60 % of cases before change to the left at three-lane measurement points
		Distance from other cars driven by 68 % of cars before moving out to the left at three-lane measurement points, corresponding value only 45 % for trucks
		Distance from other trucks driven by 67 % of trucks before moving out to the left at three-lane measurement points, corresponding value only 30 % for cars
	f ≤ 25 m	Occur in 28 % of cases before change to the left at three-lane measurement points
		Distance from other trucks driven by 40 % of trucks before moving out to the left at three-lane measurement points

G: Gap used f: Distance from vehicle in front b: Distance from vehicle behind

In the case of changes of lane to the right, gaps of less than 100 metres were used by only 20 percent of the observed vehicles. After the lane change, the distance to the car behind was less than 50 metres in 45 percent of cases. Constellations of two vehicles of the same type tend to lead to a higher proportion of gaps of under 50 metres being used (e.g. 63 percent for truck-truck).

4.3 Accident analysis

To conclude, the accidents at the measurement points on stretches of open road were analysed. This showed that cars were the cause of accidents at most of the accident black spots. However, the proportion of accidents caused by trucks increased with the severity of the accidents. In addition, there were frequent rear-end collisions, with the vehicles braking due to traffic jams or traffic conditions. In addition to above-average traffic volumes at a large proportion of the times of occurrence of the accidents, it was also found that rear-end collisions were frequent in the left-hand lane, in particular on two-lane sections of motorway.

4.4 Schlussfolgerungen zur Freien Strecke

The analyses of distance-related behaviour on 20 stretches of open road, each with two successive video recording areas (10 accident black spots 10 control points), showed that the inter-vehicle distances on a motorway section are primarily determined by the distance-related behaviour of cars. The number of accidents increases at high traffic volumes; at the same time, the number of time intervals of under two seconds (critical distances) increases at higher traffic volumes. Rear-end collisions occur frequently in the left-hand lane, where the proportion of critical distances is largest. Distances of less than 50 metres and gaps of under 100 metres are often observed during lane changes, and in particular in the case of lane changes to the left. At the same time, lane changes to the left often create situations that can be classified as critical because the following vehicle is faster in at least 80 percent of these changes and therefore has to brake in order to prevent a collision.

5. Results for junctions

5.1 Distance-related behaviour

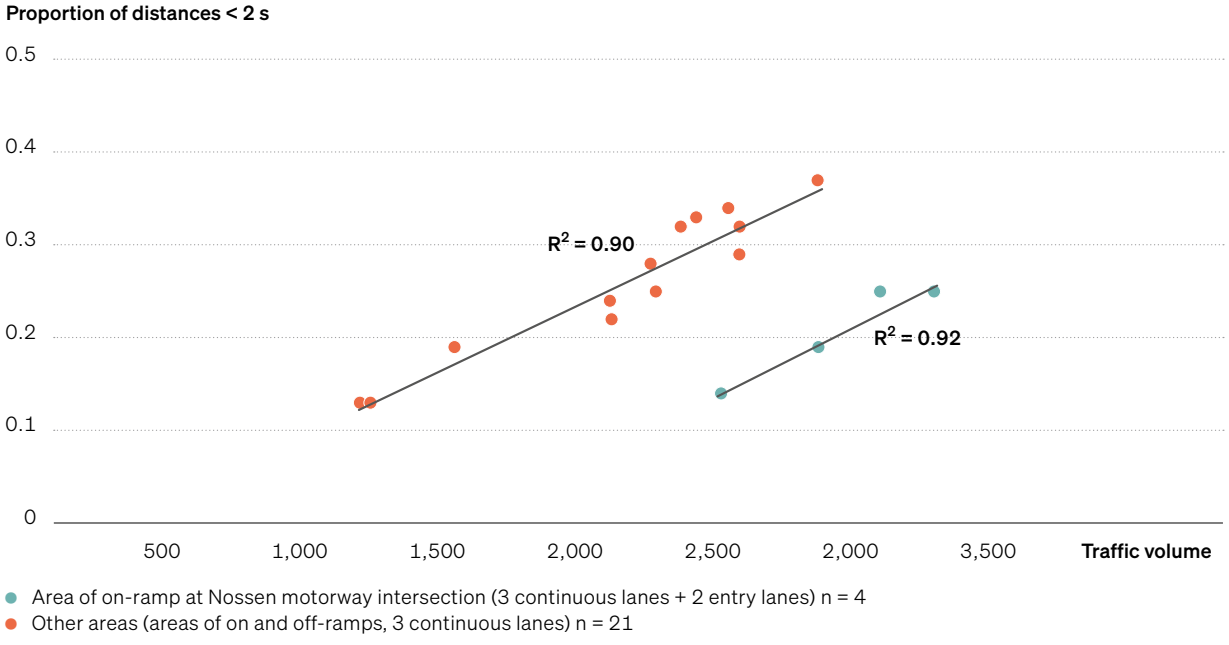
For the purposes of the analysis of distance-related behaviour in the area of the five selected junctions, only the direction of travel in which accidents frequently occurred was examined, making it impossible to compare accident black spots and control points. Instead of this, the distance-related behaviours in the area of the junctions' on-ramps and off-ramps were compared.

5.1.1 Distance-related behaviour by traffic volume

To examine the influence of traffic volume on distance-related behaviour around junctions, the study looked at the way the proportions of distances of under two seconds change at different traffic volumes. By way of an example, the results for the examined junctions with three continuous lanes are presented in Figure 12. It can be seen that the proportions of small distances increase linearly with increasing traffic volume. It is also clear that the number of lanes over which the prevailing traffic volume is distributed also has an influence.

The number of critical time intervals increases with growing traffic volume

Figure 12 · Proportion of distances of under two seconds depending on the prevailing traffic volume at three-lane junctions



5.1.2 Distance-related behaviour by position of lane in main carriageway cross-section

Distance-related behaviour on the continuous lanes in the area of junctions was then considered in more detail. Once again, it was found that the proportion of critical distances increased from the right-hand to the left-hand lane. This is shown particularly clearly by the proportions of distances of under one second. At three-lane intersections, these were five to six times as a frequent in the left-hand than in the right-hand lane. At the two-lane junctions considered in the study, the proportions of distances of under two seconds in the left-hand lane were approximately 15 percent higher than they were in the right-hand lane. Furthermore, a clear difference between the areas of the on and off-ramps can be seen at the two-lane junctions, since the proportions of critical distances in the area of the on-ramps were 19 percent higher than they were in the area of the off-ramps.

5.1.3 Distance-related behaviour by vehicle type

The analysis of distance-related behaviour at the examined three-lane junctions as a function of vehicle type and vehicle sequence showed that cars drove at a distance of under two seconds (30 percent) behind other cars more often than they did behind trucks (16 percent in the area of off-ramps and 23 percent in the area of on-ramps). By contrast, there was practically no difference in the behaviour of cars when following either cars or trucks at the examined two-lane junctions. In the area of three-lane junctions, trucks drove at a distance of less than two seconds behind another truck in front of them in approximately 20 percent of cases. Trucks drove at distances of under two seconds behind cars in only 4 percent of cases in the area of off-ramps and 7 percent of cases in the area of on-ramps. The analyses of the behaviour of the different sequences of vehicles revealed that there were more distances of under two seconds in the area of the on-ramp than the off-ramp, in particular in the area of the two-lane junctions.

5.1.4 Distance-related behaviour by speed

The examination of distance-related behaviour as a function of driving speed shows that there were no ranges of speeds associated with poorer distance-related behaviour at the three-lane junctions. At speeds of between 100 km/h and 140 km/h, all the values for the net time intervals were relatively constant and also quite evenly distributed. Speeds under 100 km/h and over 140 km/h also led to only a slightly different distribution, with lower proportions of distances of less than two seconds. At the two-lane junctions included in the study, the largest proportions of distances under two seconds were observed at speeds between 80 km/h and 110 km/h. This result is due to the fact that there is a speed limit of 100 km/h at one of the two junctions examined, meaning that the results of this examination cannot reasonably be transposed to other two-lane junctions.

5.2 Lane changes

In the case of junctions, the first step in the examination of lane changes was once again to determine their frequency of occurrence. To this end, the number of lane changes per 100 videoed vehicles was determined for each junction. At four of the five considered junctions, more lane changes occurred in the area of the on-ramp

than that of the off-ramp. At the same time, lane changes were considerably more frequent at junctions (values of between 16.1 and 65 lane changes per 100 vehicles) than they were on open stretches of road (3.7 to 20.4 lane changes per 100 vehicles). This is due to entrance and exit manoeuvres because these necessarily involve more lane changes.

5.2.1 Area of on-ramp

Since vehicle entrance manoeuvres mean that there are considerably more lane changes to the left in the area of a junction's on-ramp, the evaluations specifically concentrate on such changes. Gaps of less than 100 metres were used in up to 53 percent of cases in order to change from the slip lane to the continuous right-hand lane of the main carriageway. During such manoeuvres, the following vehicle was travelling faster in at least 60 percent of cases and 20 km/h faster or more in 15 percent of them. Gaps of less than 50 metres before and after moving-out were used more frequently on two-lane (60 percent) than on three-lane motorways (40 percent). Even smaller gaps (less than 25 metres) were used before moving out to the left, accounting for between 20 and 64 percent of cases depending on vehicle constellation.

5.2.2 Area of off-ramp

Lane changes to the right were most frequent in the off-ramp area of motorway junctions. Most changes (22 percent) with a gap of less than 100 metres were performed from the middle to the right-hand lane of three-lane motorways. After such manoeuvres, the following vehicle was faster in approximately 35 percent of cases. Up to 40 percent of vehicles used gaps of less than 50 metres to the following vehicle before and after moving out. In the case of truck-truck constellations, even gaps of less than 25 metres were used after moving out to the right in 31 percent of cases.

5.3 Accident analysis

The analysis of the accidents at the examined junctions showed that cars are often the main cause of accidents that occur at times of high traffic volumes. By contrast, trucks are also the cause of accidents when traffic volumes are low. At the same time, the proportion of accidents caused by trucks increases with increasing accident severity. It can also be seen that when the traffic volume is high at the time of accident occurrence, the accidents frequently occur in the left-hand lane. There were frequent rear-end collisions, with vehicles braking due to traffic jams or traffic conditions. No particularly high frequency of accident occurrence was observed in connection with lane changes.

5.4 Conclusions regarding junctions

A total of five junctions were analysed, three of them with three-lane and two of them with two-lane main carriageways in the area of the junction. This very small sample of differently configured junctions means that it is scarcely possible to draw generally valid conclusions concerning distance-related behaviour at junc-

tions. It is, however, possible to make certain general observations concerning the distance-related behaviour at the examined junctions.

Thus, it was found that the distances maintained between vehicles worsen with increasing traffic volume. Cars maintain smaller distances than trucks. The distance-related behaviour can also be considered to be worse the further to the left the lane used is. Lane changes occur in the area around junctions significantly more frequently than on stretches of open road, thus suggesting that these changes of lane have an effect on the traffic situation at junctions. However, it was not possible to determine any direct influence of lane changes on accident occurrence. This finding notwithstanding, the possibility of an indirect influence cannot be excluded. This would be the case, for example, if a number of following vehicles had to brake as a result of a lane change, thus leading to a rear-end collision in another location. However, it is not possible to deduce such concrete situations from the accident reports.

6. Recommendations

It is possible to derive the following recommendations based on the results and conclusions of the analyses conducted on accident occurrence, distance-related behaviour and lane changes.

Infrastructure and traffic

→ At motorway sections with conspicuously high accident levels and high levels of capacity utilization or with a poor level of service (LOS), the traffic flow should be improved by means of traffic management systems or network management systems, as well as by the introduction of (temporary) speed limits or of no-overtaking zones. It may be necessary to enforce these measures by means of effective fixed or mobile speed and distance monitoring systems.

Networking of infrastructure and vehicles

→ The use of traffic jam warnings to allow drivers to adapt their behaviour (e.g. by adapting their speed and distance) as well as real-time warnings of the ends of traffic jams at navigation devices installed in vehicles and at mobile devices from other mobility service providers can help prevent or reduce accidents resulting from insufficient safety distances on motorways.

→ The networking of infrastructure and vehicles using cooperative intelligent traffic systems (C ITS) should be encouraged in order to allow road users to adapt their driving behaviour in good time.

Advanced driver assistance systems

→ The mandatory installation of advanced driver assistance systems (ADAS) in new vehicles pursuant to the European Parliament's General Safety Regulation (GSRII), for example in the form of automatic emergency braking systems, emergency stop signals, drowsiness and attention warnings and intelligent speed adaptation (ISA), will have positive effects on road traffic safety. However, their effectiveness in practical use should be systematically analysed in order to permit changes to their design as required.

→ The more widespread diffusion of level 2 assisted driving functions for cars and trucks may help harmonize the traffic flow on motorways and possibly also lead to improvements in road traffic safety. These functions consist of intelligent ACC (adaptive cruise control) that adapts both the safety distance to the vehicle in front and the driving speed to the speed limit and also keeps the vehicle centred in the lane. These are level 2 assisted driving functions which continue to leave the driver with full control of driving tasks. EuroNCAP assesses these systems because correctly conceived driver involvement in driving tasks is of vital importance for road traffic safety. Generally speaking, this applies equally to cars and trucks. A further development to level 3 driving functions, in which the driver hands over the driving tasks to the vehicle, could have a

further positive effect on road traffic safety. The effectiveness of these systems should also be analysed in the context of real-life accident occurrence in order to identify any negative effects at an early stage.

Traffic behavior and campaigns

→ Appropriate campaigns might further raise road users' awareness of potential dangers arising from disruptions to the traffic flow.

→ Raising car drivers' awareness of the distances to be maintained through campaigns that explain the applicable regulations in easy-to-understand terms based on the schedule of penalties for road traffic offences (Annex, Table 2).

→ These campaigns should be accompanied by reinforced, regular mobile and, if appropriate, fixed distance and speed monitoring (together with dynamic speed limits made necessary in the light of traffic conditions).

Outlook

→ The attribute "Traffic jam" should be included in road accident reports as a specific feature of motorway accidents.

→ Further-reaching research on the influence of visibility on safety distances as well as on accidents and their consequences may provide further insight that can help prevent or reduce accidents due to insufficient safety distances on motorways. This should be complemented by research on the influence of lane changes (on open stretches of road as well as at junctions) on accident occurrence and traffic flow on motorways.

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