Increase of Traffic Safety by Surveillance of Speed Limits with Automatic Radar Devices on a Dangerous Section of a German Autobahn: A Long-Term Investigation

RUEDIGER LAMM and JUERGEN H. KLOECKNER

ABSTRACT

Experiences in the Federal Republic of Germany have indicated that the introduction of speed limits often has only a short-term effect on reducing speeds, and consequently the number of accidents, unless police regularly enforce the speed limits. Posted speed limits alone will not guarantee compliance. Only when backed up by strict police enforcement can speed limits both reduce speed and alleviate accidents. To examine the influence of speed limits by strict surveillances by police, one of the most dangerous downgrade Autobahn sections in the Federal Republic of Germany was equipped with lane-related radar devices and additional DO NOT PASS signs for trucks. The results of a long-term investigation from 1970 to 1982 are as follows: (a) in 1971 the design speed was exceeded by most of the passenger cars in the left and middle lanes, whereas in 1981 few passenger cars exceeded the speed limit in either lane; (b) the 85th percentile speeds were reduced in all lanes for passenger cars and trucks, and a more uniform traffic flow was noted; (c) the accident frequency, as related to personal injury, was reduced by a ratio of 18:1 between 1971 and 1981, and the number of fatalities dramatically decreased; and (d) between 1974 and 1983 a total of 30 million German marks was paid in fines. The experiences have demonstrated that the common impact of reasonable lane-related speed limits and strict surveillance by police with automatic radar devices has had a decisively positive influence on driving behavior and accident reduction. The investigation period of more than 10 years appears to be long enough to verify that the improvements are permanent.

It is a documented fact in the United States and Europe that reasonable and systematic traffic surveillance can reduce the number and severity of accidents, especially on dangerous road sections. In many cases the danger of a road section is directly attributable to improper speed estimations by the driver. Besides alcohol abuse, not fastening seat belts, and inattention, most of the excessive speed errors occur with reference to road design, primarily in the sense of exceeding the critical speed for a curve or a downgrade and thereby losing control.

Therefore, strong efforts should be made by police to enforce the speed limits, at least on dangerous road sections. The purpose of this paper is to discuss the extent to which surveillance by police can produce an evident decrease in accidents. Experience gained in one of the most dangerous Autobahn (Interstate) sections in the Federal Republic of Germany, Elzer Mountain near the town of Wiesbaden, is used as the focus of the discussion.

ELZER MOUNTAIN

The Autobahn (A3) between Cologne and Frankfurt was built in the 1930s with two lanes in each direction, plus a median and paved shoulders.

Elzer Mountain lies in the route of this Autobahn and is located about 96.5 km south of Cologne and 48 km north of Frankfurt in hilly topography. Because of the high traffic increase in the 1960s [average daily traffic (ADT) 1960 ≈ 15,000 vehicles per day, both directions; ADT 1968 ≈ 30,000 vehicles per day, both directions], a third traffic lane and an emergency lane were added in 1969 in both directions.

Figure 1 shows the major part of the horizontal and vertical alignment on Elzer Mountain on Autobahn A3. Note the generous horizontal alignment of this Autobahn section, with relatively safe radii between 1500 and 2000 m.

The character of a generous and consistent align-

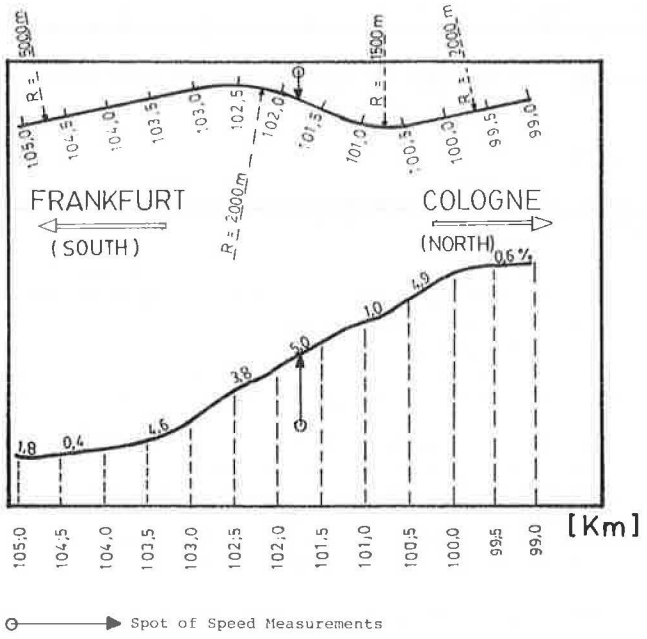


FIGURE 1 Horizontal and vertical alignment of Elzer Mountain.

ment is further supported by three wide traffic lanes per direction (lane width = 3.8 m) plus an additional emergency lane (Figure 2). In this connection the obviously good horizontal alignment superimposed by relatively high downgrade sections of up to 5 percent poses a real danger that is extremely difficult to recognize by the drivers. Drivers on such a downgrade tend to exceed safe driving speeds and thereby jeopardize their chances of stopping safely in an emergency.

FIGURE 2 Alignment of Elzer Mountain, downgrade direction.

In addition, there were great variations in vehicle speeds between passenger cars and trucks. For example, speed measurements indicated that 15 percent of the passenger cars in the left lane exceeded 150 km/h and in the middle lane they exceeded 135 km/h, whereas in the right lane truck speeds between 15 and 110 km/h were recorded (Figure 3). At this time there were no general speed regulations on German Autobahnen, and the great variations in vehicle speeds in the area of Elzer Mountain led to numerous hazardous driving situations.

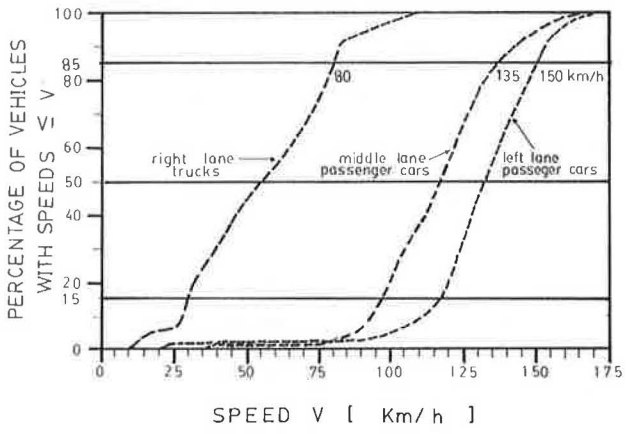


FIGURE 3 Characteristic distributions of speeds for passenger cars and trucks, downgrade direction.

After the end of the construction period and in spite of adding a third lane, drivers obviously were still unable to identify the steep downgrade sections of Elzer Mountain as dangerous because about 200 accidents occurred per year in 1970 and 1971 on a section length of only 7.2 km (Table 1). That meant that there were exactly 27 accidents per kilometer per year for the downgrade direction.

The data in Table 1 give the accident frequency on Elzer Mountain from 1961 to 1982 (1). Note that until 1972-1973 the downgrade direction from Cologne to Frankfurt was decisively more dangerous than the upgrade direction from Frankfurt to Cologne.

Furthermore, it should be mentioned that until 1970-1971, in spite of the addition of a third lane, the number of accidents with personal injuries was comparable with the number of accidents with injuries between 1964 and 1967. Since 1972 a continuous decrease of accidents with personal injuries can be noticed for the downgrade direction from Cologne to Frankfurt. The construction period for the third lane from 1968 to 1969 should not be taken into consideration here.

SPEED AND ACCIDENT ANALYSIS

To be able to make appropriate proposals for improving the accident situation on Elzer Mountain, the Institute of Highway and Railroad Design and Construction of the University of Karlsruhe conducted a comprehensive analysis of the speed distributions and the main accident causes (2). The investigation period was from April 1, 1970, to March 31, 1972.

Figure 3 shows characteristic distributions of speeds for a collection of passenger cars and trucks at one of the steepest downgrade sections on Elzer Mountain, at km 101.7 (see Figure 1). The 85th percentile speed in the left lane was 150 km/h, in the middle lane it was 135 km/h for passenger cars, and in the right lane it was 80 km/h for trucks. That meant that 15 percent of both passenger cars and trucks exceeded these speeds. The maximum design speed of 100 km/h, which had been permissible at that time in the Federal Republic of Germany for grades up to 5 percent, was exceeded by about 95 percent of the passenger cars in the left lane and by about 80 percent of the passenger cars in the middle lane. The general speed limit for trucks of 80 km/h in the Federal Republic of Germany was exceeded by 15 percent of vehicles of this type.

Figure 4 shows the computed accident rates of different accident types. For passenger cars the accident type "congestion" was dominant, whereas for trucks the accident type "run-into" was more relevant. The accident type run-into is related only to two vehicles (e.g., in a case when the driver of a following vehicle underestimates the speed of a vehicle in front and then normally causes a rear-end collision). The accident type congestion, which includes by definition more than two vehicles, in many cases originates from previous run-into accidents.

Because of the great differences in the driving speeds among trucks and between trucks and passenger cars on the downgrade section of Elzer Mountain (Figure 3), the predominance of run-into accidents and consequently the high portion of congestion accidents could be expected. For example, 54 percent of the accident damage of about $3.1 million on Elzer Mountain before the investigation period, from April 1970 to March 1972, was produced by run-into accidents of trucks alone.

Therefore, to reduce the severity and number of accidents on Elzer Mountain, the traffic flow was made more uniform by narrowing the great variations in vehicle speeds.

COUNTERMEASURES

To alleviate the accident situation on Elzer Mountain, in 1972 the Institute of Highway and Railroad Design and Construction of the University of Karlsruhe proposed lane-related speed limits that should be under surveillance by automatic radar devices (1, 2), combined with DO NOT PASS signs for trucks.

TABLE 1 Number of Accidents at Elzer Mountain, Long-Term Investigation

YEAR	Direction: Cologne-Frankfurt (Downgrade)			Direction: Frankfurt-Cologne (Upgrade)			Both Directions			ADT Vehicles per Day Both Directions
	Property Damage	Injuries	All	Property Damage	Injuries	All	Property Damage	Injuries	All	
60										
61	219	70	289			39			328	15849
62	161	69	230			43			273	17294
63	142	51	193			65			258	18871
64	164	85	249			65			314	20591
65	225	91	316			67			383	22469
66	227	96	323			90			413	24653
67	107	87	194	22	18	40	129	105	234	27049
68	116	102	218	33	15	48	149	117	266	29678
69	183	145	328	32	16	48	215	161	376	32562
70	116	79	195	32	18	50	148	97	245	35727
71	102	93	195	38	21	59	140	114	254	35015
72	114	63	177	30	15	45	144	78	222	34316
73	54	30	84	22	10	32	76	40	116	33632
74	24	19	43	32	6	38	56	25	81	33791
75	35	21	56	20	7	27	55	28	83	33951
76	27	6	33	11	16	27	38	22	60	32304
77	20	11	31	21	4	25	41	15	56	30737
78	15	5	20	18	10	28	33	15	48	35681
79	24	6	30	16	19	35	40	25	65	38233
80	17	9	26	22	9	31	39	18	57	38893
81	23	6	29	22	8	30	45	14	59	39351
82	21	5	26	19	6	25	40	11	51	40347

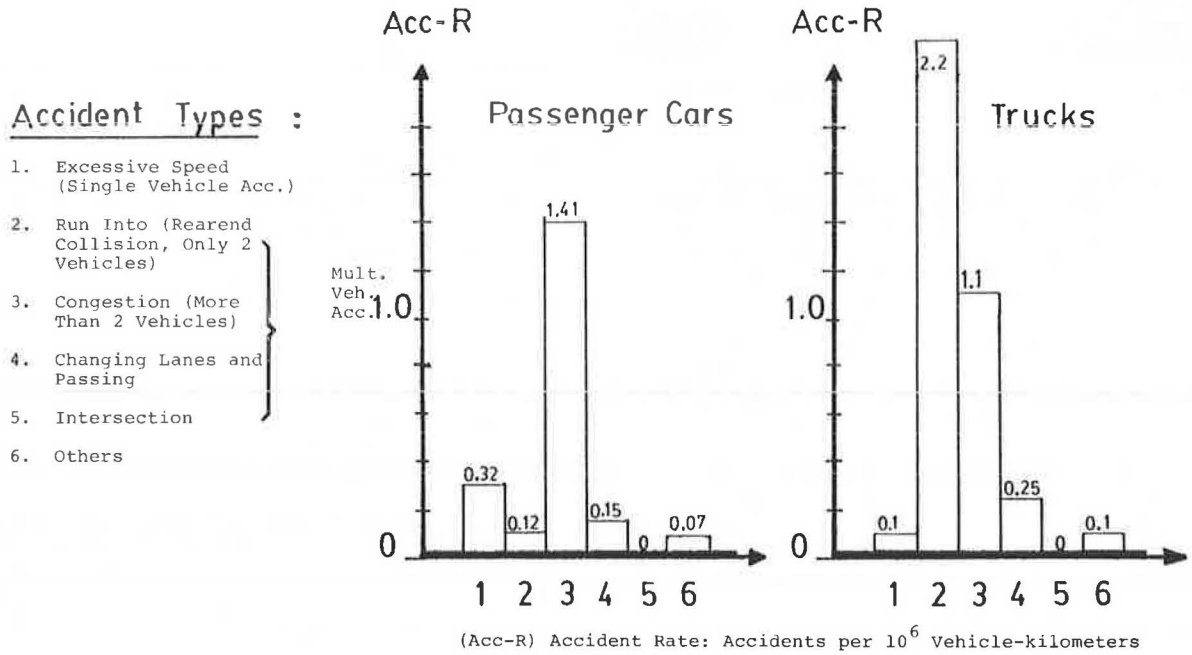


FIGURE 4 Accident rates caused by different accident types, downgrade direction (April 1, 1970-March 31, 1972).

To correct the extremely heterogeneous distributions of the driving speeds (Figure 3) and to reduce the accident risk (Figure 4), the allowable maximum speed was limited to 100 km/h for passenger cars and to 40 km/h for trucks. In addition, the speed limit of 100 km/h for passenger cars was assigned to the left and middle lanes only, whereas the speed limit of 40 km/h was directed to the right lane only (Figure 5).

To prevent numerous passing and lane-changing maneuvers of passenger cars in the left and middle lanes, for both lanes the same speed limit of 100 km/h was chosen, which corresponded to the maximum allowable design speed for a gradient of 5 percent. To prevent the middle lane from being occupied for passing maneuvers by slower vehicles, especially trucks, DO NOT PASS signs for trucks were also installed.

Figure 6 shows the traffic sign plan for Elzer Mountain in the downgrade direction. The speed limit signs were installed on four sign bridges across the Autobahn; the new speed and traffic regulations were introduced on April 1, 1972.

The experiences with general or local speed limits in the Federal Republic of Germany often were not satisfactory, especially in the case of rare surveillance by police. Therefore, the second

FIGURE 5 Traffic sign bridge at km 103.0 combined with DO NOT PASS signs for trucks, downgrade direction.

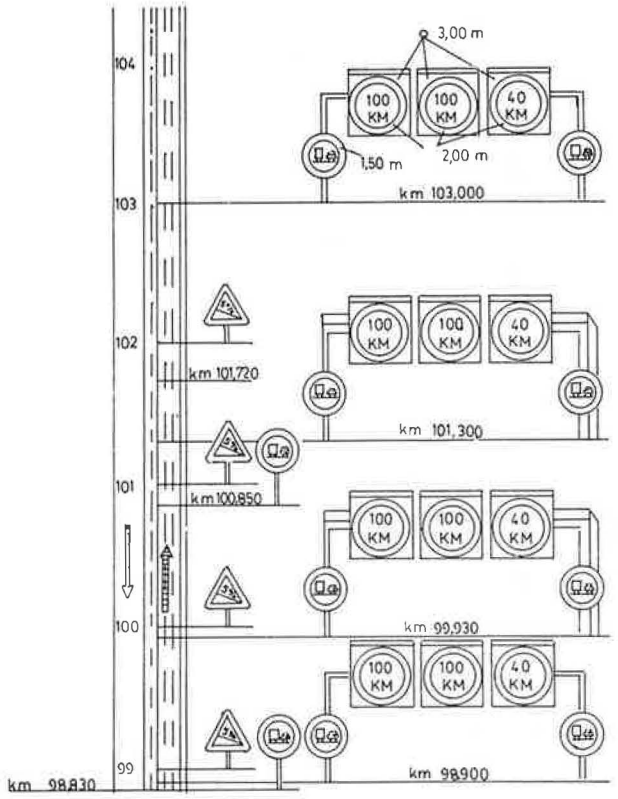


FIGURE 6 Traffic sign plan for Elzer Mountain, downgrade direction.

and the third traffic sign bridges were modified to use automatic radar devices, which were recommended by the Minister of Economy and Technique, State Hessen, Federal Republic of Germany (1).

Figure 7 (3) shows the traffic sign bridge at km 101.3 with the three automatic lane-related radar devices. The radar devices were installed in May 1973.

In addition to the traffic sign plan shown in Figure 6, the warning sign shown in Figure 8 (3) was installed at the beginning of Elzer Mountain at km 98.8, before the first speed limits began, to inform the driver by a visual impression of the danger of the steep downgrade road section ahead.

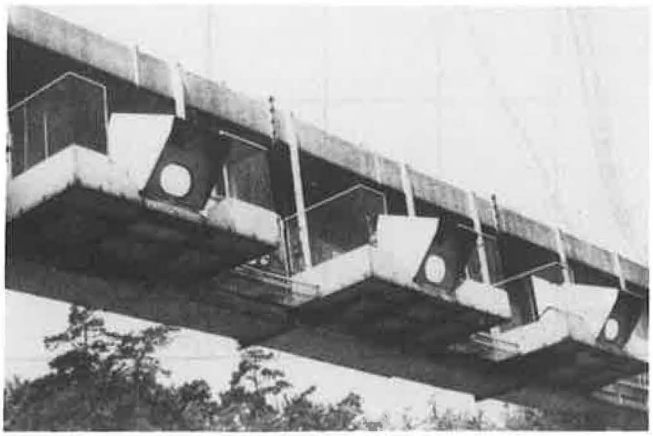


FIGURE 7 Automatic lane-related radar devices, downgrade direction *(3)*.

FIGURE 8 Warning sign at beginning of Elzer Mountain *(3)*.

SPEED EVALUATION: LONG-TERM INVESTIGATION

The first speed measurements (before investigation) at km 101.7 at Elzer Mountain were taken in October 1971. The characteristic distributions of driving speeds for passenger cars in the left and middle lanes and for trucks in the right lane are shown in Figure 3.

After the introduction of the speed limits in April 1972, an After I-Investigation, with comparable speed measurements, was conducted in October 1972. The results are shown as curve 2 for passenger cars (left lane) in Figure 9, for passenger cars (middle lane) in Figure 10, and for trucks (right lane) in Figure 11. Note that the 85th percentile speeds between curves 1 and 2 in the left and middle lanes could be reduced by about 25 to 30 km/h for passenger cars, but that still 60 percent of the passenger cars in the left lane and about 30 percent in the middle lane exceeded the speed limit of 100 km/h related to curve 2. For trucks (Figure 11), note that only about 10 percent exceeded the speed limit of 40 km/h in the right lane.

In May 1973 the automatic radar devices were installed, and in 1974 new speed measurements under comparable weather and daytime conditions were conducted. The results are shown in each case as curve 3 in Figures 9-11 (After II-Investigation). For the left lane an additional speed reduction of about 20 km/h could be reached, and the overall reductions for passenger cars in the left lane now amounted to about 45 or 50 km/h between 1971 (curve 1) and 1974 (curve 3), as related to the 85th percentile speed shown in Figure 9. Furthermore, the steep increase of the speed distribution of curve 3 indicates that the traffic flow became decisively more uniform. Only 78 percent of traffic violations by passenger cars were detected by the automatic radar devices, which were set to measure speeds exceeding 110 km/h.

In the middle lane (Figure 10) the overall speed reduction between curve 1 (1971) and curve 3 (1974) reached about 35 km/h, as related to the 85th percentile speed. Here less than 3 percent of the drivers were exceeding speeds of 110 km/h.

Curve 3 for the right lane (Figure 11) for trucks shows that in contrast to curve 2 (After I-Investigation, 1972) there is a certain speed increase, especially in the lower speed classes below the indicated speed limit of 40 km/h. On the other hand, the traffic flow for trucks now became uniform, so that this increase did not have any negative influence on the safety situation. The overall speed reduction for trucks between curve 1 (1971) and curve

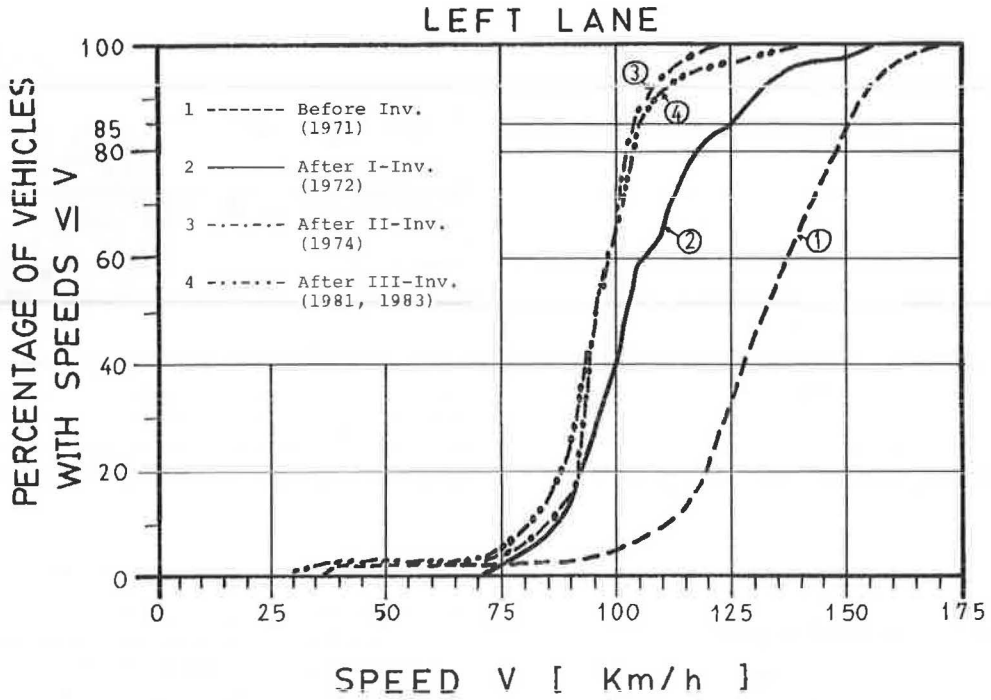


FIGURE 9 Characteristic distributions of speeds for passenger cars in the left lane between 1971 and 1983 at km 101.7, downgrade direction.

3 (1974) was about 40 km/h, as related to the 85th percentile speed. About 7 percent of the trucks were detected by the automatic radar devices, which were set to measure speeds exceeding 45 km/h.

In 1981 and 1983 two additional speed measurements in the course of the long-term investigation were conducted at Elzer Mountain (After III-Investigation). The results are expressed by curve 4 in Figures 9-11. It is to be noted that the observed differences between the 1974, 1981, and 1983 speed measurements are negligibly small. These differences mean that, by the surveillance of the automatic radar devices, the speed distributions and the traffic flow revealed no evident changes over 10 years for

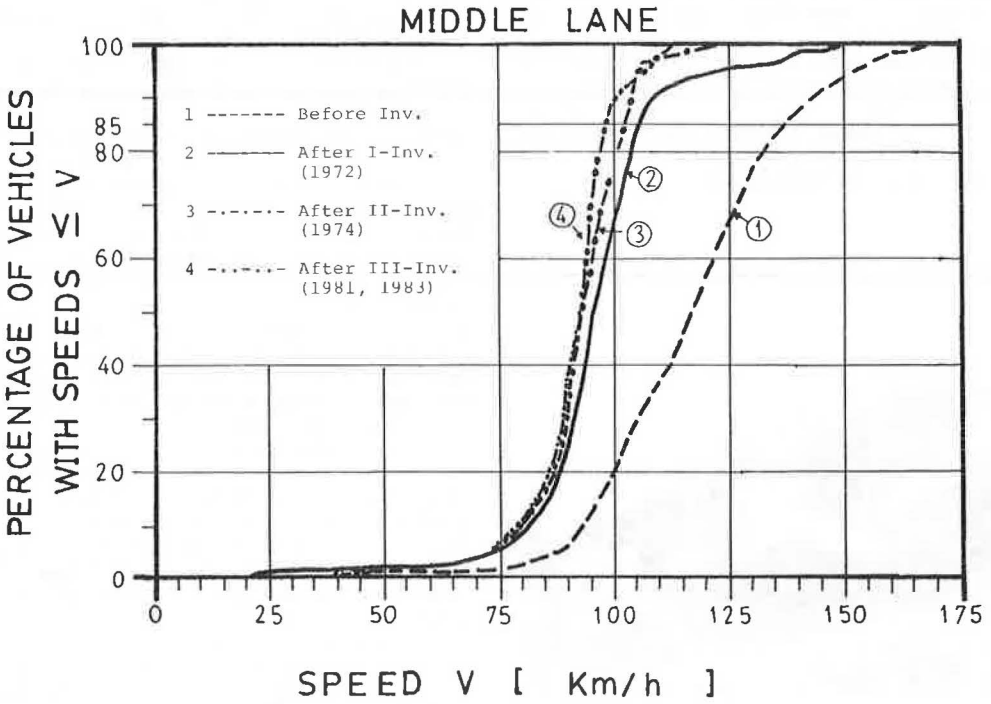


FIGURE 10 Characteristic distributions of speeds for passenger cars in the middle lane between 1971 and 1983 at km 101.7, downgrade direction.

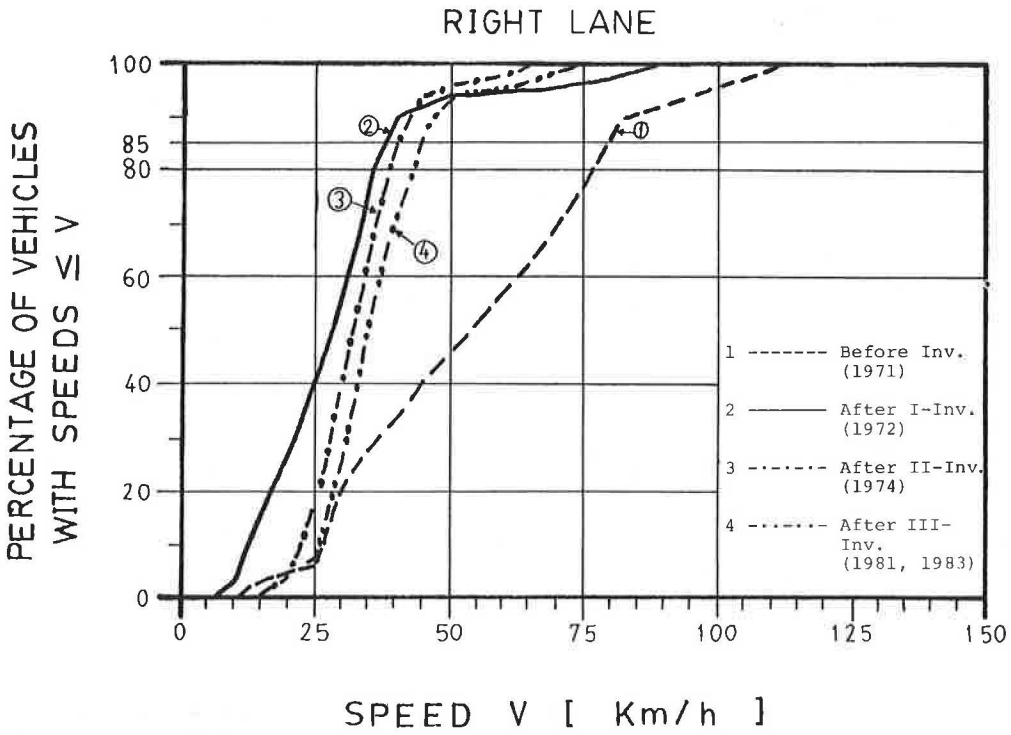


FIGURE 11 Characteristic distributions of speeds for trucks in the right lane between 1971 and 1983 at km 101.7, downgrade direction.

passenger cars in the left and middle lanes in the downgrade direction of Elzer Mountain. The little speed increase of trucks in the right lane has not had any impact on traffic safety, as the following accident investigation will verify.

ACCIDENT EVALUATION: LONG-TERM INVESTIGATION

The data in Table 1 give the development of the accident frequency between 1961 and 1982 for the 7.2-km-long investigation section at Elzer Mountain. As already mentioned, until 1972-1973, the downgrade direction from Cologne to Frankfurt was decisively more dangerous than the upgrade direction. But since 1972, with the introduction of the lane-related speed limits and especially since 1973 with the installation of the automatic radar devices, the accident frequency has decreased continuously from about 200 accidents in 1970-1971 to 84 accidents in 1973 to about 25 to 30 accidents at the beginning of the 1980s for the downgrade direction. The number of fatal and personal injury accidents went down, too. From 80 to 90 injuries per year (7 or 8 fatalities included) in 1970-1971, this number decreased to 30 injuries (3 fatalities included) in 1973 and to about 5 to 10 injuries (1 fatality per year on average) since 1976. Since that time the differences between the number of accidents for the downgrade and the upgrade directions at Elzer Mountain has been insignificant.

The obvious decrease of the accidents since 1973, combined with the low accident level since 1976 for the downgrade direction, cannot be a coincidence. It has to be attributed to the lane-related speed limits and the strict surveillance by police, which became possible for the first time in the Federal Republic of Germany by use of the automatic radar devices.

Furthermore, note that for more than one decade there were no other traffic regulations or structural actions at Elzer Mountain. Also, the ADT has not increased substantially during the past decade (Table 1) because a portion of the growing north-south through traffic elected to travel by a newly built parallel Autobahn on the other side of the Rhine River.

These statements are confirmed by the data in Table 2 and Figure 12. The data in Table 2 give the accident rates for the different driving directions at Elzer Mountain compared with the average accident rates for the whole Autobahn network of the Federal Republic of Germany between 1961 and 1982. The accident rates are again related to accidents involving property damages, personal injuries, and all accidents.

The fatal and personal injury accidents are of special interest in the long-term comparison. The data for these accidents can be considered to be relatively accurate because the figures have been identified and interpreted by the police; the data related to accidents with property damage may fluctuate over the years, however, especially in the case of long-term investigations. For example, the costs of reportable property-damage accidents are changing with inflation. In the Federal Republic of Germany the costs for reporting property-damage accidents were 500 marks [≈ $200 (U.S. dollars)] or more until 1965; between 1965 and 1982 costs of 1,000 marks (≈ $400) or more had to be reported, and since 1983 the reportable property damage has increased to 3,000 marks (≈ $1,200). Therefore, the following investigations are related to the more accurate data of accidents with personal injuries.

Figure 12 shows the accident rates only for accidents with personal injuries and fatalities for the downgrade direction from Cologne to Frankfurt, for the upgrade direction from Frankfurt to Cologne at Elzer Mountain, and also for the entire German Autobahn network. For the downgrade direction, a first

TABLE 2 Accident Rates at Elzer Mountain and Average Accident Rates for Whole German Autobahn Network, Long-Term Investigation

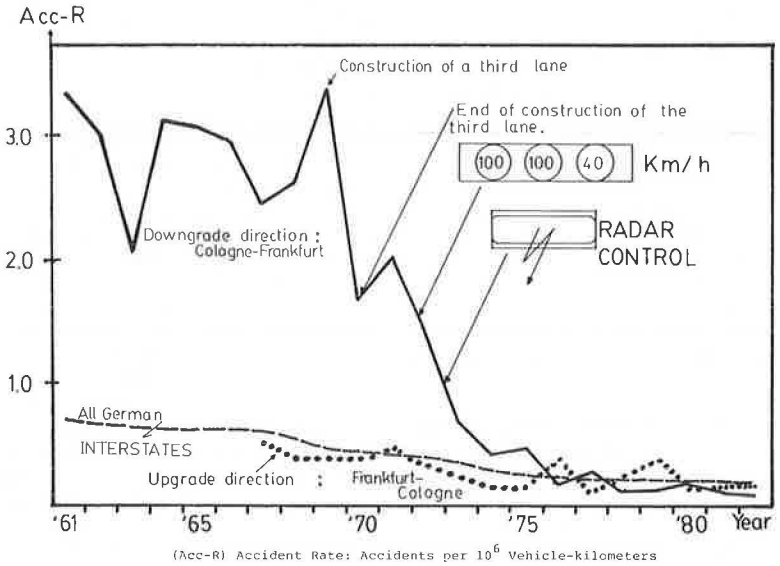
YEAR	Direction: Cologne-Frankfurt (Downgrade)			Direction: Frankfurt-Cologne (Upgrade)			Both Directions			Interstate Network		
	Property Damage	Injuries	All	Property Damage	Injuries	All	Property Damage	Injuries	All	Property Damage	Injuries	All
60											0.69	
61	10.52	3.36	13.88			1.87			7.87		0.71	
62	7.08	3.04	10.12			1.89			6.01		0.68	
63	5.73	2.06	7.78			2.62			5.20		0.64	
64	6.06	3.14	9.20			2.40			5.80		0.63	
65	7.62	3.08	10.70			2.27			6.49		0.63	
66	7.01	2.96	9.97			2.78			6.37		0.63	
67	3.01	2.45	5.46	0.62	0.51	1.13	1.81	1.48	3.29		0.61	
68	2.97	2.62	5.59	0.85	0.38	1.23	1.91	1.50	3.41		0.56	
69	4.28	3.39	7.67	0.75	0.37	1.12	2.51	1.88	4.39		0.47	
70	2.47	1.68	4.18	0.68	0.38	1.07	1.58	1.03	2.62		0.45	
71	2.22	2.02	4.24	0.83	0.46	1.28	1.52	1.24	2.76		0.42	
72	2.53	1.40	3.93	0.67	0.33	1.00	1.60	0.86	2.46	0.41	0.39	0.81
73	1.22	0.68	1.90	0.50	0.23	0.72	0.86	0.45	1.31	0.41	0.36	0.77
74	0.54	0.43	0.97	0.72	0.14	0.86	0.63	0.28	0.91	0.37	0.28	0.66
75	0.78	0.47	1.26	0.45	0.16	0.61	0.62	0.31	0.93	0.35	0.24	0.60
76	0.64	0.14	0.78	0.26	0.38	0.64	0.45	0.26	0.71	0.39	0.23	0.62
77	0.50	0.27	0.77	0.52	0.10	0.62	0.51	0.19	0.69	0.43	0.22	0.65
78	0.32	0.11	0.43	0.38	0.21	0.60	0.35	0.16	0.51	0.48	0.22	0.70
79	0.48	0.12	0.60	0.32	0.38	0.70	0.40	0.25	0.65	0.48	0.21	0.69
80	0.33	0.18	0.51	0.43	0.14	0.57	0.38	0.16	0.54	0.49	0.20	0.69
81	0.44	0.12	0.56	0.43	0.15	0.58	0.44	0.14	0.57		0.19	
82	0.40	0.09	0.49	0.36	0.11	0.47	0.38	0.10	0.48		0.19	

Accident Rate: Accidents per 10^6 Vehicle-kilometers

success could be noticed by the end of the construction of a third lane in 1970 and 1971. However, the accident rates of these 2 years are still about 4.5 times higher in comparison with the accident rates of the upgrade direction at Elzer Mountain and in comparison with the average accident rates of the German Autobahn network.

With the introduction of the lane-related speed limits in 1972 and the surveillance by automatic radar devices in 1973, the accident rates for the downgrade direction were decreasing continuously until 1976. Since 1976 there have been no more significant differences in the chi-square tests for a selected level of confidence of 95 percent between the accident rates of the downgrade and the upgrade driving directions at Elzer Mountain. The same is true for the average accident rates in the German Autobahn network (see Table 2 and Figure 12).

The experiences at Elzer Mountain have shown that reasonable speed regulations under surveillance by automatic radar devices can reduce the number and severity of accidents decisively. As related to personal injuries, the number of accidents and the accident rates were reduced by a ratio of about 18:1 between 1971 and 1982, whereas the number of at least seven or eight fatalities per year until 1972 has decreased to one fatality per year, on average, since 1977 for the downgrade direction at Elzer Mountain. Furthermore, the investigation period of more than 10 years appears to be long enough to verify that the improvement of the accident situation has permanence and that the common impact of lane-related speed limits and surveillance by police has reduced the number and severity of accidents to a level that can be indicated today as normal. As already mentioned, there were no changes



(Acc-R) Accident Rate: Accidents per 10^6 Vehicle-kilometers

FIGURE 12 Accident rates for accidents with personal injuries at Elzer Mountain and for the German Autobahn network.

in traffic regulations or structural activities and no substantial increase of the ADT (Table 1) during the past decade at Elzer Mountain to alter the previous statements.

In conclusion, it should be noted that on no other Autobahn sections in the Federal Republic of Germany have similarly high absolute or relative accident decreases been observed during the past decade.

POLICE PROCEDURES

The automatic radar devices at Elzer Mountain have operated continuously since 1973. They are installed on traffic sign bridges across the Autobahn and are lane related (see Figure 7). They are set to measure speeds exceeding 110 km/h for the left and the middle lanes and speeds exceeding 45 km/h for trucks in the right lane. If a vehicle exceeds these speeds, it is automatically measured and photographed. During nighttime, twilight, and rain periods additional strobe lights are used to illuminate the vehicles.

Figure 13 (3) shows a typical photograph, which indicates the speed, site, date, time, and license plate of the speeding vehicle. At least once a day the rolls of film are changed and evaluated by the police. Moving traffic violation tickets then are delivered to the vehicle owners by mail, and they have to declare if they themselves drove the vehicle or who was the driver of the vehicle. During 1982, 63 percent of all vehicle owners or named drivers paid the fine at once, 27 percent had to be reminded a second time, and about 10 percent contested the traffic citation.

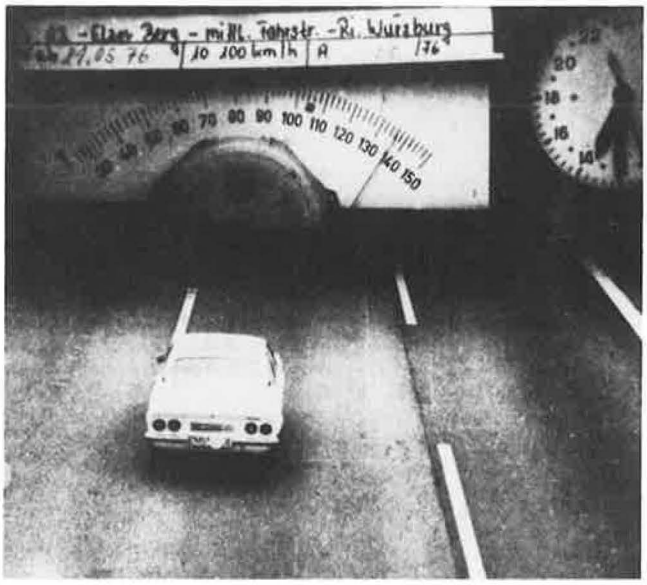


FIGURE 13 Photograph made by an automatic radar device at Elzer Mountain *(3).*

In addition to the continuous operation of the automatic radar devices, several times per year, especially during weekends and vacation times, the speed limits at Elzer Mountain are under direct surveillance by the police. In those periods police officers control the driving speeds directly from the traffic sign bridges [Figure 14 (3)] and inform their colleagues a few kilometers ahead by radio of

FIGURE 14 Police officer controlling speeding vehicles on traffic sign bridge at Elzer Mountain *(3).*

speeding drivers. The drivers are stopped and have to pay the fine on the spot, which is standard practice in Germany [Figure 15 (3)]. This procedure has proved its worth by keeping down the percentage of speeding German drivers, who would otherwise maintain they were not the drivers cited for a traffic violation. This method also provides control of drivers from other European countries (1,4).

FIGURE 15 Speeding drivers stopped at Elzer Mountain to pay fine *(3).*

It may be of additional interest that the main age group of drivers exceeding the speed limits at Elzer Mountain is between 35 and 44 years, followed by the age group of drivers between 25 and 34 years.

In 1982 the average fine at Elzer Mountain was 44.13 German marks (about $20). About 70,000 drivers in 1982 exceeded the indicated speed limits (i.e., about 190 drivers per day). The total sum in fines came to about 3.1 million marks (about $1.5 million) in 1982. As an example, the exact amount was 3,194,020 marks for 1978, and 3,049,937 marks for 1979, or an average of about $1.5 million per year. From 1974 to 1983, during which time the automatic radar devices at Elzer Mountain were continuously working, a total of about 30 million marks ($15 million) of paid fines was collected.

The radar devices of Elzer Mountain were frequently reported by the German newspapers, broad-

cast, and television to educate the public that the radar devices were not radar traps but traffic safety devices. Nevertheless, the previously mentioned amounts of money make clear that there is a always a certain portion of drivers who will not obey reasonable traffic or speed regulations that are necessary for traffic safety, especially on extremely dangerous road sections like Elzer Mountain.

Therefore, the only way to keep the number and severity of accidents down in these cases is by strict surveillance by police, even if such methods are not desired by traffic safety engineers. The authors of this paper would prefer that the individual drivers be conscious of good driving habits and the safety of other highway users with a minimum of police surveillance, but that probably will never occur.

CONCLUSIONS

Experiences in the Federal Republic of Germany have shown that the introduction of speed limits on dangerous road sections, unless they are controlled by the police (1,4), have, if anything, only a short-term effect on speed reductions and on the alleviation of accidents.

A long-term investigation of the relation between driving behavior and accidents when speed limits are strictly enforced by police with automatic radar devices was conducted at Elzer Mountain. The following comprehensive statements and evaluations about this long-term investigation from 1970 to 1982 can be made.

1. On the steep downgrade sections with gradients up to 5 percent at Elzer Mountain, the driving speeds on all three lanes were irresponsibly high, with great variations in the driving speeds, especially among passenger cars and trucks. Consequently, there were numerous passing and lane-changing maneuvers with high, dangerous risks, especially by trucks. The Before-Investigation in 1971 indicated that the maximum design speed of 100 km/h for grades up to 5 percent was exceeded by about 95 percent of the passenger cars in the left lane and by about 80 percent of the passenger cars in the middle lane. The general speed limit of 80 km/h for trucks in the Federal Republic of Germany was exceeded by 15 percent of vehicles. The personal injury accident rates in 1971 for the downgrade direction at Elzer Mountain were about 4.5 times higher than the comparable values for the upgrade direction, and the same was true for the whole German Autobahn network. The high number and severity of accidents were caused mainly by rear-end collisions of trucks.

2. In 1972 lane-related speed limits (100 km/h in the left and middle lanes and 40 km/h in the right lane) and additional DO NOT PASS signs for trucks were introduced. In 1973 automatic radar devices to control the speed limits were installed. Since then significant reductions in the driving speeds, combined with a uniform traffic flow in all three lanes and a decisive improvement of the accident situation, can be noticed for the downgrade direction at Elzer Mountain. For example, in 1981 in the left lane only 7 percent (passenger cars), in the middle lane only 3 percent (passenger cars), and in the right lane only 10 percent (trucks) were detected by the automatic radar devices. These were set to measure speeds exceeding 110 km/h for passenger cars in the left and middle lanes and 45 km/h for trucks in the right lane. Again, as related to personal injuries, the accident frequencies and the accident rates were reduced by a ratio of about 18:1 between 1971 and 1982, whereas the number of at least seven or eight fatalities per year until 1972 decreased, on average, to one fatality per year since 1977 for the downgrade direction at Elzer Mountain. Since 1976 there have been no more significant differences between the accident rates of the downgrade and upgrade direction at Elzer Mountain and the average accident rates of the entire German Autobahn network.

3. The experiences at Elzer Mountain have demonstrated that the two-pronged impact of reasonable lane-related speed limits and strict surveillance by police with automatic radar devices has reduced the number and severity of accidents to a level that can be considered today as normal. The investigation period of more than 10 years appears to be long enough to verify that the improvement in the accident situation has permanence. On no other Autobahn section could a similarly high absolute or relative accident decrease be observed during the past decade.

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REFERENCES

1. D. Felke. The Effectiveness of Speed Limits by Police Surveillance. In Police Information of the State of Hessen, Vol. 2, Feb. 1980, pp. 10-15.
2. H.G. Krebs, R. Lamm, and M. Blumhofer. Introduction of Automatic Speed Devices--Accident and Speed Evaluations on Interstate (Autobahn A3). In Speed Limits in Rural Areas, Minister of Economy and Technique, State Hessen, Federal Republic of Germany, 1974, pp. 23-47.
3. Do You Follow Speed Limits of 80 km/h? Traffic Watch, Vol. 4, July/Aug. 1976, pp. 102-109.
4. D. Felke. Activities by Police in Traffic--A Contribution to Traffic Safety. Traffic Safety, Vol. 29, Feb. 1983, pp. 102-109.

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