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Speed on German highways in heavy rain

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Abstract

Highway traffic safety is adversely affected by precipitation, especially in areas with insufficient water drainage. The hydroplaning risk is mainly influenced by the thickness of the water film. An equally important parameter for the hydroplaning incidence is the driven speed.

Several previous investigations on highways showed that road users reduce their speed during heavy rain. However, up to now the results were rarely differentiated any further according to type of precipitation (spray, rain, ...) and/or intensity of precipitation (quotient of precipitation quantity and time). Hence the question must be asked, to what extent road users reduce their speed in dependency of precipitation intensity and whether this speed lies below the hydroplaning (aquaplaning) speed.

The hydroplaning speed indicates when tires must be expected to lose traction and ride on a cushion of water on the carriageway. It is possible to determine hydroplaning (aquaplaning) speeds in dependence on various factors. Amongst other factors, the degree of impairment is depending on the water film thickness on the carriageway. For the determination of water film thicknesses on carriageways as well as aquaplaning (or hydroplaning) speeds the software PLANUS has been developed within a research project.

Within this present investigation the speed choice of free-flowing passenger cars riding the left lane was analysed for different intensities of precipitation. In a next step this actually driven speeds on the German motorways were compared to aquaplaning speeds – the speed at which tires looses traction and ride on a cushion of water.

The results showed for 3 of the 9 measuring points randomly selected that the actually driven speed exceeded the critical hydroplaning speed (up to 30 km/h) at which tires could start hydroplaning on the water film.

Various accident investigations have shown that wet road surface conditions lead to a distinct increase in accident risk as compared to a dry carriageway. This is especially true for superelevation development sections (where the superelevation rate goes through zero).

In order to reduce the increased accident risk in superelevation development sections in wet condition, design, infrastructure or traffic engineering measures are necessary.

It must be the target to reduce the accident risks in sections with hydroplaning risk, by creating sufficient reserves between actual and hydroplaning speeds.

Speed on German highways in heavy rain

1. Driving safely even in heavy rain ?

According to recent research results global climate change will produce more frequent and heavier rainfall than previous calculations predict. With rising temperatures there will also be an increase in extreme weather situations (Lenderink, 2008). This will affect road traffic as well. Especially in areas with insufficient water drainage traffic safety is impaired during intense precipitation.

Several previous investigations on motorways showed that road users reduce their speed during heavy rain. However, up to now the quoted reduction figures were rarely differentiated any further according to type of precipitation (spray, rain, ...) and/or intensity of precipitation (quotient of precipitation quantity and time). Hence the question must be asked, to what extent road users reduce their speed in dependency of precipitation intensity and whether this speed lies below the hydroplaning (aquaplaning) speed.

The hydroplaning speed indicates when tires must be expected to lose traction and ride on a cushion of water on the carriageway. It is possible to determine hydroplaning (aquaplaning) speeds in dependence on various factors. Amongst other factors, the degree of impairment is depending on the water film thickness on the carriageway. For the determination of water film thicknesses on carriageways the software PLANUS has been developed within a research project (Ressel, 2008). With the aid of this software water film thickness can be calculated depending on rainfall (rain volume according to time and space), geometry and carriageway surface material.

According to the investigation at the University of Stuttgart (Ressel, 2008), the accident risk in wet conditions in superelevation development sections is up to five times higher than on dry surfaces.

Within this present investigation the speed choice of free-flowing passenger cars was analysed for different intensities of precipitation and the hydroplaning speed was determined using the PLANUS software under different marginal conditions.

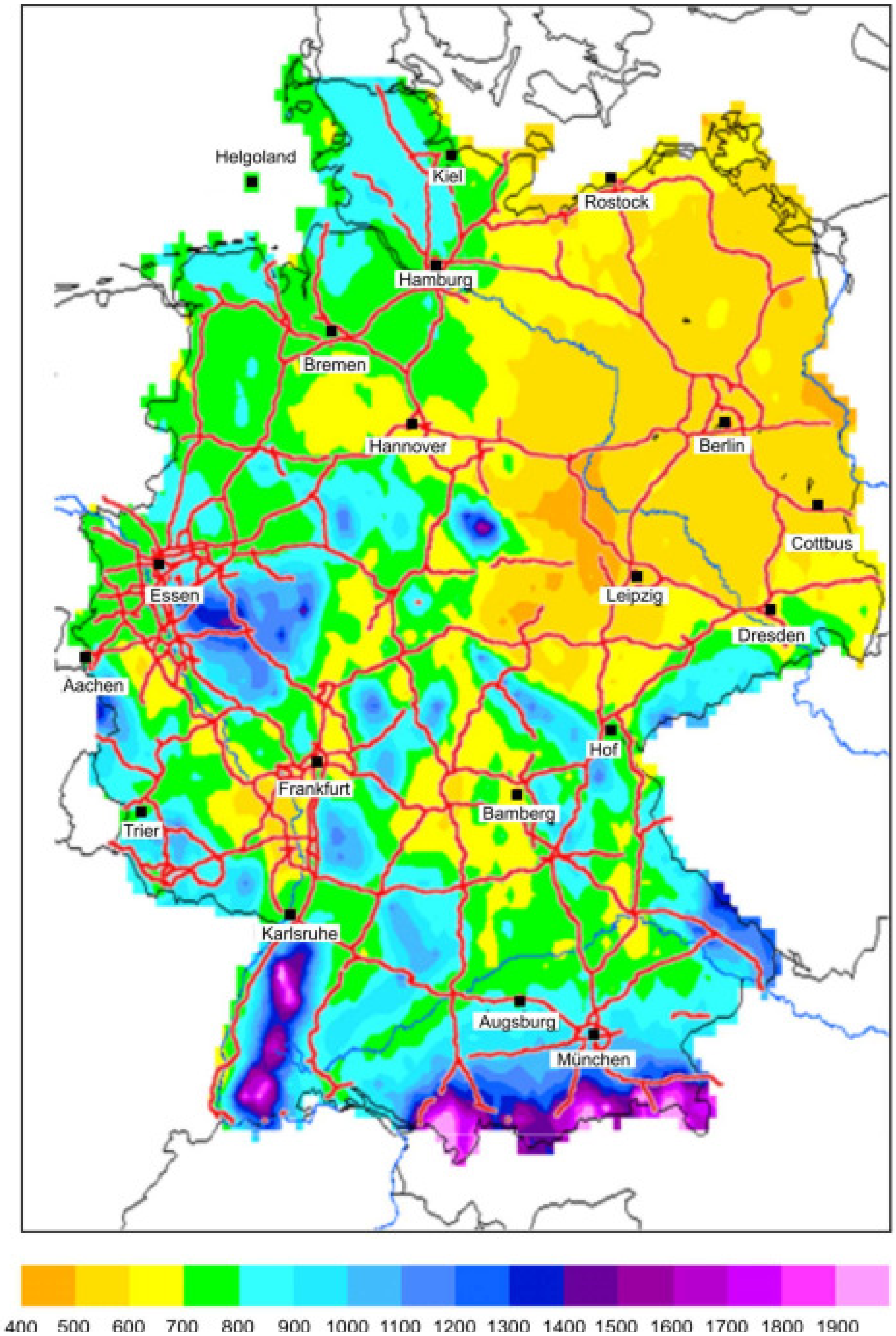
2. Precipitation in Germany

In a first step a review of national and international literature was carried out to reveal the available knowledge. At first literature was searched for information about spatial and timely distribution of different precipitation intensities in Germany. Rain, which has a high intensity in relation to its duration and therefore occurs rarely, is called torrential rain in meteorological terms. As from threshold levels of 10-25 l/m^2 in 1 hour, which relates to 10-25 mm/h, Germany's National Meteorological Service (Deutscher Wetterdienst – DWD) issues weather warnings for torrential rain. In very severe weather the rain quantity can rise up to 50 mm/h and more. Short but severe precipitations are more likely than longer lasting severe precipitations.

In this investigation, a threshold level of 10 mm/h was determined for heavy rain, 5–10 mm/h was considered moderate rain and for light rain the figure was >0-5 mm/h.

Despite precipitation being characterised by a pronounced spatial and timely variability, there are regions in Germany where very high precipitation intensities prevail. Especially mountainous areas are affected. The Harz, the Rothaargebirge, the Schwäbische Alp, the Black Forest, the Bavarian Forest and the Alps are characterized by especially high precipitations (FIGURE 1).. This investigation's result is therefore of special relevance for motorway sections within these regions.

FIGURE 1 Average yearly precipitation in Germany; reference period; 1961-1990; data source: © Deutscher Wetterdienst, Offenbach - superimposed with the motorway network



3. How fast do they really drive?

Precipitation and speed data were collected at a total of nine measuring points on motorways to monitor speed reduction at different precipitation intensities. Included were five three-lane and four two-lane carriageways. The measuring points were situated in North Rhine-Westphalia and in Bavaria. Speed data were taken from automatic, continuous counting stations, the 1-minute-interval precipitation data were collected by precipitation measuring devices which were located in close proximity to these counting stations.

Free-flowing traffic with little mutual influencing of vehicles' speed choice can mainly be found in the left lane of a one-directional carriageway whilst the speed of traffic in the right-hand lane is determined by trucks. For this reason the speed level of the uninfluenced respectively free-flowing passenger car traffic in the left-hand lane (v_f) was in the main focus of this investigation. As the criterion for a free-flowing car a time gap distance of 7 sec. to cars going in front or following was chosen.

From the timely corresponding precipitation and speed data the speeds of free-flowing passenger cars at different precipitation intensities were determined.

In order to consider the possible influence of the traffic load on the speeds on the single measurement days, they were subjected to the Kolmogorov-Smirnov-test to verify the conformance of their probability distributions. This procedure was chosen to enable an aggregation of days with similar distribution and the detection of days with extraordinary incidents. Even in the generation of frequency distributions for the recorded speeds v_f of each single measurement day and the depiction of the cumulative frequency polygons these "extraordinary" days could be identified and excluded from the investigation.

Data of different days in May, June and July 2007 were evaluated. In total there were 96 "dry" days and 97 days with rain.

First a median speed for free-flowing passenger cars in the left lane was determined for each measuring point (v_f dry). Then the relation between the speeds of free-flowing cars and precipitation intensities of single days was examined. The diagrams (figure 2 – 3) showing the daily course of different measuring points display: the speeds of free-flowing passenger cars, as well as constrained vehicles, the average speed determined for all free-flowing passenger cars on dry surface and the intensity of precipitation.

Herein the reduction of passenger car speeds in all lanes in incipient heavy rain (>10 mm/h) becomes obvious.

FIGURE 2: Speeds and precipitation

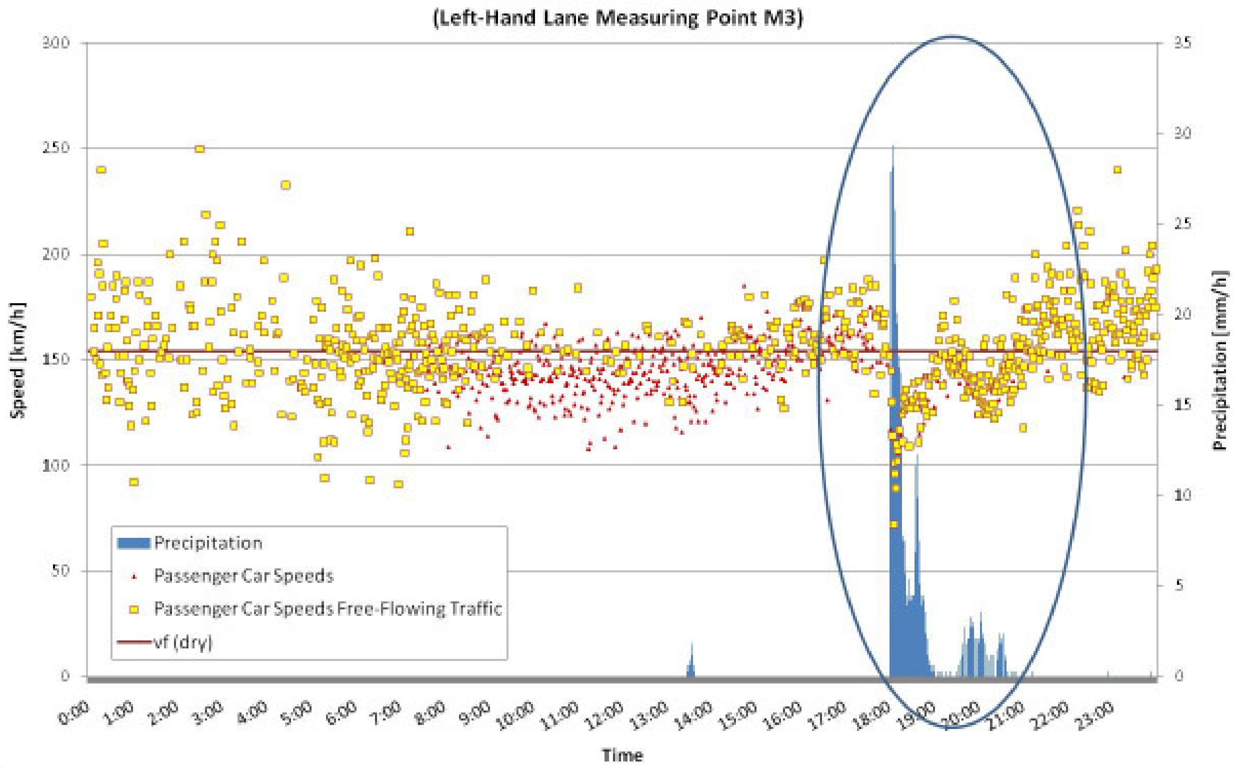
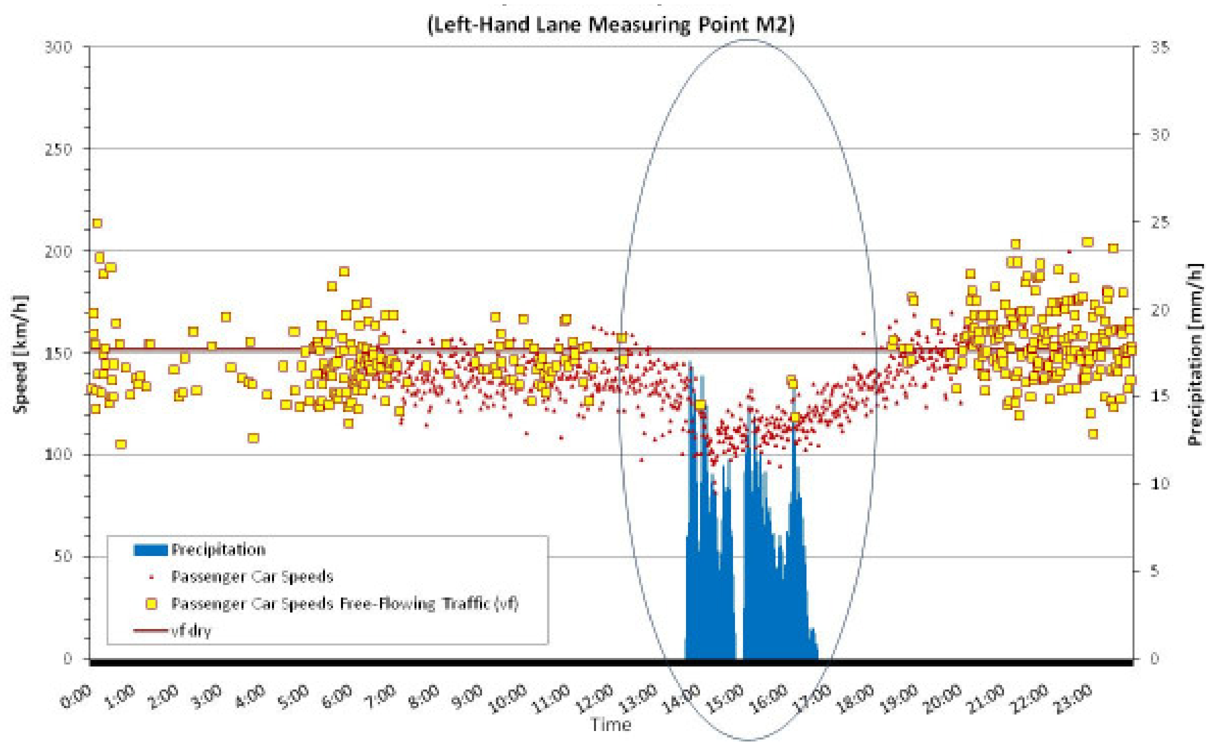
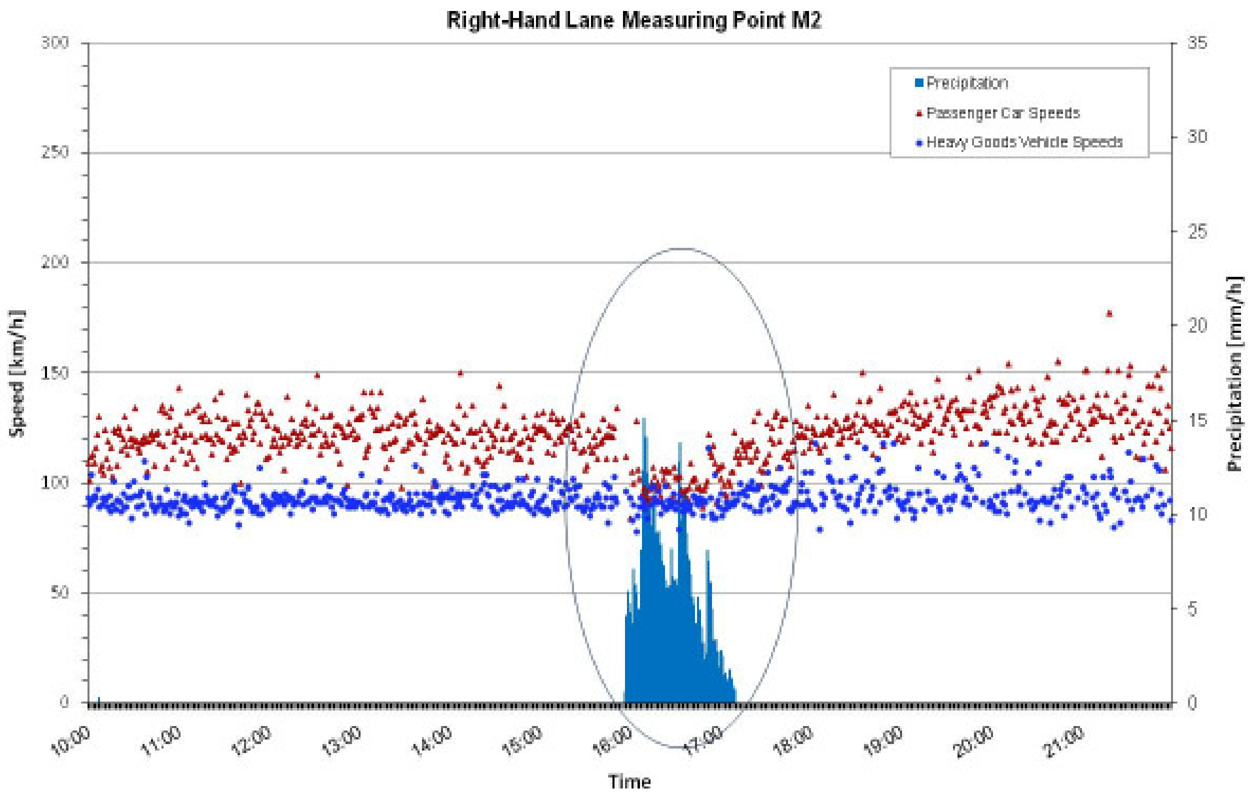


FIGURE 3 Speeds and precipitation



As another result of this investigation it must be mentioned that the speed of trucks is almost independent from precipitation intensities. Even in heavy rain events the speed of trucks remained relatively constant. Figure 4 exemplary displays the speed of all passenger cars and trucks in the right-hand lane at one measuring point for a time period of 12 hours which includes both, times with and without precipitation,

FIGURE 4 Change in speeds of passenger cars and trucks in the right hand lane in precipitation



The measured precipitation intensities were divided into three classes to aggregate the values and for better illustration. The intensity classes 0<r≤5 mm/h (light rain), 5<r≤10 mm/h (moderate rain) and r>10 mm/h (heavy rain) were chosen. Since heavy rain intensities are rarer than lighter rain intensities, there were fewer measured values available than in the other precipitation intensity classes. A total of approx. 500 data pairs with a precipitation intensity of >10 mm/h could nevertheless be evaluated. For precipitation intensities of between 5-10 mm/h there were almost twice as many measured values at hand. For precipitation intensities of 0-5 mm/h there were approx. 7.200 data pairs, on days without precipitation about 40.000.

Table 1 depicts the median values of speeds of free-flowing passenger cars in the left lane for the various precipitation intensity classes as well as the respective standard deviation and the number of evaluated data pairs for the nine measuring points. The speeds were between 146 and 162 km/h on dry surface, whilst in very heavy rain (>10 mm/h) they dropped to values between 104 and 122 km/h.

TABLE 1 Speeds vfmean at measuring points for different precipitation intensities

Measuring Points	Speed [km/h] Standard Deviation [km/h] Number [-]	Precipitation Intensity [mm/h] 0	above 0-5	above 5-10	>10
M 1	vf mean	162	145	134	104
	σ	20	23	22	21
	n	5320	274	3	4
M 2	vf mean	147	136	131	117
	σ	23	21	20	20
	n	2759	660	106	87
M 3	vf mean	152	131	127	122
	σ	18	13	12	17
	n	5652	801	360	142
M 4	vf mean	154	139	132	119
	σ	18	16	17	17
	n	2140	948	228	60
M 5	vf mean	153	138	124	114
	σ	20	17	16	16
	n	9981	986	113	45
M 6	vf mean	160	146	127	121
	σ	17	18	11	12
	n	10638	2233	133	161
M 7	vf mean	158	148		
	σ	11	14		
	n	2603	432		
M 8	vf mean	162	141		
	σ	10	15		
	n	1166	486		
M 9	vf mean	146	137		
	σ	14	16		
	n	1645	347		
Total Number Data		41904	7167	943	499

The results of the statistical evaluations are below also depicted as box plots (pics. 5-8). The box plots for each measuring point show the median, the two 25% and 75% quartiles and both extreme values. Thus the box (the square) comprises 50% of the data, the height of the box indicates the dispersion. The median is depicted as a further quantile situated inside the box which thus gives an impression of the skewness of the data's dispersion. In addition to the mentioned characteristic values of the measurements at each measuring point, the average figure for the speed of free-flowing passenger cars in the left lane (v_{fmean}) based on all measuring points, is depicted as a line. This average value lies at 156 km/h in dryness, at 141 km/h in light rain (up to 5 mm/h), at 128 km/h in moderate rain and at 119 km/h in heavy rain (> 10 mm/h).

FIGURE 5 Box-Plot, Speeds of free-flowing passenger cars in the left lane at 9 measuring points – in dry conditions

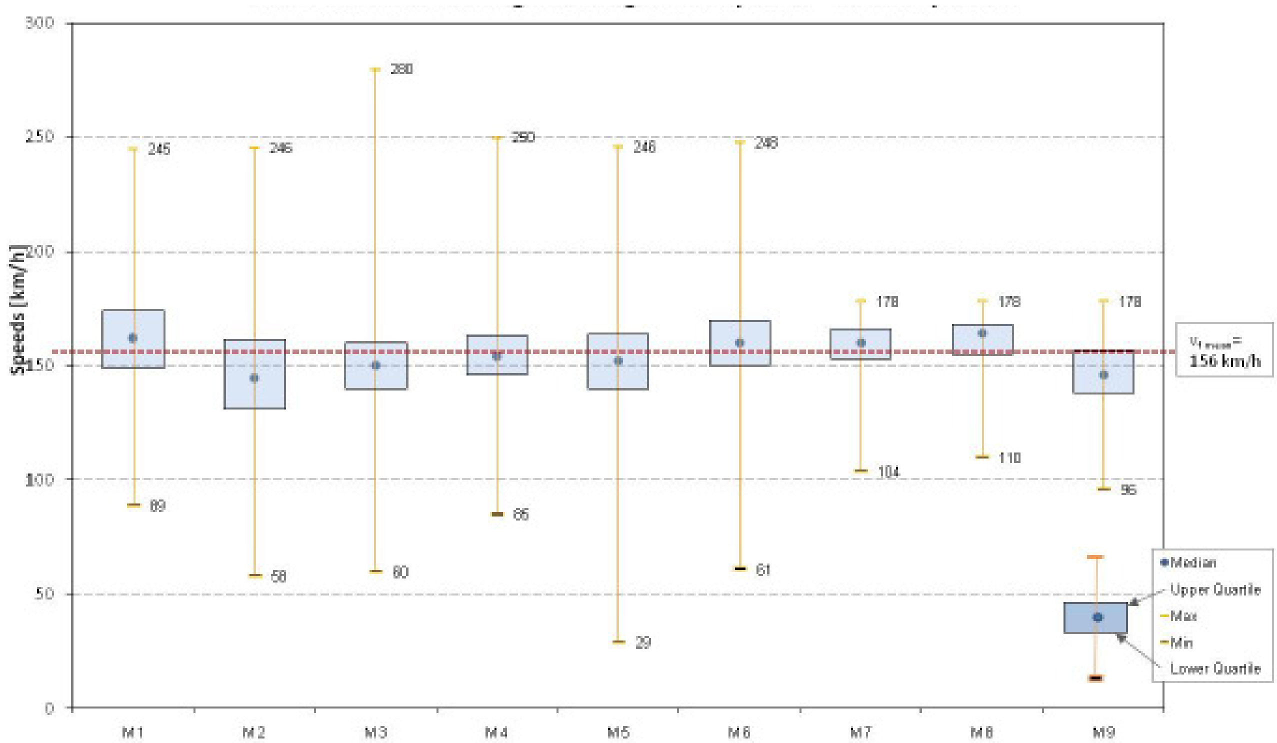


FIGURE 6 Box-Plot, Speeds of free-flowing passenger cars in the left lane at 9 measuring points – in light precipitation (>0-5 mm/h)

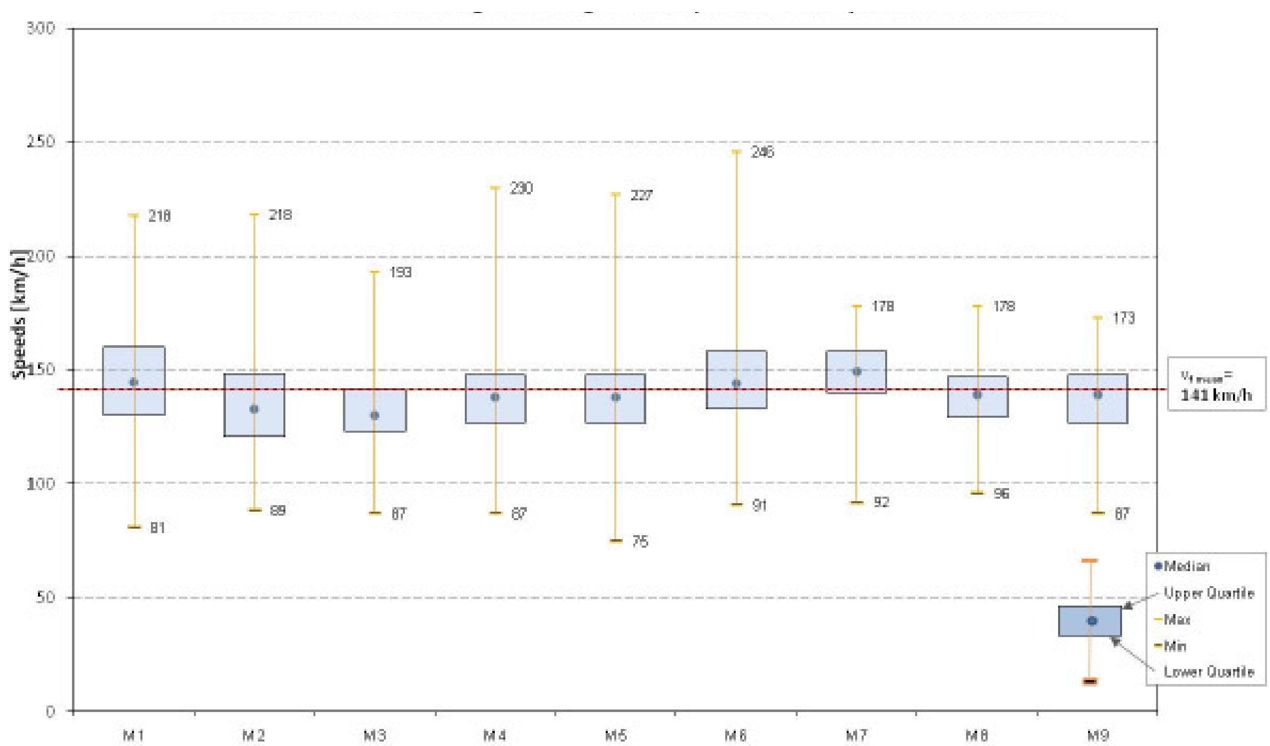


FIGURE 7 Box-Plot, Speeds of free-flowing passenger cars in the left lane at 9 measuring points – in moderate precipitation (5-10 mm/h)

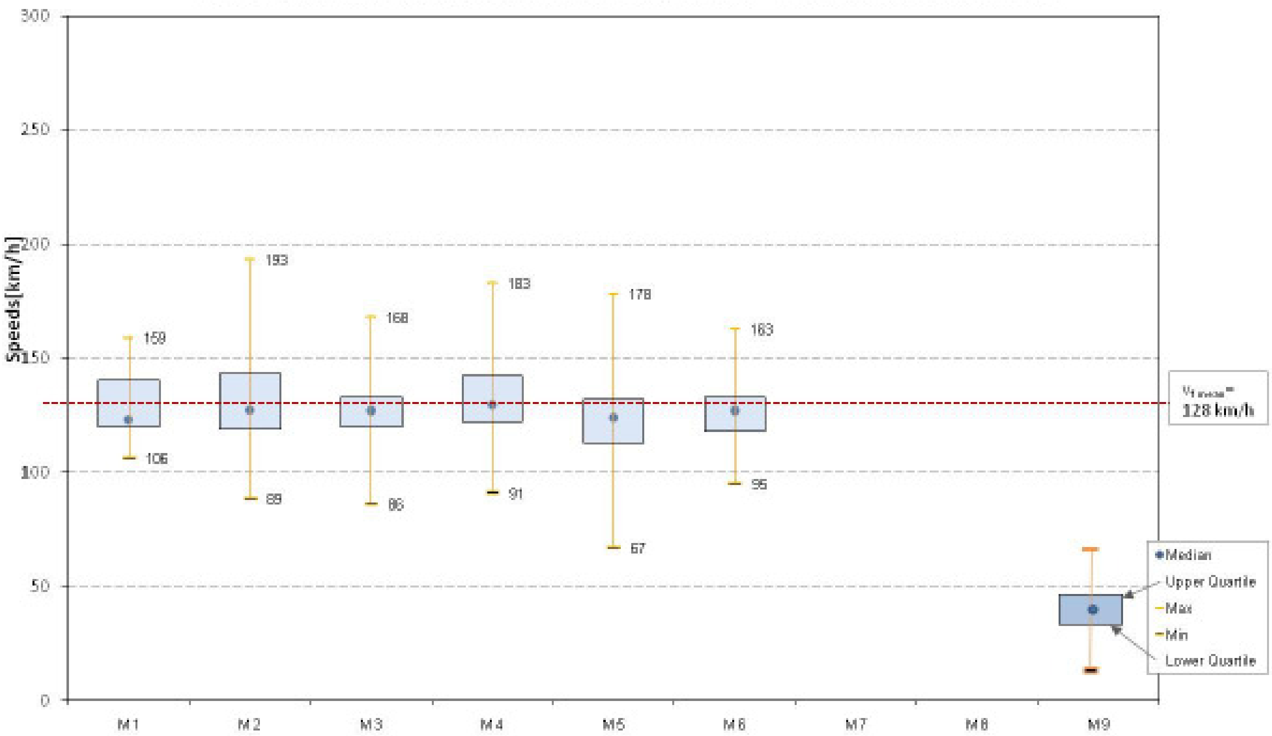
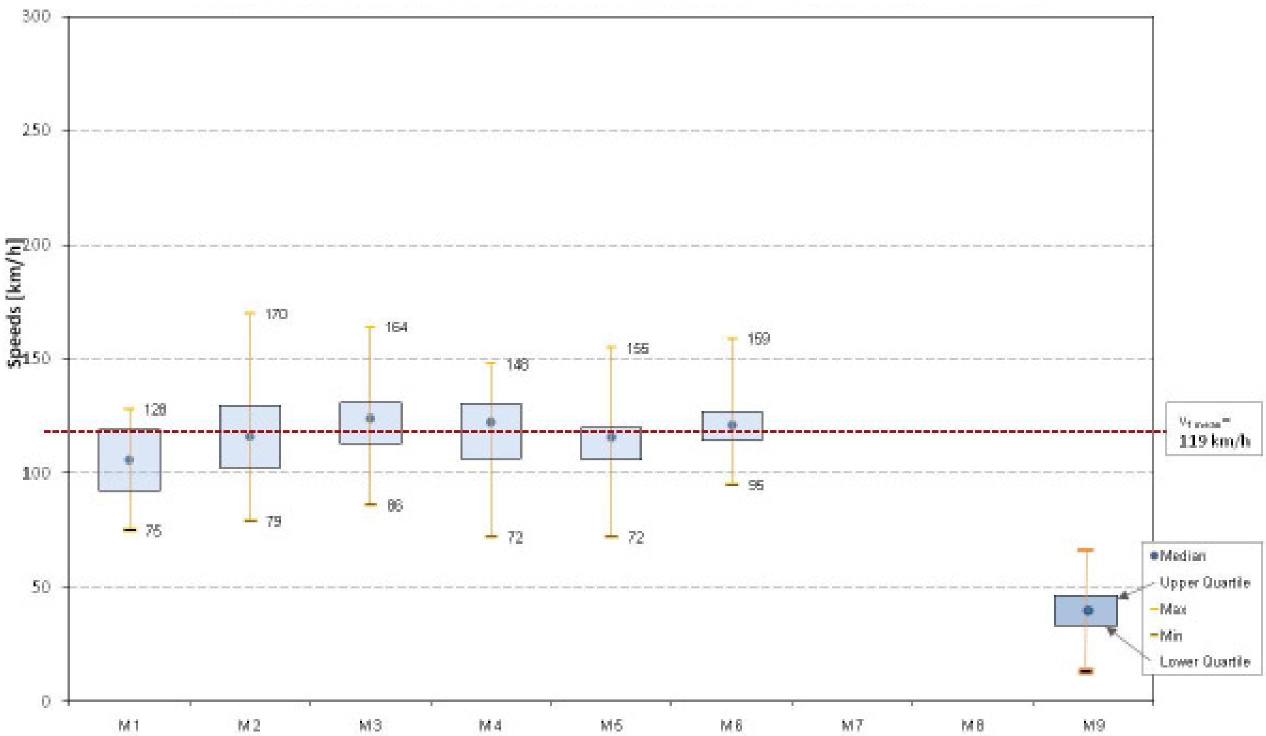


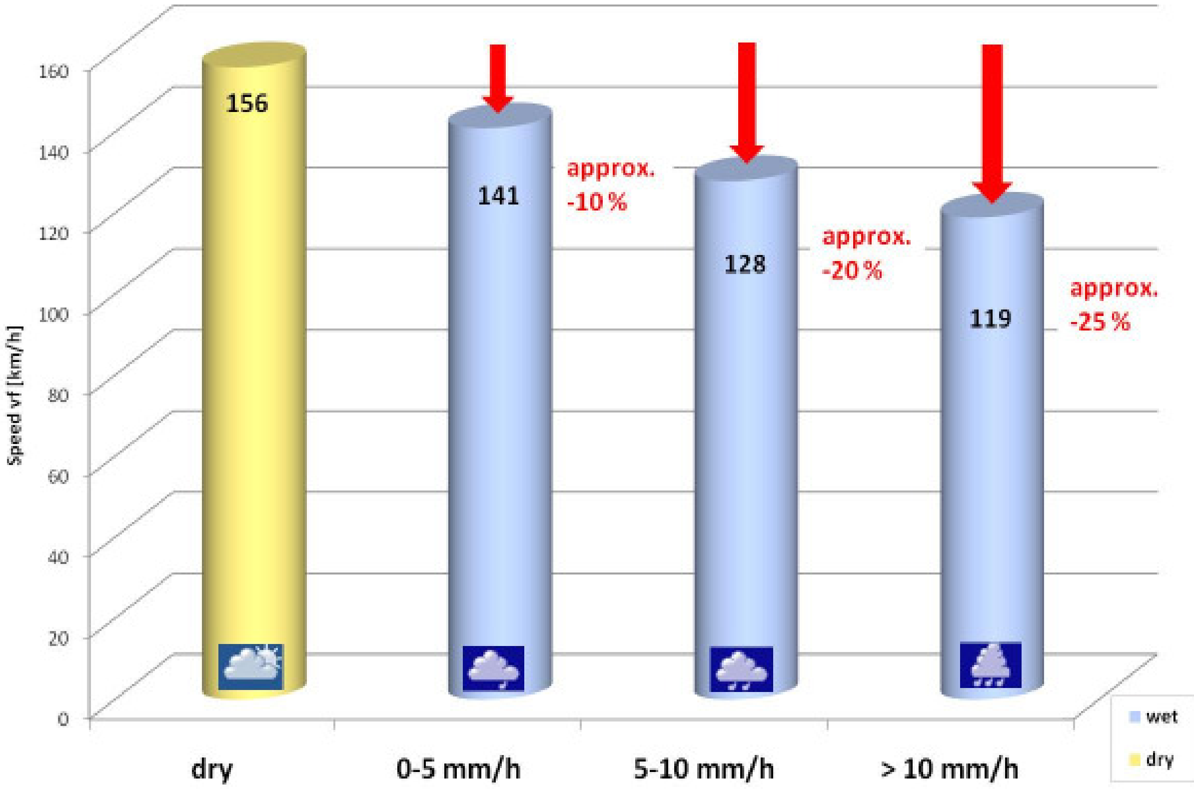
FIGURE 8 Box-Plot, Speeds of free-flowing passenger cars in the left lane at 9 measuring points – in heavy precipitation (≥ 10 mm/h)



The comparison of the mean values demonstrates the influence of precipitation intensity on the speed of free-flowing cars.

This investigation confirmed that the intensity of precipitation has an influence on passenger car speeds. The result of this investigation, the reduction of free-flowing passenger car speeds in different rain intensities, is illustrated in FIGURE 9.

FIGURE 9 Decrease in speeds of free-flowing passenger cars for different precipitation intensities



4. Hydroplaning (Aquaplaning)

The higher the vehicle speed, the higher the risk for hydroplaning in wet conditions. If a tire rolling on wet surface at high speed is rising up and sliding on a "wedge" of water respectively if the tire is separated from the road surface by a closed water film this is referred to as hydroplaning or aquaplaning,

Various accident investigations have shown that wet road surface conditions lead to a distinct increase in accident risk as compared to a dry carriageway. This is especially true for superelevation development sections (where the superelevation rate goes through zero). According to Ressel the accident risk at motorways is doubled during wet conditions compared to dry conditions but superelevation sections have a five times higher accident risk than comparison routes without. Ressel also observed that safe driving on motorways in heavy rain at speeds of almost 110-120 km/h is possible. In superelevation development sections, however, this speed drops to approx. 80 km/h.

The hydroplaning risk is mainly influenced by the thickness of the water film, which is determined by the precipitation intensity. An equally important parameter for the hydroplaning incidence is the driven speed – but the type of road surface, the alignment parameters of the carriageway, the vehicle type and the tires' tread depth also have a strong influence.

Using the PLANUS software, the water film thickness can be calculated in dependence of precipitation intensity, carriageway geometry and surface structure. Based on this information, the hydroplaning speed can be derived in dependence of the tire tread depth. These hydroplaning speeds indicate as of when hydroplaning due to tires losing contact with a wet road surface must be expected.

The hydroplaning speeds for all 9 measuring points were determined using PLANUS and then compared to the actual free-flowing passenger car speeds (v_f). This was done once for the basic rain yield $r_{15/n=1}$.which, according to the design guidelines for roads, part drainage (RAS-Ew), is exceeded once a year as well as for the rain yield which corresponds to heavy rainfall (>10 mm/h).

TABLE 2 Comparison of hydroplaning speeds with actual speeds vf

Measuring Point	Gradient [%]	Change of Cross Fall	Number of Lanes	Hydroplaning Speeds [km/h]		Speed vf [km/h]	
				for Basic Rain Yield	in Heavy Rain >10mm/h	In Heavy Rain >10mm/h	Critical
	Carriage-way	Carriage-way	Carriage-way	Left-Hand Lane	Left-Hand Lane	Left-Hand Lane	
M 1	-0,5	yes	3	75	83	113	yes
M 2	-1,5	yes	2	79	92	117	yes
M 3	-3,9	yes	2	79	97	122	yes
M 4	0,4	no	2	101	145	126	
M 5	-1,8	no	2	>150	>150	117	
M 6	1,9	yes	3	121	>150	123	
M 7	0,5	no	3	>150	>150	*(148)**	
M 8	-3,3	yes	3	78	96	*(141)**	(yes)
M 9	3,5	no	3	>150	>150	*(137)**	

*At measuring points M 7-M 9 speeds were only determined for a precipitation intensity of 0-5 mm/h. According to PLANUS the hydroplaning speed v_{aq} at cross section M 8 lies at 142 km/h for a rain rate of 4 mm/h.

The analysis of the 9 investigated measuring points shows that at three locations the actual speed is considerably higher (differences more than 30 km/h) than the hydroplaning speed calculated with the aid of PLANUS (see Tab. 2). These three locations are routes with changes in cross fall. This result is in consensus with Ressel's findings, who determined that the accident risk on a wet road surface is up to five times higher in superelevation development areas than on the adjacent route sections.

5. Conclusion

This investigation has shown that motorists do not adequately adapt their speeds in wet conditions especially in superelevation development sections. In order to reduce the increased accident risk in superelevation development sections in wet conditions as shown by Ressel, design, infrastructure or traffic engineering measures are necessary. Thus, when it comes to the alignment, all possibilities for a reduction of water film thickness in superelevation development sections should be taken into consideration, e.g. shifting the zero cross fall point into areas with higher gradient, shortening the superelevation development section, change in gradient. If these measures do not suffice, the software PLANUS can be used to calculate the influence of slotted drains on water film thickness and to optimise their number, position and dimensioning. Such analyses could also be recommendable for superelevation development sections of roads already under operation which are characterised by a high accident rate. The calculation of hydroplaning speeds can further contribute to the assessment whether a reduction of the speed limit in wet conditions should be necessary.

It must be the target to reduce the accident risks in sections with hydroplaning risk, by creating sufficient reserves between actual and hydroplaning speeds.

6. References

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