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Parameter Study Report

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EUSight
European Sight Distances in perspective

Parameter Study Report

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Executive summary

Part of the CEDR Transnational Road Research Programme Call 2013: Safety is the research project European Sight Distances in perspective – EUSight. The objective of this research project is to conduct a detailed examination of the subject of stopping sight distance (SSD) and its role and impact on highway geometric design of divided highways or motorway situations, taking into account differences (and similarities) between EU Member States.

Sight distance (SD) means the unobstructed visibility that is needed to be able to safely and comfortably perform the driving task and to avoid conflicts or collisions with obstacles or other road users. Stopping sight distance (SDD) means the distance over which a driver needs to be able to overlook the road to recognize a hazard on the road and stop his vehicle in time.

This report describes the result of Work Package 4 of the EUSight project. For the parameters involved in SSD, this WP investigated the distribution of parameter values currently 'on the road', differences among countries in EU member states, and future developments of the parameters. These serve as input for WP6 where a set of recommended parameter values for use in determining SSD in European road design will be compiled.

List of definitions

Driver eye height

The vertical distance between the road surface and the position of the driver's eye.

Obstacle

A stationary obstacle on the road that requires a stopping manoeuvre. Examples of obstacles are a stationary vehicle (represented by the tail lights of a car) and an obstacle on the road (lost load of a truck).

Perception-Reaction Time (PRT)

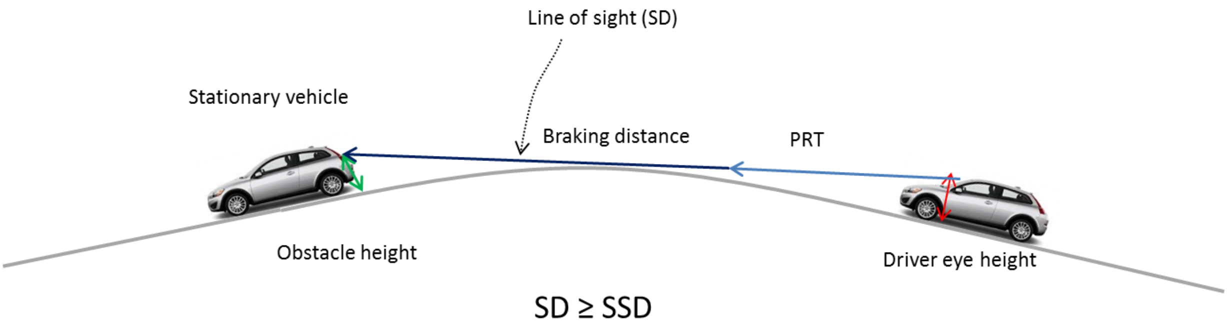
The time it takes for a road user to realize that a reaction is needed due to a road condition, decides what manoeuvre is appropriate (in this case, stopping the vehicle) and start the manoeuvre (moving the foot from the accelerator to the brake pedal).

Sight distance (SD)

This is the actual visibility distance along the road surface, over which a driver from a specified height above the carriageway has visibility of the obstacle. Effectively it is the length of the road over which drivers can see the obstacle, given the horizontal and vertical position of the driver and the characteristics of the road (including the road surroundings).

Stopping Sight Distance (SSD)

SSD is nothing more than the distance that a driver must be able to see ahead along the road to detect an obstacle and to bring the vehicle to a safe stop. It is the distance needed for a driver to recognise and to see an obstacle on the roadway ahead and to bring the vehicle to safe stop before colliding with the obstacle and is made up of two components: the distance covered during the Perception-Reaction Time (PRT) and the distance covered during the braking time.



1 Introduction

In the process of road design, sight distances are of great importance for traffic flow and traffic safety. Adequate sight distance is needed to enable drivers to adapt their speed to the alignment of the road; to stop in front of a stationary obstacle; to overtake a slower vehicle safely on a carriageway with two-way traffic; to merge with (or cross) traffic at an intersection comfortably; and to process roadside information on traffic signs.

Part of the CEDR Transnational Road Research Programme Call 2013: Safety, is the research project European Sight Distances in perspective – EUSight. The objective of this research project is to conduct a detailed examination of the subject of stopping sight distance (SSD) and its role and impact on highway geometric design, taking into account differences (and similarities) between EU Member States. This research considers stopping sight distance from different (related) approaches: human factors (‘the driver’), road characteristics, vehicle characteristics and conditions (like wet conditions, darkness or tunnels). Since SSD is related to many different aspects, multiple approaches and methodologies are needed to determine state-of-the-art parameter values.

This report describes the result of Work Package 4 of the EUSight project: Parameter Studies. For the various parameters identified in the previous Work Package 3 (Stuiver et al., 2015), the main questions are:

- What is the distribution of parameter values currently ’on the road’,
- what can be said about differences among countries in EU member states, and
- what can be said about future developments of the parameters.

2 Approach

In WP3, a structure that depicts the relationship among parameters involved in SD and SSD was developed (Stuiver et al., 2015). This structure is shown in Figure 1.

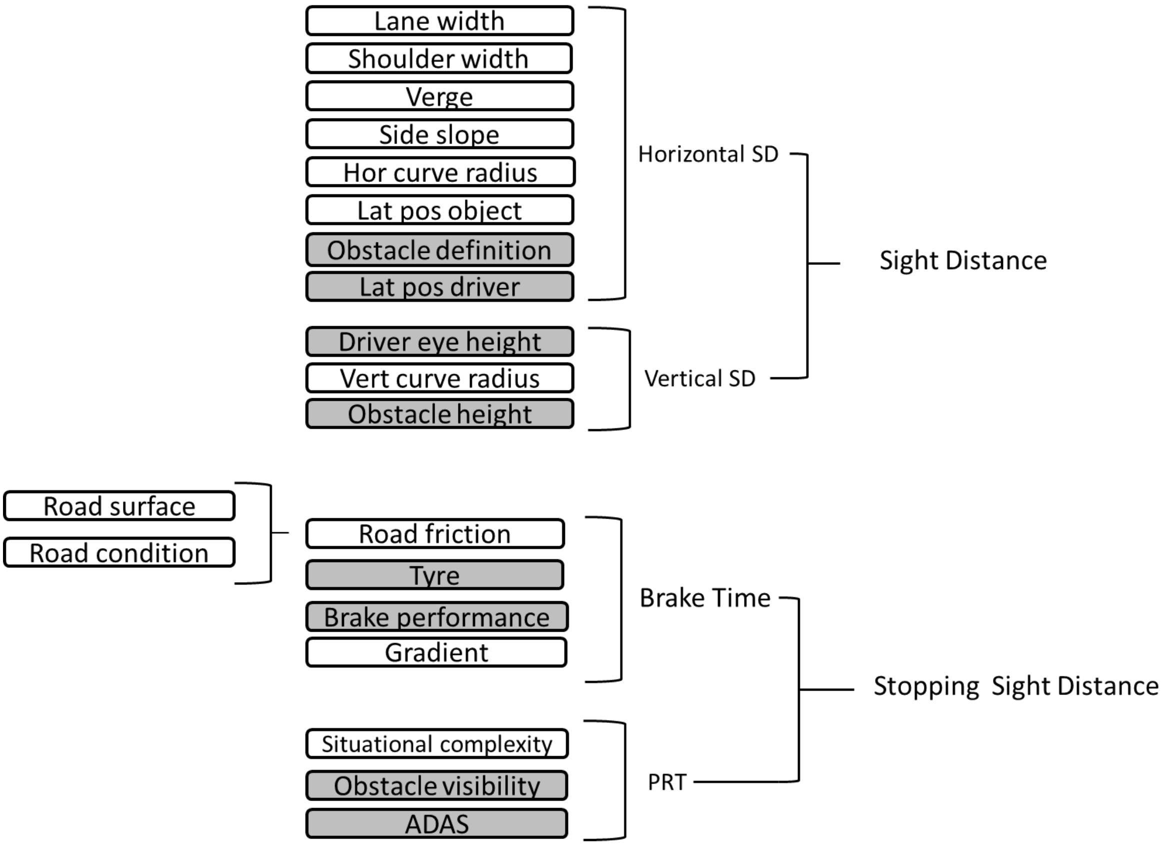


Figure 1: Parameters relevant for SD and SSD; parameters with white background are under direct influence of road design; parameters with grey background are not

In this chapter, the various parameter values will be discussed. This overview is based on desk-top research, building further on the literature and guidelines review (Van Petegem et al., 2014) as well as the scenario report (Stuiver et al., 2015) developed in the earlier work packages of this project.

For differences among EU member states, the same set of countries as in WP2 is considered, viz.:

- Denmark
- France
- Germany

- Ireland
- Netherlands
- Switzerland
- UK

Before presenting the results per parameter or per group of parameters in Chapter 4, relevant further background information concerning the braking time is presented in Chapter 3. In Chapter 5 the main results are discussed and conclusions are drawn.

3 Background

3.1 Brake time

The braking time needed for drivers to stop in front of a stationary object or other obstruction on the motorway, depends on a number of factors:

- Road friction: the road friction limits the maximum deceleration rate. The road friction is determined by the characteristics of the road surface and the tyre. Road friction of a specific surface is influenced by the (weather) conditions.
- Brake performance: the characteristics of the brake system affect the deceleration capabilities of the vehicle.
- Human factors: the driving behaviour determines the actual deceleration behaviour.

The relationship among these factors is shown in Figure 2. The range of the different factors relevant for the deceleration rate, is illustrated with the blue part of the bar. To give an example, in case of a combination of a poor road surface condition, a worn-out tyre (low tread depth) and thick water layer on the road, the minimum road friction occurs; the possible deceleration rate is relatively low.

Given a certain road friction (the orange part of the top bar), the brake systems of the vehicles limit the actual deceleration capabilities in those conditions: the orange part in the brake performance bar has a deceleration rate range with a maximum equal to the road friction in those conditions. Within this range of physical possible decelerations, the drivers can ‘choose’ their actual deceleration rate.

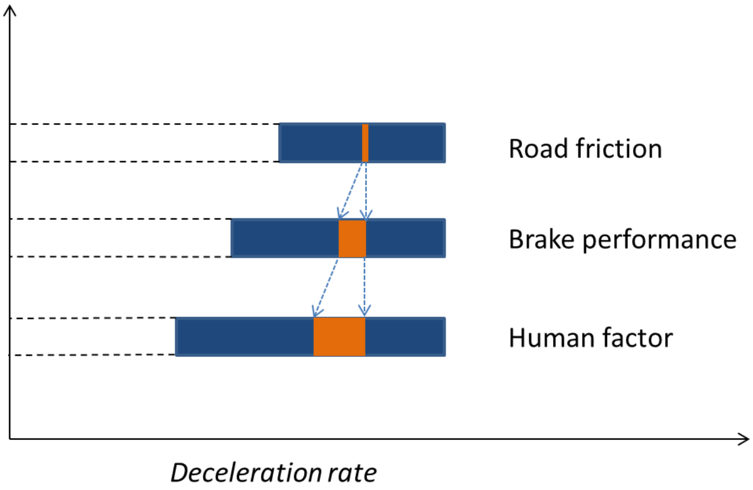


Figure 2: Factors influencing deceleration rates

Before elaborating on these factors, first the theory behind road friction is explained: in this road surface and vehicle characteristics are considered together.

3.1.1 Theory and relationship of road friction

Figure 3 shows the parameters related to the road friction.

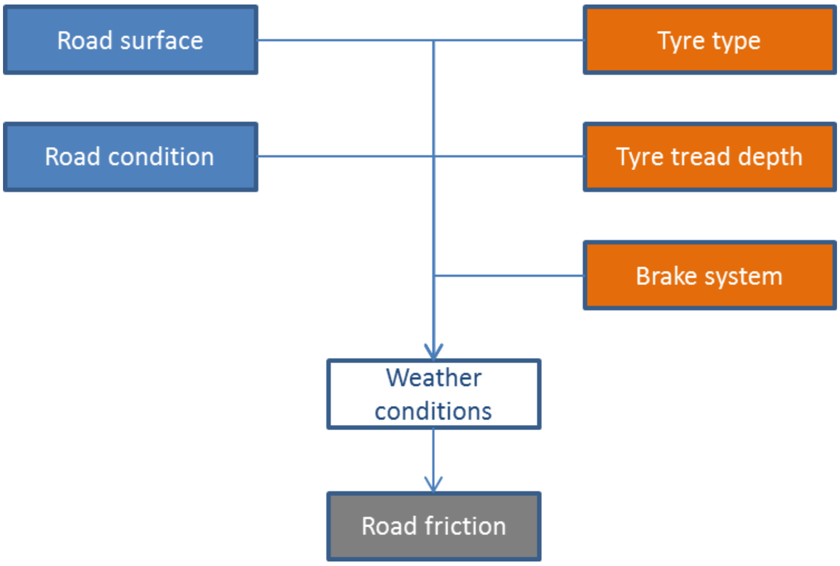


Figure 3: Parameters related to road friction

In this section the relationship between these parameters are described. The description is quoted from 'The little book of tyre pavement friction' (Flintsch et al., 2012).

Road friction is the force that resists the relative motion between a vehicle tyre and a road surface" (Hall et al., 2009). The friction force between tyre and road surface is generally characterized by a dimensionless coefficient known as coefficient of friction (μ), which is the ratio of the tangential force at the contact interface to the longitudinal force on the wheel. These forces are shown in Figure 4.

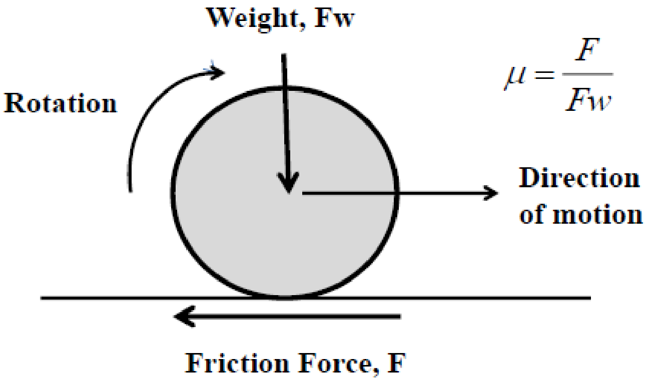


Figure 4: Force body diagram for rotating wheel

Tyre surface friction is the result of the interaction between the tyre and the road surface, not a property of the tyre or the road surface individually. This interaction plays a critical role in highway safety as it keeps the vehicles on the road by allowing drivers to make safe manoeuvres. It is also used in highway geometric design to determine the adequate minimum stopping distance (Hall et al., 2009).

Although poor skid resistance is seldom the first cause of a crash – there is typically a human error that makes an emergency manoeuvre necessary – a crash will only occur if the friction demanded by the individual driver for the manoeuvre being attempted is greater than that which the road surface in that location and the particular brake performance acting together can provide, in the particular set of circumstances (weather and tyre condition), and if skidding or wheel slipping leads to a loss of control or to a collision.

Pavement friction is dominated by the texture, or roughness, of the surface, with different texture components making different contributions. Of fundamental importance on both wet and dry roads is the microtexture of the surface, that is, the fine-scale texture (below about 0.5mm) on the surface of the coarse aggregate in asphalt or the sand in cement concrete that interacts directly with the tyre rubber on a molecular scale and provide adhesion. This component of the texture is especially important at low speeds but needs to be present at any speed.
On wet pavements, as speed increases skid resistance decreases and the extent to which this occurs depends on the macrotexture, typically formed by shape and size of the aggregate particles in the surface or by grooves cut into some

surfaces. Generally, surfaces with greater macrotexture have better friction at high speeds for the same low-speed friction (Roe & Sinhal, 1998).

When a tyre is free rolling in a straight line, the tyre's contact patch is instantaneously stationary and there is little or no friction developed at the tyre/road interface, although there may be some interactions that contribute to rolling resistance. However, when a driver begins to execute a manoeuvre that involves a change of speed or direction, forces develop at the interface in response to acceleration, braking, or steering that cause a reaction between the tyre and the road which enables the vehicle to speed up, slow down, or track around a curve.

During braking, as the braking force increases, the reacting force increases until it approaches a point at which the peak coefficient of friction available between the tyre and the road is exceeded (this normally occurs between 18 and 30 percent slip). At this point (commonly known as "peak friction"), the tyre continues to slow down relative to the vehicle speed and to slip over the road surface, even though the wheel is still rotating. If the braking force continues, the tyre slips even more. Eventually complete locking of the wheel occurs, at which time the wheel stops rotating and the tyre contact patch skids over the road surface. This is illustrated in Figure 5.

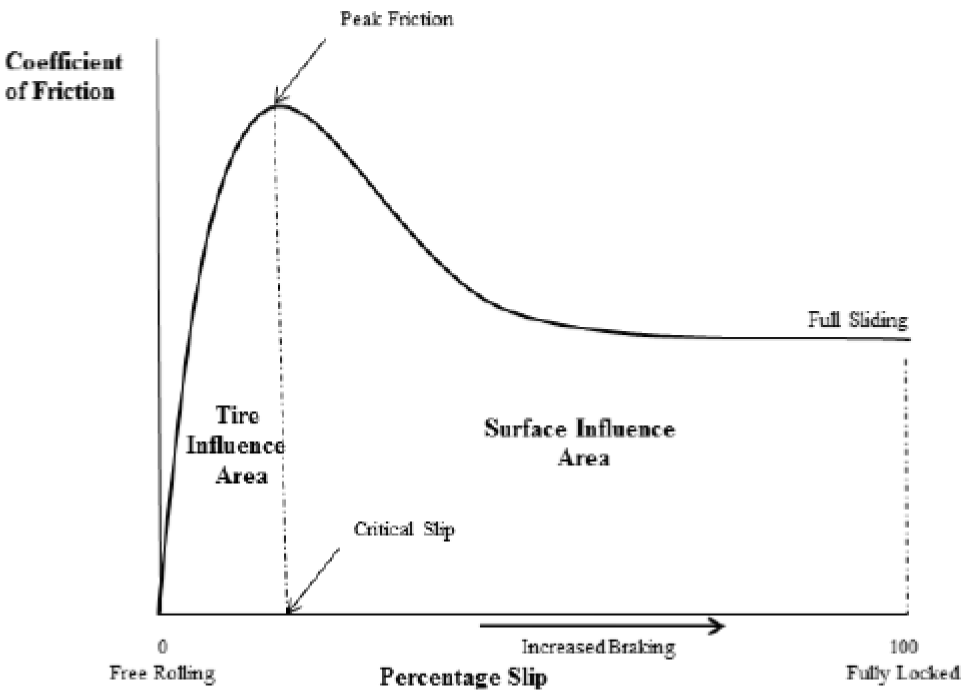


Figure 5: Friction versus slip

On a dry road surface, there is often little difference between peak and sliding friction and relatively little effect of speed. However, on a wet road, peak friction is lower than in dry conditions, the sliding friction is typically lower than peak friction, and both usually (but not always) decrease with increasing speed. The differences between wet and dry, and peak and sliding friction, depend not only on vehicle speed and tyre properties (including tread depth and pattern), but also to a large extent on the characteristics of the road surface, particularly its state of microtexture, the form and magnitude of the macrotexture, and the amount of water and other contaminants on the pavement (the importance of which is discussed further below). It is important to point out that when friction measurements occur on the left side of the peak, these will be mostly influenced by the characteristics of the tyre, whereas those measurements made on the right side of the peak, will be influenced by those properties of the surface (macrotexture).

The situation is exacerbated when braking and cornering occur simultaneously, because the available friction has to be shared between the two mechanisms. If the peak is exceeded, the sideforce goes down to near zero and the operator loses all control of steering. This is why anti-lock braking systems (ABS) are important. They detect the onset of wheel slip and momentarily release and then re-apply the brakes to make sure the peak friction is not exceeded and to reduce the likelihood of side-slip occurring, thus helping the driver to maintain control. Similar ideas are used in some modern vehicle control systems to reduce the risk of side-slip occurring under simultaneous acceleration and cornering.

However, it is important to appreciate that while the instantaneous deceleration rates (and inversely stopping distances) with ABS functioning may be greater than for a vehicle skidding with locked wheels, there can be situations (particularly when the road is wet and the friction level is low) when the average friction (including the times when the wheel is released as well as those when it is slipping) will be less than in the locked-wheel condition.

There are several operational factors that can affect the friction measurement. Better understanding of these factors can help highway agencies to establish standard testing condition and approaches for correcting measurement taken under different conditions.

- The water film thickness is one of the factors that has been proven to affect the friction measurements. The water on the pavement surface decreases the tyre pavement contact area which results in reduction in friction. This effect is known to be more noticeable in higher speeds (>40 mph) compared to lower speeds (Hall et al., 2009).
- Worn tyres are known to be more sensitive to water film thickness. Pavement macrotexture and tyre treads can provide channels for water to escape through the tire pavement contact area which results in increasing the traction between tyre and the pavement surface. The effect of water film thickness on locked wheel skid trailer measurements is illustrated in Figure 6 and it suggests that smooth tyres are more sensitive to the changes of water film thickness. Due to the lower sensitivity of ribbed tyres to operational test conditions and water film thickness, some recommend them as the preferred choice for friction measurements (Henry, 2000). However, ribbed tyres are less sensitive to the pavement

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macrotexture, so it is recommended that their measurements be accompanied by macrotexture measurements.

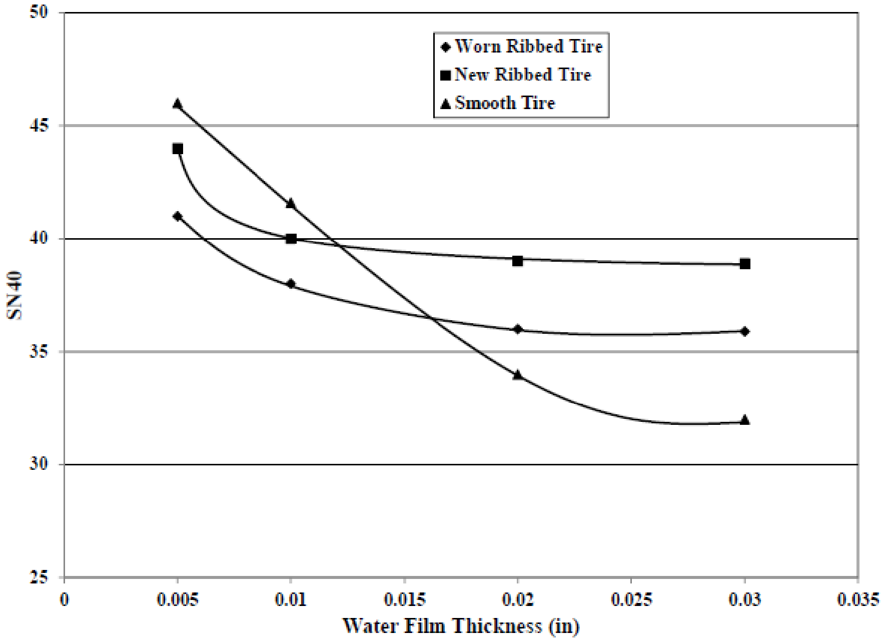

Figure 6: Effect of water film thickness on deceleration

4 Results

4.1 Brake time

4.1.1 Introduction

The ‘standard’ formula for stopping sight distance includes a parameter representing the tangential coefficient of friction or deceleration rate.
For the different design speeds, a road design guideline has to prescribe friction coefficients (or deceleration rates), taking into account the distribution of characteristics of the road surface and the vehicles on the road in different conditions.

In this section the coefficients of frictions in the studied guidelines of WP2 are summarized. Also the effect of road surface, car and tyre characteristics on the friction coefficient and deceleration rates are explained. Furthermore, the distribution of these parameter values is presented.

4.1.2 Guidelines

Figure 7 shows the tangential friction coefficients from the road design guidelines studied in WP2.

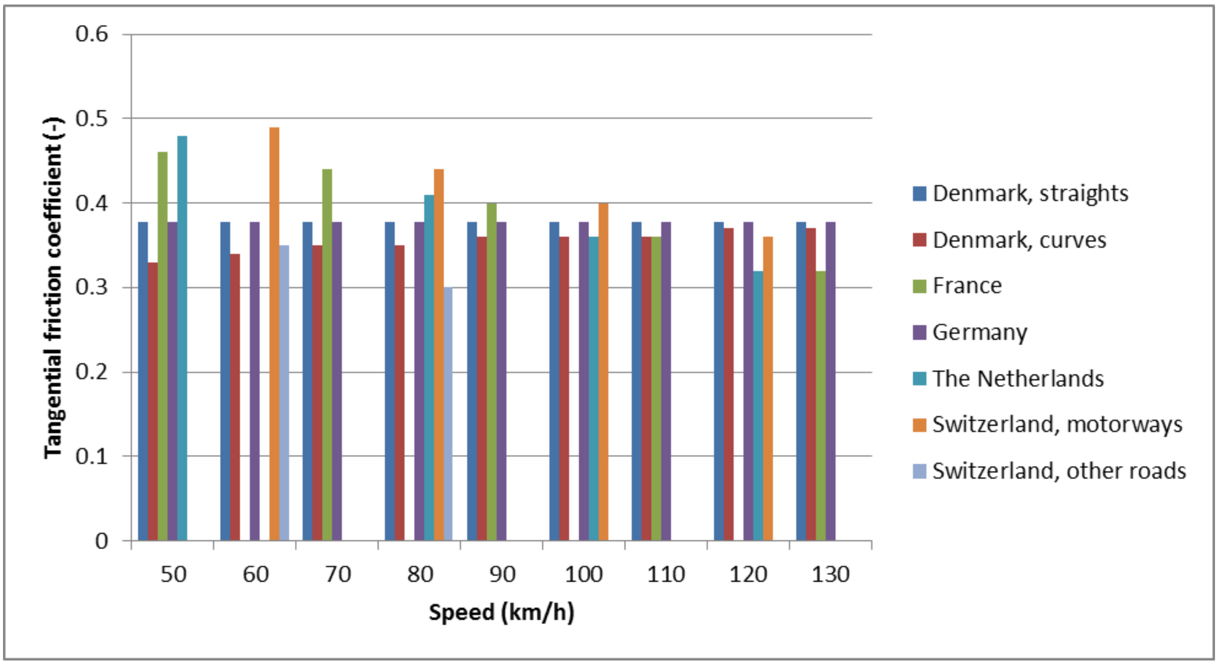

Figure 7: Tangential friction coefficients in road design guidelines

The friction coefficients vary from 0.3 (Switzerland 80 km/h non-motorway) to 0.49 (Switzerland 60 km/h motorway). Most friction coefficients are in the range of 0.35-0.40.

Some countries use friction coefficients that decrease with increasing speed, others use constant coefficients.

Most guidelines do not contain background information about studies or assumptions which led to the chosen friction coefficients.

4.1.3 Braking tests

In WP5 'Driving experiment' (Broeren & Wools, 2015), the reports of a number of test track measurements were studied, which gave insight into the relationship between road surface characteristics, tyre characteristics, water layer depths and deceleration rates. In this section the results are summarized.

Road surface friction coefficient
Van der Sluis (2002) investigated the relation between the friction coefficient and speed with braking trials. Table 1 shows the parameters of the braking trials.

Parameter	*Value*
Car type	Ford Mondeo, Fiat Multipla, Ford Ka, Mercedes ML 270, Mercedes E 240, Toyota Avensis, VW Golf Kombi
Braking system	With and without ABS
Tyre tread depth	2-7mm
Test tracks	Closed circuits and closed motorways sections
Surface type	Different types of road surface (with a wide range of friction coefficients)
Water layer depth	0.5mm
Initial speed	80, 90, 100, 110, 120 and 130 km/h

Table 1: Parameters braking trials (Van der Sluis, 2002)

Figure 8 and Figure 9 show the Mean Fully Developed Deceleration (MFDD) as a function of the friction coefficient (all measurements with a water layer depth of 0.5mm). Because this relation strongly depends on the brake system (with or without ABS), both relations are shown.

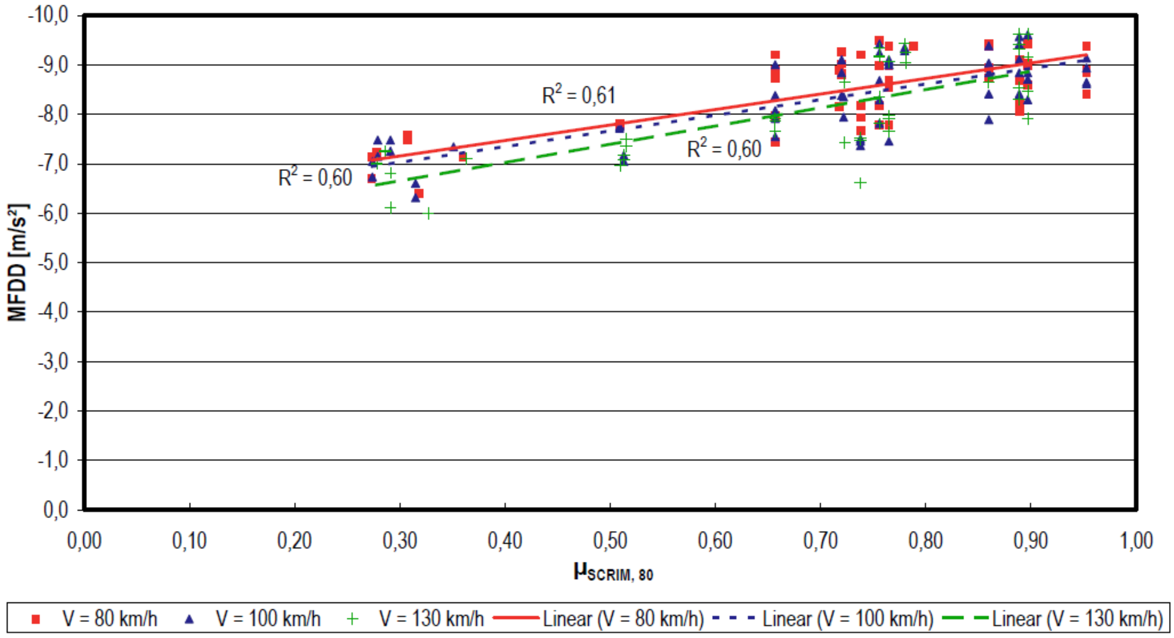

Figure 8: Deceleration as a function of friction coefficient (with ABS)

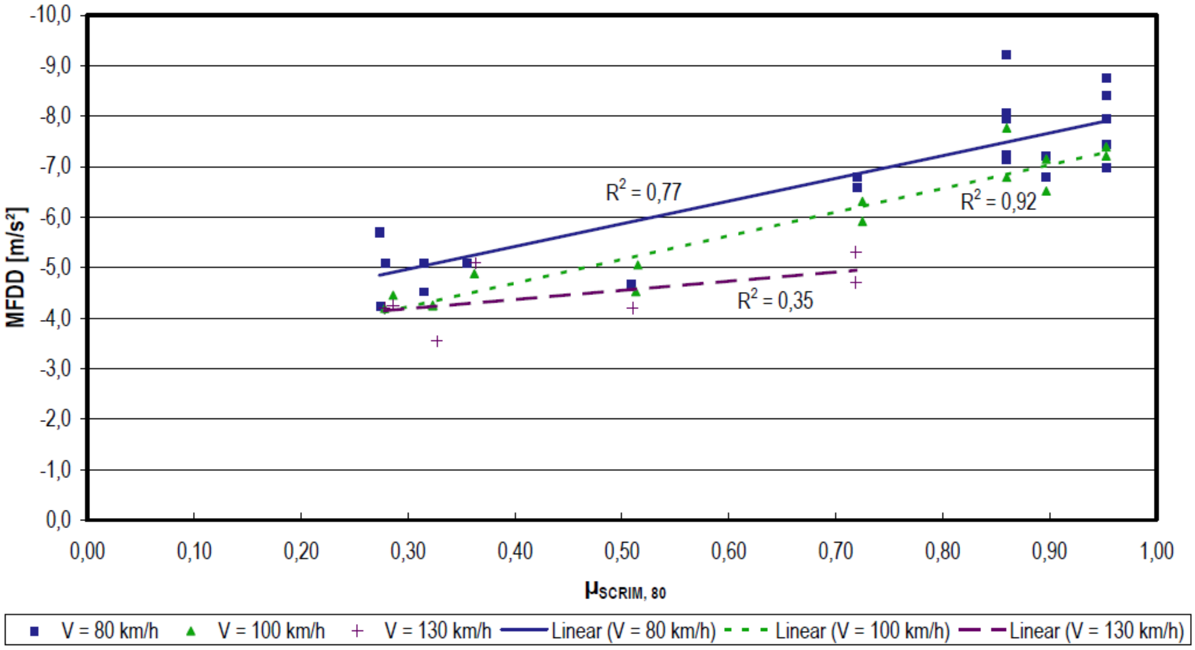

Figure 9: Deceleration as a function of friction coefficient (without ABS)

For both vehicles, with and without ABS, the friction coefficient (μ,scrim) influences the maximum (average) deceleration rates. For vehicles without ABS, the friction coefficient has a more significant effect on the deceleration rates. Furthermore, the results show that the deceleration rate for vehicles with ABS is almost speed independent, while for vehicles without ABS speed affects the deceleration rate.

Figure 10 shows the differences between cars with and without ABS. From left to right the friction coefficient increases. The deceleration rate of a car without ABS is approximately 1-3m/s^2 lower than for a vehicle with ABS.

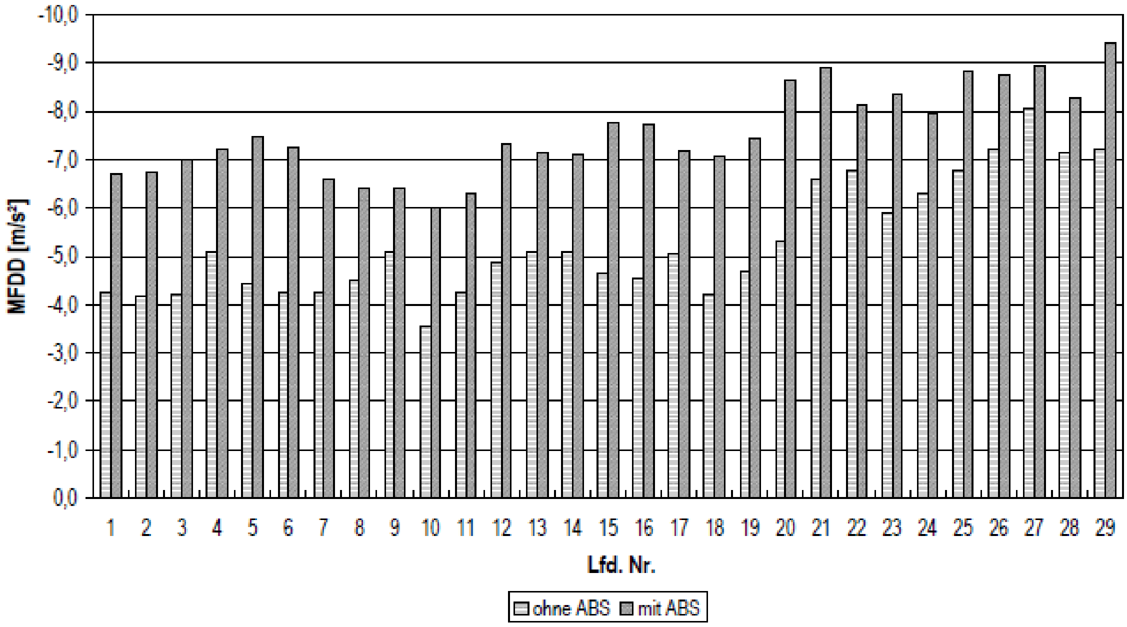

Figure 10: Deceleration rate with ("mit") and without ("ohne") ABS

Von Loeben (2004) also studied the relationship between the condition of the road surface and the deceleration rate, by carrying out braking trials. These trails were performed on several road stretches (with different friction coefficients), with different tyre (tread depths) and vehicle characteristics (vehicle type, with and without ABS). Also three water layer depths were included (0.3, 0.7 and 1.0mm).

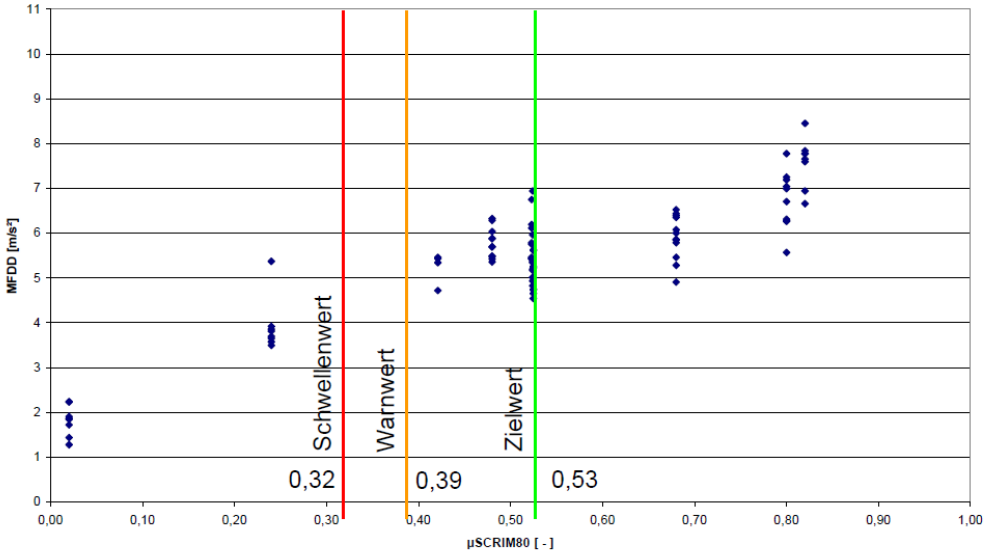

Figure 11: Deceleration as a function of friction coefficient

These results confirm the relationship between the friction coefficient and the deceleration rate: low friction coefficient (because of a poor road surface condition and/or the water layer depth), restrict the maximum deceleration rate.

Tyre characteristics
From the study from Van der Sluis (2002) the effect of the tyre quality (tread depth) on the deceleration rate can also be derived. Figure 12 shows this relationship.

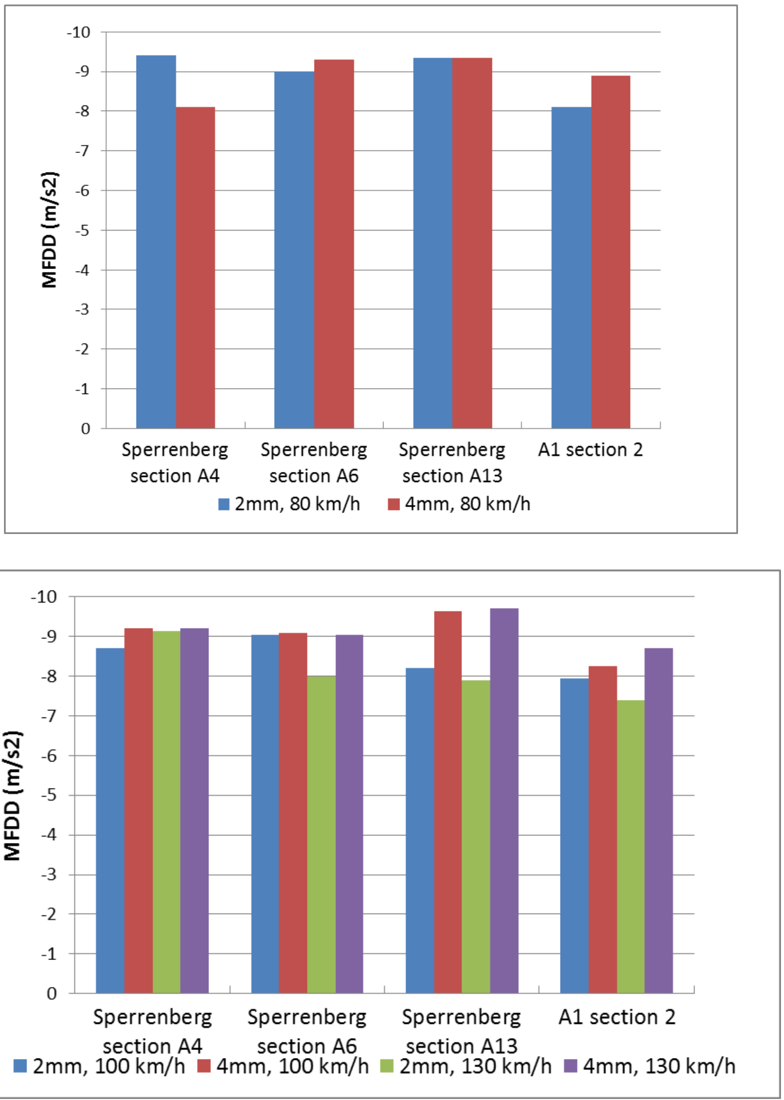

Figure 12: Relation between tyre tread depth and deceleration rate

The braking trials reported in Figure 12 were all carried out with the same car, equipped with ABS. The water layer depth was 0.5mm.

The effect of the tyre tread depth (2mm or 4mm) is relatively small at lower speeds. At higher speeds the effect is in the range of 0.5-1.5m/s^2 (5-15%).

Water layer depth

In the braking trials of Greibe (2007), the effect of the friction coefficient under dry and wet conditions on the deceleration rate was analysed (for different speeds). In this trial the water layer depth in wet conditions was approximately 1.3-1.6mm. The braking trials were only performed with cars equipped with ABS.

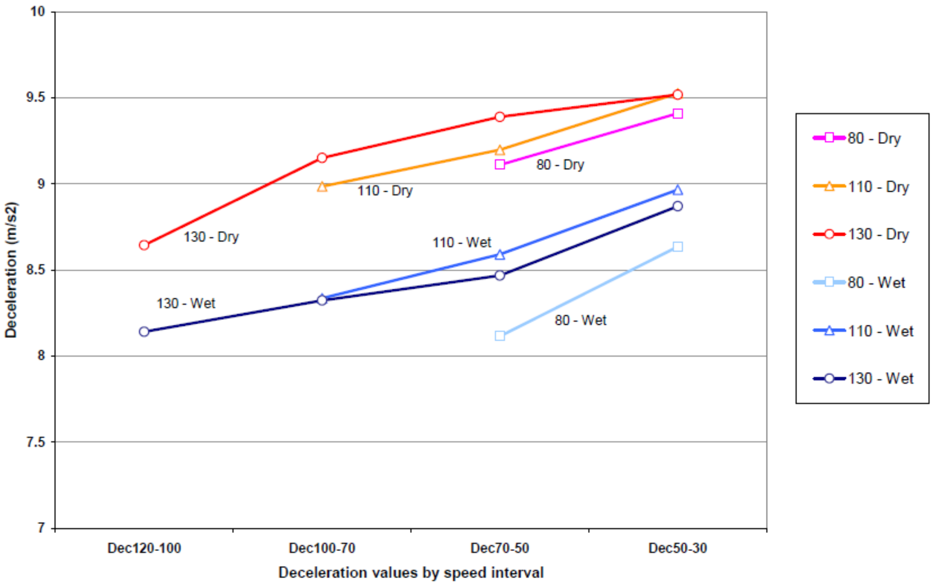

Figure 13: Difference in deceleration rate between dry and wet road surface

The figure shows that the deceleration rate is influenced significantly by the condition of the road surface (dry or wet); the deceleration is approximately 0.5-1.0m/s^2 higher on a dry road surface.

4.1.4 Distribution of Parameter Values

In the previous section the effect of road surface, car and tyre characteristics on the decelerations rates are described. This section deals with the distribution of the parameters and the appropriate parameters value choices regarding the stopping sight distance definition.

Water layer depth
In the quoted braking trials described in the previous section, deceleration rates were measured with different water layer depths:

- Von Loeben: 0.3, 0.7 and 1.0mm
- Greibe: 1.3 – 1.6mm
- Van der Sluis: 0.5mm

The water layer depth restricts the maximum deceleration rate, especially of cars without ABS. Figure 14 shows the relationship between the water layer depth and the coefficient of friction for several types of road surfaces (Welleman, 1977).

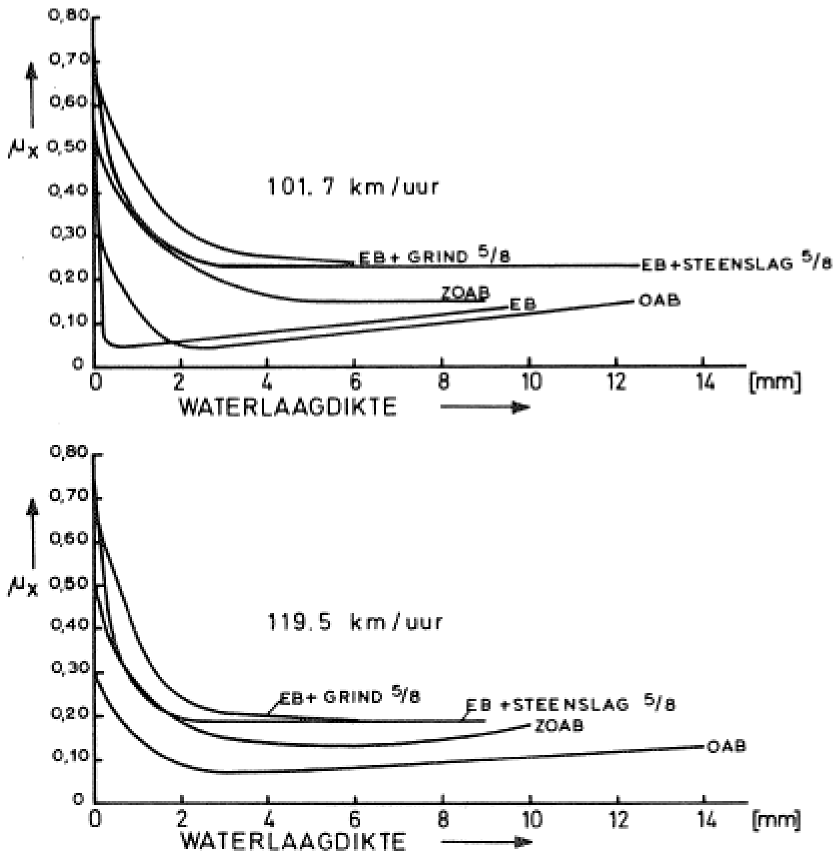

Figure 14: Friction coefficient as a function of the water layer depth ('waterlaagdikte')

The question is which water layer depth should be considered as a representative value in relation to the stopping sight definition?

The rainfall intensity is the most important factor influencing the water layer depth on the road surface (beside the road surface type). Rainfall patterns vary over the EU Member States.

With respect to the water layer depth, the most relevant indicator is not the daily precipitation, but the amount of rainfall in a short time period. The intensity of the rainfall, in relation to the drainage capacity of the road surface, determines the water layer depth on the road.

Because of the effect of climate change, the intensity of the rainfall is increasing in parts of Europe, especially in Nothern and Central Europe. This is shown in Figure 15 (EEA-JRC-WHO, 2008).

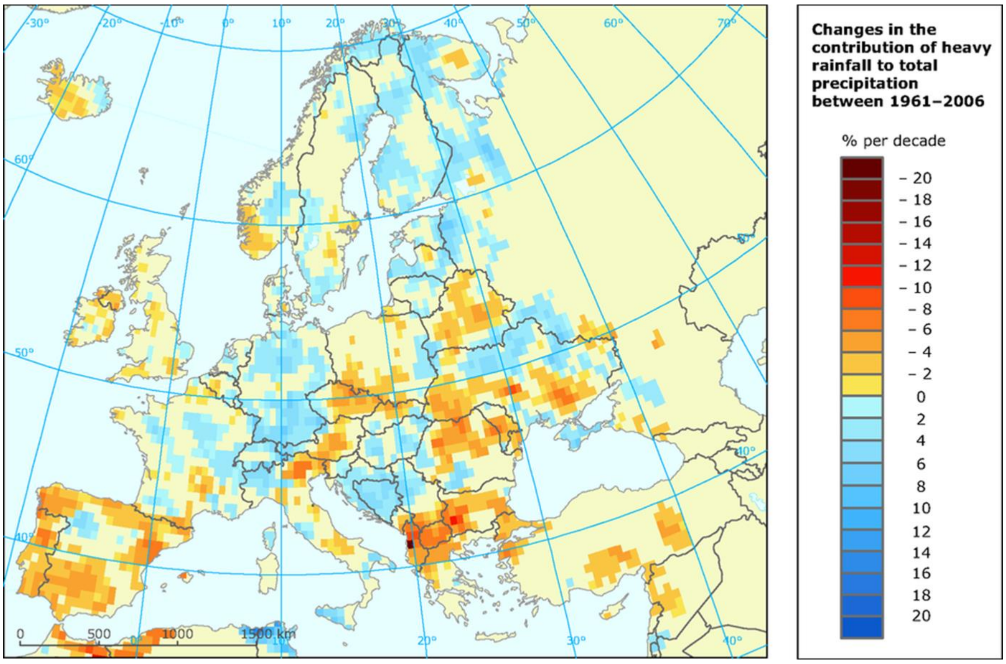

Figure 15: Changes in rainfall patterns

Figure 16 shows the change of the heavy rainfall in the Netherlands over the years (Lenderink & Van Meijgaard, 2008), showing an overall inceasing frequency of heavy rainfall.

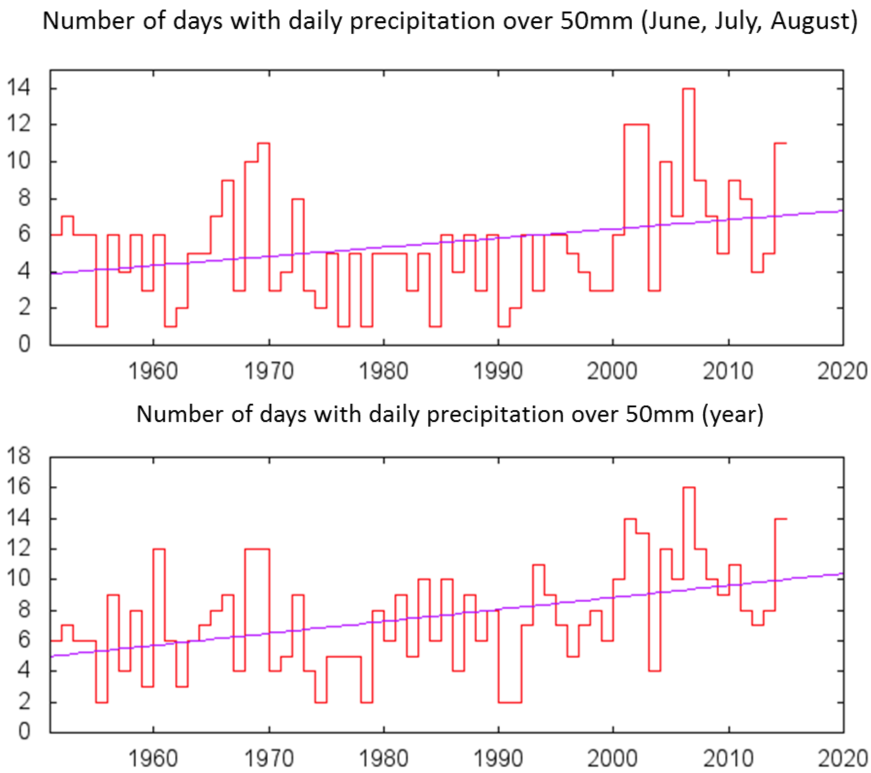

Figure 16: Number of days with precipitation over 50mm in the Netherlands

Because of the changes in precipitation patterns the Dutch Nation Road Authority (Rijkswaterstaat) has updated the standard rainfall curves for designing civil constructions (Malda & Terpstra, 2006). Figure 17 shows the updated curves.

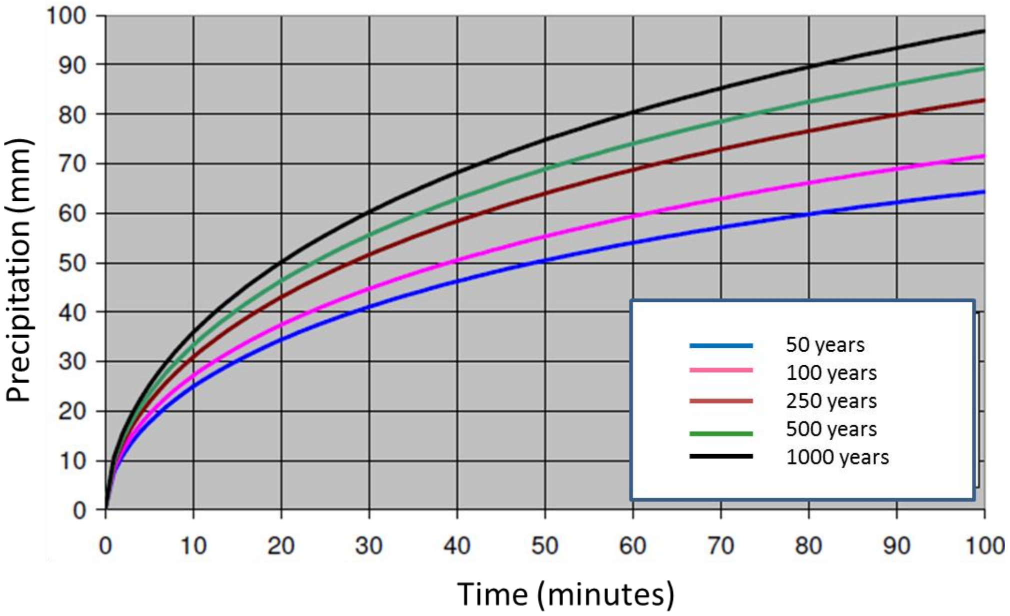

Figure 17: Precipitation curves for designing civil objects in the Netherlands

From the standard rainfall curve, the normative water layer depth should be calculated.

Figure 18 shows an example from Germany (Van der Sluis, 2002). The graph on the left gives the rainfall patterns of four weather stations. The horizontal axis of the graph on the right corresponds with the rainfall intensity, the vertical axis with the water layer depth (with a cross slope of 2.5%, a carriageway width of 10.5m and a closed asphalt surface).

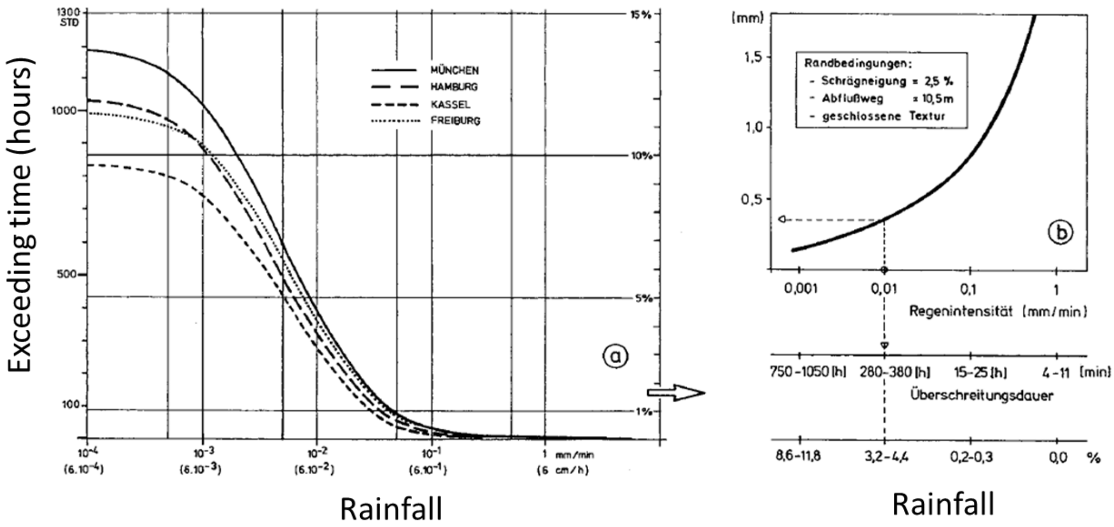

Figure 18: Water layer depth as a function of the rainfall intensity

In this example a water layer depth of 0.1mm is occurring approximately 10% of the time, a water layer depth of 1mm approximately 0.3% of the time.

Because the actual water layer depth on the road depends on many factors, it is not possible to determine a general representative water layer depth. However, because of the increasing intensity of the rainfall in many countries, it is recommended that deceleration rates are chosen that are on the conservative range of the distributions measured in the braking trials.

Despite the fact that countries in Southern Europe (Spain, Portugal and Greece) have a significantly lower annual precipitation level than Central and Northern Europe, in these countries short intense rainfall periods also occur. Therefore, it is not recommended to distinguish between the EU Member States with respect to the water layer depth.

Tyre tread depth
Similarly to the water layer depth, the tyre tread depth restricts the maximum deceleration rate. Two approaches are possible regarding the distribution of tyre tread depths:

1. The actual distribution of the tyre tread depths are considered;
2. The legal minimum tyre tread depths are used as a starting point.

There is very little information available of the distribution of tyre tread depths of vehicle fleets. Therefore, and also from traffic safety point of view, using the legal minimum tyre tread depths is the preferred parameter.

Commissioned by the Directorate General for Mobility and Transport of the European Commission, TNO and TML carried out a study on some safety-related aspects of tyre use (Jansen et al., 2014). This study contains a selection of tread depth legislation recommendations across the EU, obtained from questionnaires.

The results are indicative of the variety of legislation recommendation of tread depth for summer tyres and winter tyres respectively.

Country	Summer tyre Legal/recomm	Winter tyre Legal/recomm
Croatia	1.6/-	1.6/-
Denmark	1.6/2.5	1.6/2.5
Finland	1.6/4.0	3.0/5.0
Germany	1.6/3.0	1.6/4.0
Greece	1.6/-	1.6/-
Ireland	1.6/3.0	1.6/-
Italy	1.6/-	1.6/-
Netherlands	1.6/2.5	1.6/2.5
Poland	1.6/-	1.6/-
Spain	1.6/-	1.6/-
Sweden	1.6/3.0	3.0/-

Table 2: Tyre tread depth legislation/recommendations for passenger car tyres

The minimum legal tyre tread depth is in most countries 1.6mm; only Finland and Sweden have minimum tyre tread depths of 3.0mm for winter tyres. The recommended (minimum) values are in a range between 2.5 and 4.0mm.

Braking system: with or without ABS
ABS is becoming increasingly common on new vehicles. Due to a commitment by the European Car Manufacturers Association, all new cars have to be equipped with ABS from the middle of 2004. Since 2009 all new cars have also to be equipped with BAS (Brake Assist System).

This means that the share of vehicles equipped with ABS is increasing: within a limited period of time almost 100% of the vehicle fleet will have ABS.

The penetration level of vehicles with ABS will probably vary over the EU Member States. Countries with a relatively old vehicle fleet will have a lower share of cars equipped with ABS than countries with a relatively modern vehicle fleet.

The European Environment Agency (EEA) reports the average age of the EU vehicle fleet; Figure 19 shows the results (European Environment Agency).

- The average age of passenger cars decreased slightly from 8.8 years in 1995 to 8.2 years in 2009 while that of the two-wheeled vehicles decreased from 14.0 to 13.3 over the same period. The average age of light and heavy-duty vehicles has increased from 9.7 and 10.7 respectively to 11.7 and 11.5 over the same period.

- The average age of passenger cars in the EEA varies widely between countries. The lowest average age for the year 2009 was observed in Luxembourg (3.8 years), highest in Greece and Cyprus (14.6 years).
- The registration of new vehicles has increased over the same period, suggesting that the penetration rate of modern technologies is accelerating.

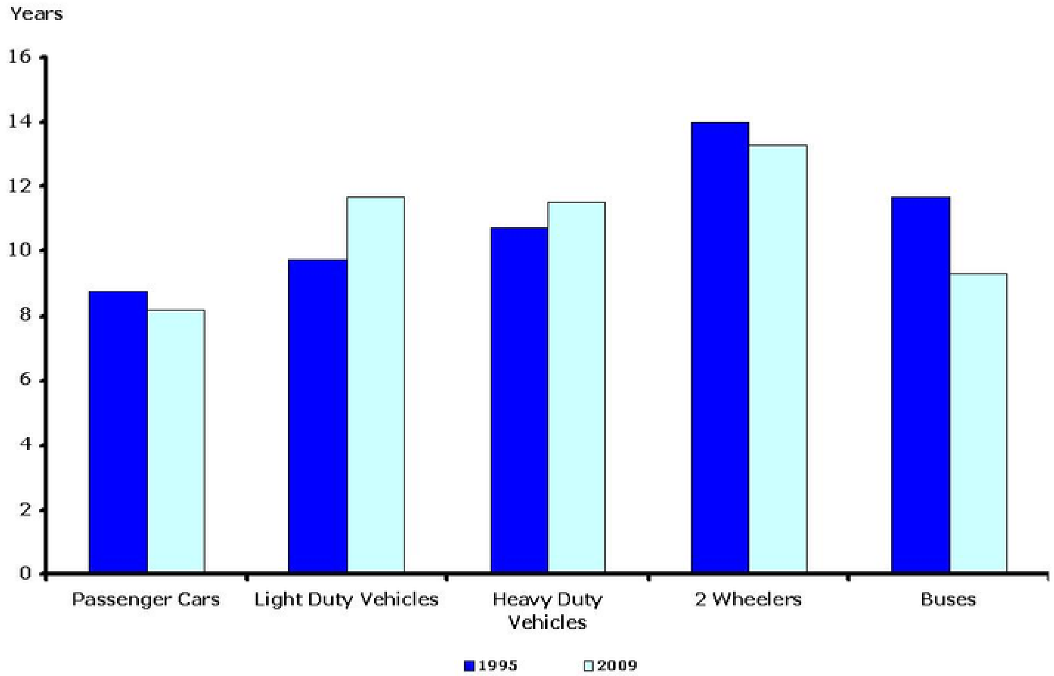

Figure 19: Average age of road vehicles in the EU in 1995 and 2009

The results are confirmed by the statistics published by the European Automobile Manufacturers Association; Figure 20 shows the average passenger car age for a number of countries in 2011 (Anfac).

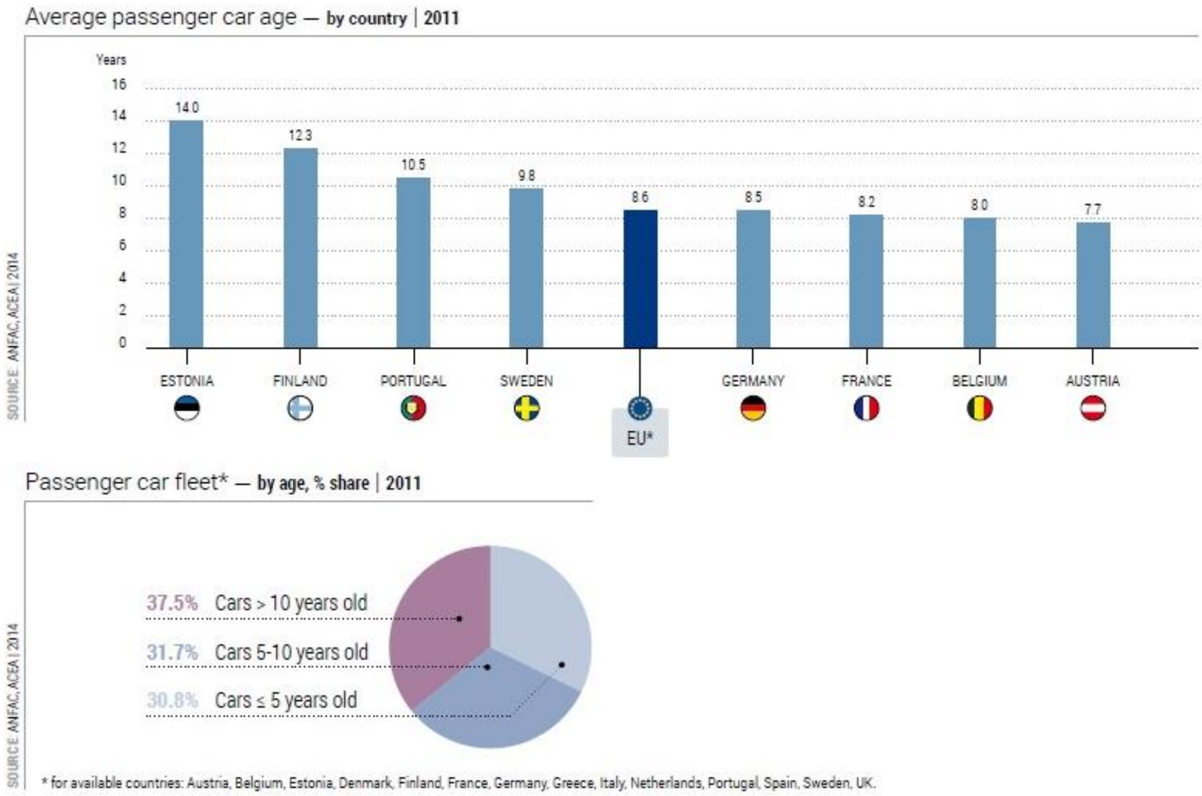

Figure 20: Average age of passenger cars in a number of EU-countries in 2011

This study also reports an average age of passenger cars between 8 and 9 years. From this study it can also be concluded that over 35% of the EU vehicle fleet is more than 10 years old.

This means that a significant share of the EU vehicle fleet will not be equipped with ABS; the SSD considerations will have to be based on vehicles not equipped with such systems.

Road friction coefficients
The friction coefficient of different road surfaces are measured with standard tests with fixed conditions. Because of the fixed conditions, the friction coefficient of different road stretches can be compared. One of the most commonly used tests is the Sideway-force Coefficient Routine Investigation Machine (SCRIM).

Figure 21 shows an example of the distribution of road friction coefficients (based on SCRIM) of a selection of German national roads (8687 road stretches) with road surfaces aged between 1 and 10 years (Van der Sluis, 2002).

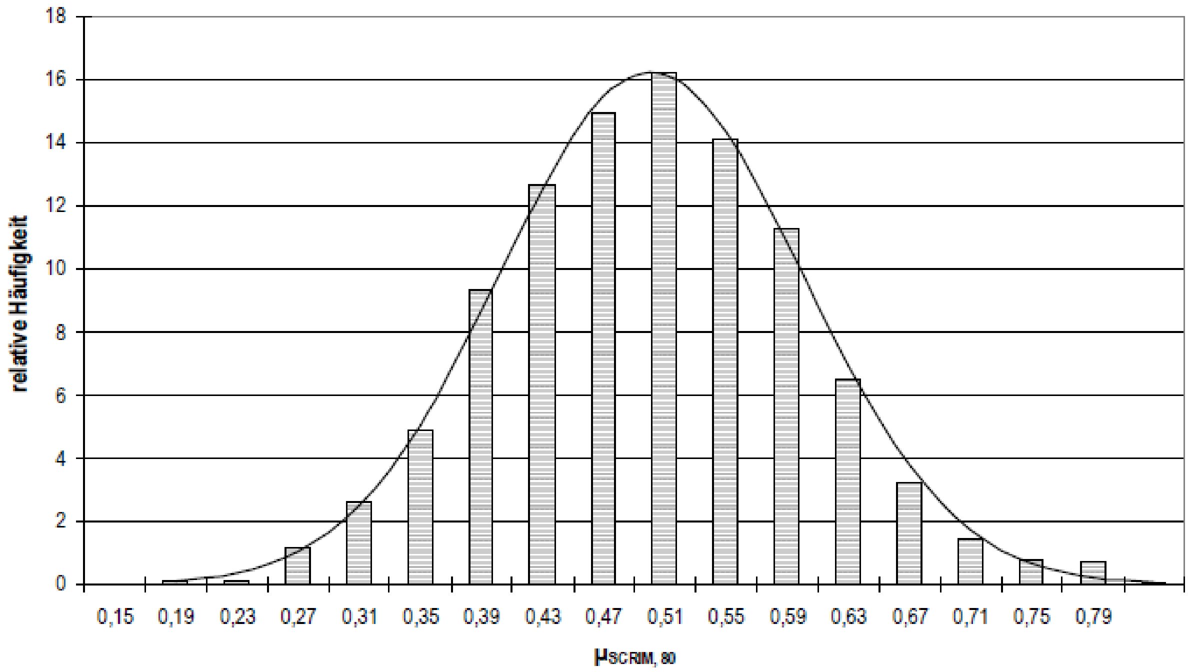

Figure 21: Distribution of friction coefficients of German Roads (Van der Sluis, 2002)

The set of measured fritcion coefficients has a normal distribution. The average friction coefficient is approximately 0.5. The share of friction coefficients smaller than 0.4 is about 10%.

A Dutch study on a methodology for policy changes regarding wet road road friction (Groenendijk, 2013), also contains a distribution of road friction of the National road network (2010-2011). Figure 22 shows the results.

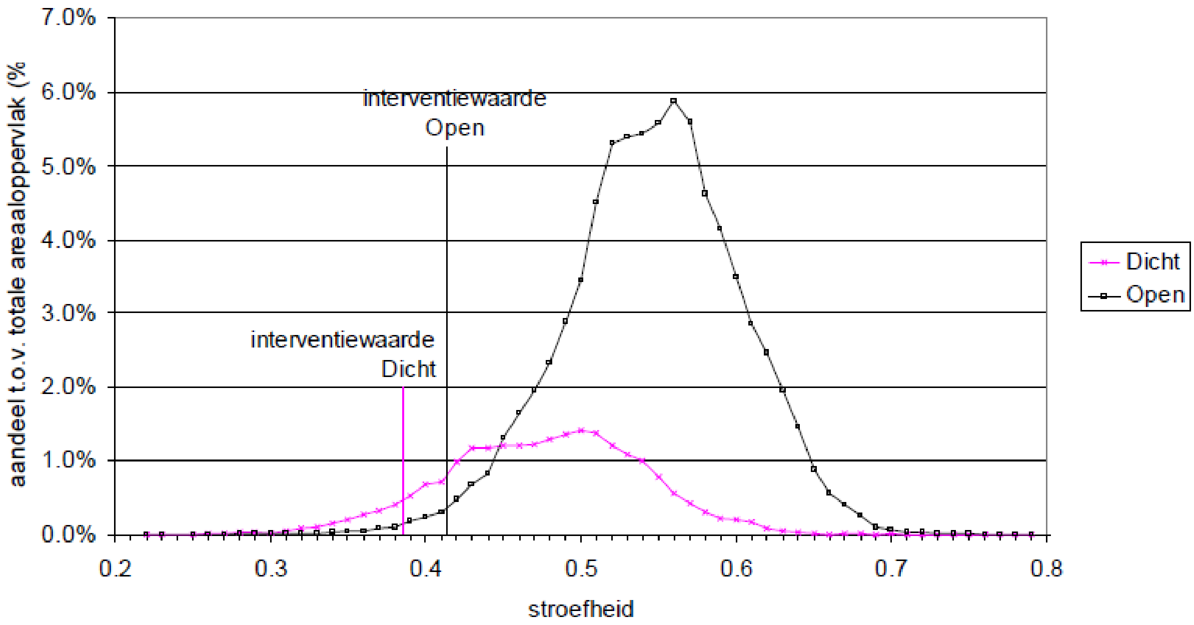

Figure 22: Distribution of friction coefficients of Dutch National Roads (pink: dense asphalt, black: open asphalt)

The avarage friction coefficient of the studied Dutch National road network with open asphalt is somewhere between 0.5 and 0.6.

The share of friction coefficients smaller than 0.4 is approximately 1-3% (for roads with open asphalt). For roads with a dense asphalt surface, the avarage friction coeffient is lower than for roads with an open asphalt layer. Also the share of low friction coefficients is larger compared to roads with open asphalt.

Note: Because of the different friction coefficient measurement procedures in Germany and The Netherlands, it is not possible to compare both distributions.

Beside the actual distribution of friction coefficients of roads, it is interesting to consider the minimum friction coefficients according to the guidelines and legislation of European countries.

Table 3 shows the minimum friction coefficients of a selection of European countries (Van der Sluis, 2002). The values in the fourth column refer to the situation of new road segments, the values in the last refer column to the maintenance requirements (the need for an overlay).

Country	*Test*	*Speed (km/h)*	*Minimum friction coeff. New road surface*	*Speed (km/h)*	*Minimum friction coeff. Maintenance*
Belgium	Odoliograph	80	0.45	-	-
Denmark	Stradograph	60	0.40	60	0.40
Finland	VTT friction lorry	60	0.60 (speed limit 120) 0.50 (speed limit 100) 0.40 (speed limit 80)	-	-
France	ADHERA	120	0.20	-	-
	SCRIM		-	60	0.45
Germany	SKM	80	0.46	80	0.32
UK	SCRIM	50	0.35	50	0.35
Netherlands	DWW-trailer	50	0.52 (100m value) 0.45 (5m value)	50	0.38
Norway	ROAR		0.50	-	-
Austria	SRM		-	60	0.45
Poland	SRT3		-	60	0.25
Sweden	Skiddometer	70	0.50	70	0.50
Switzerland	Skiddometer	40 60 80	0.48 (speed limit <60) 0.39 (speed limit <100) 0.32 (speed limit >100)	-	-
Spain	SCRIM	-	-	50	0.35

Table 3: Minimum road friction coefficients

Deceleration rates

The water layer depth, the tyre tread depth and the braking system come together in the the (maximum) deceleration rate. This section deals with the range of deceleration rates. The actual braking performance of drivers in practice is not considered in this section.

Figure 23 shows a schematic distribution of maximum deceleration rates. In cases where there is an unfavourable combination of water layer thickness, tyre tread depth and braking system, the maximum deceleration rate will be relatively low. In cases where there is a dry road surface, a high tyre tread depth and a vehicle equipped with ABS, the deceleration is high.

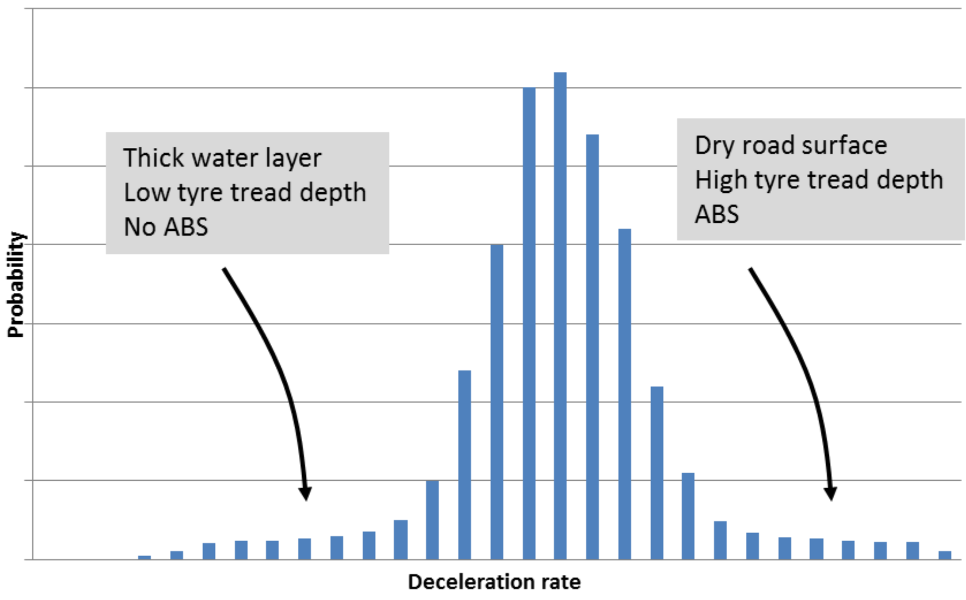

Figure 23: Schematic distribution of deceleration rates

To create insight into the actual values of the distribution of the deceleration rate, the results of the braking trials of Van der Sluis are summarized in Table 4. Because the worst case conditions are normative in the stopping sight distance definition, only the deceleration rates in these conditions are shown.

Water layer depth (mm)	*Tyre tread depth (mm)*	*ABS*	*Road friction*	*Initial speed (km/h)*	*Deceleration rate (m/s^2)*
0.5	4	No	0.315	80	4.52
0.5	4	No	0.323	100	4.24
0.5	4	No	0.725	100	5.91
0.5	4	No	0.719	130	5.31
0.5	2	No	0.315	80	4.52
0.5	2	No	0.323	100	4.24
0.5	2	No	0.327	130	3.55
0.5	2	No	0.725	100	6.31
0.5	2	No	0.719	130	4.71
0.5	4	No	0.355	80	5.08
0.5	4	No	0.362	100	4.88
0.5	4	No	0.363	130	5.08
0.5	4	No	0.274	80	4.24
0.5	4	No	0.278	100	4.19
0.5	4	No	0.278	130	4.20

Table 4: Deceleration rates in relation to the road friction coefficient, tyre tread depth and initial speed

On road stretches with low friction coefficients and a vehicle without ABS, the maximum deceleration rate is limited to values of about 3.5-4.5m/s^2.

4.1.5 Gradient

The gradient of a road influences the braking distance of a vehicle: an uphill slope decreases the braking distance, a downhill increases the braking distance. Figure 24 shows the effect of the gradient on the stopping sight distance (speed 120 km/h, road friction coefficient 0.37, perception-reaction time 2.5 sec). The difference in SSD between an uphill slope with a gradient of 7% compared to a downhill slope with the same gradient, is in the region of 60m.

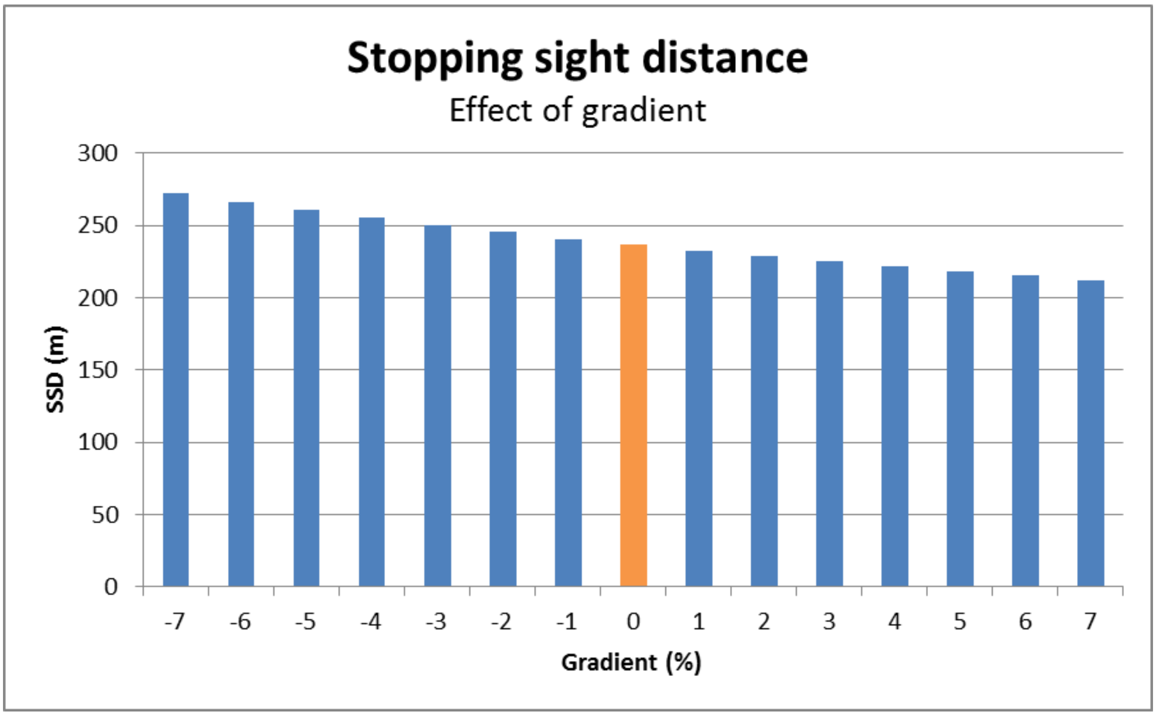

Figure 24: Effect of the gradient on the stopping sight distance

However, the distribution of gradients of roadway networks is not relevant in relation to the determination of the stopping sight distance parameters as the gradient is input by the road designer and is not a constant value in the guideline definition.

4.2 Sight distance

This section deals with the situations in which the view of a driver of an obstacle is restricted; restricted sight distance can be the result of geometric characteristics of the road and objects in the verge or median of the road. Because the (available) sight distance also depends on the position of the driver (both horizontal and vertical) in the cross section and the dimensions and position of the obstacle, relations with those aspects are also covered in this section.
First, sight obstructing conditions in the horizontal alignment are discussed, then those in the vertical alignment and finally those in the combined alignment.

4.2.1 Horizontal sight distance

4.2.1.1 Introduction

Sight obstruction in the horizontal alignment is caused by vertical objects in the verge or median of the carriageway in a horizontal curve. Examples of sight obstructing objects are:

- Guardrails
- Safety barriers
- Bridge parapets
- Tunnel walls
- Bushes
- Noise barriers
- Cuttings and side slopes

Figure 25 shows some examples of sight obstructions in the horizontal alignment.

Figure 25: Examples of sight obstructions in the horizontal alignment

4.2.1.2 Parameters

The roadway should provide an envelope of clear visibility. The way in which an object in the verge or median of the carriageway actually blocks the sight of a driver of an obstacle in the road depends on a number of parameters. Figure 26 shows the parameters that are related to sight obstructions in the horizontal alignment.

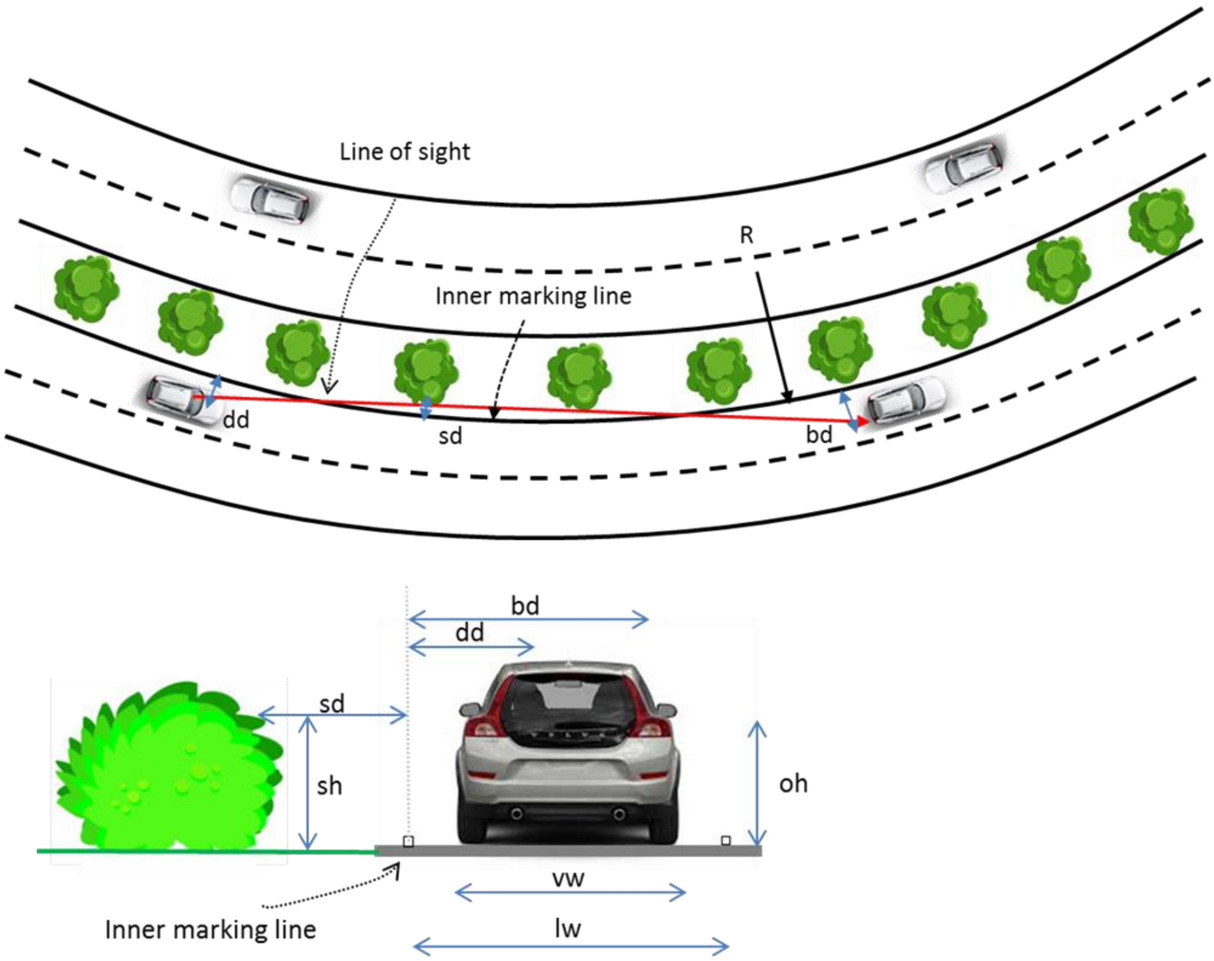

Figure 26: Parameters related to sight obstructions in the horizontal alignment

In this model the inner marking line is used as the reference: all horizontal distances are related to this reference. It is also possible to use the centre line of the carriageway as a reference.

The line of sight is the line between the horizontal (eye) position of the driver and the obstacle. In this example the obstacle is represented by the outer brake light of a car. The available sight distance (SD) should be at least equal to the stopping sight distance (SSD).

The following parameters affect the available sight distance:

- The combination of the radius (R) of the curve and the distance to the sight obstructing object (sd).

- The horizontal position of the driver in the cross section, indicated with dd. The distance dd is (indirectly) determined by the lane width and the vehicle width.
- The position of the obstacle (bd) in the cross section.
- The height of the sight obstructing object (sh) in relation to the height of the obstacle (oh) and the driver eye height (dh).

The relationship between the parameters in the last bullet are illustrated in Figure 27.

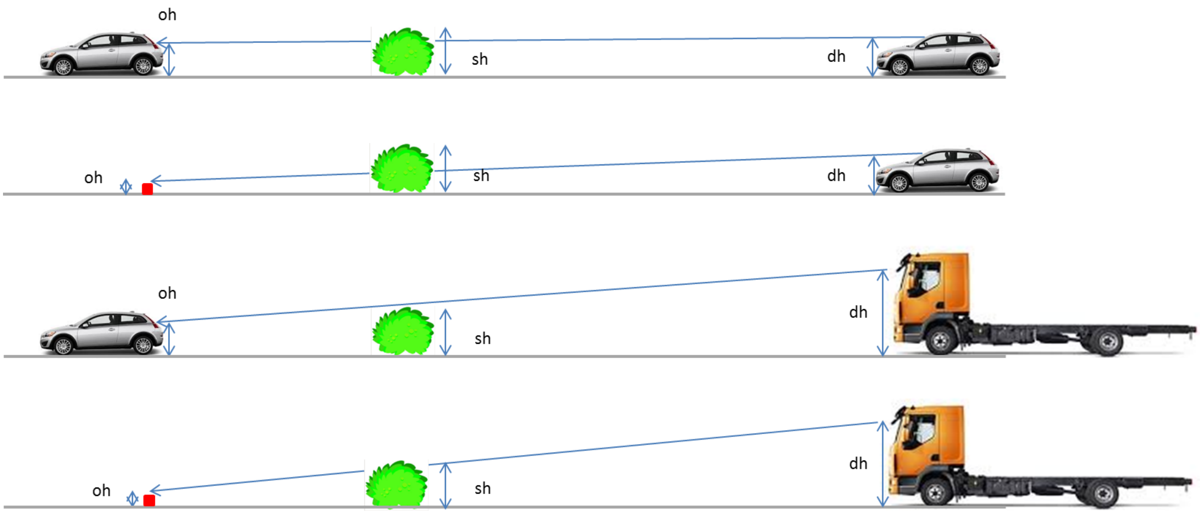

Figure *27: Relationship between driver eye height, obstacle eye height and sight obstruction*

Figure 27 contains four combinations of the driver eye height and obstacle height. In the case of relatively large eye and obstacle height, the driver is able to see over the top of the sight obstructing object (the third parameter).

From this figure it can also be concluded that the besides the height, the position of the sight obstructing object is of relevance as well; if the sight obstructing object were positioned closer to the obstacle, then it would not block the driver's sight of the obstacle in the two bottom situations.

The length of the road stretch with a sight obstruction and shortage of the necessary sight distance (the difference between SD and SSD), is the result of the combination of all the factors mentioned above.

Figure 28 shows an example of the available sight distance (black bars) and the stopping sight distance (red line) along an alignment, calculated with a sight distance evaluation model (V&W, 2001).

The vertical axis represents the sight distance in meters (SD and SSD) and the horizontal axis the station along the alignment.

In this example the alignment contains a road stretch with a shortage of the available sight distance; from station 2250 to station 2700 the shortage of the sight distance is approximately 10 meters. The sight obstruction is caused by the tunnel wall (see Figure 29).

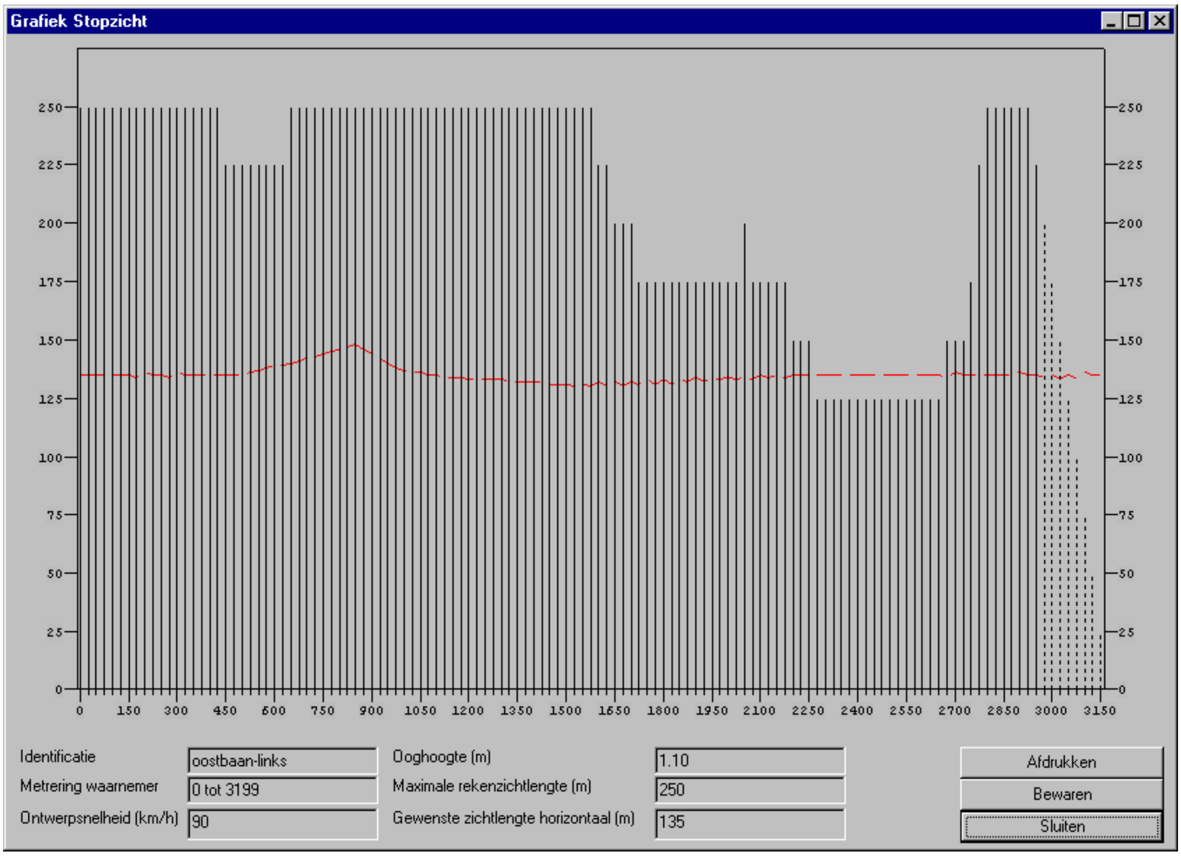

Figure 28: Example of sight distances (black bars) and stopping sight distance (red line)

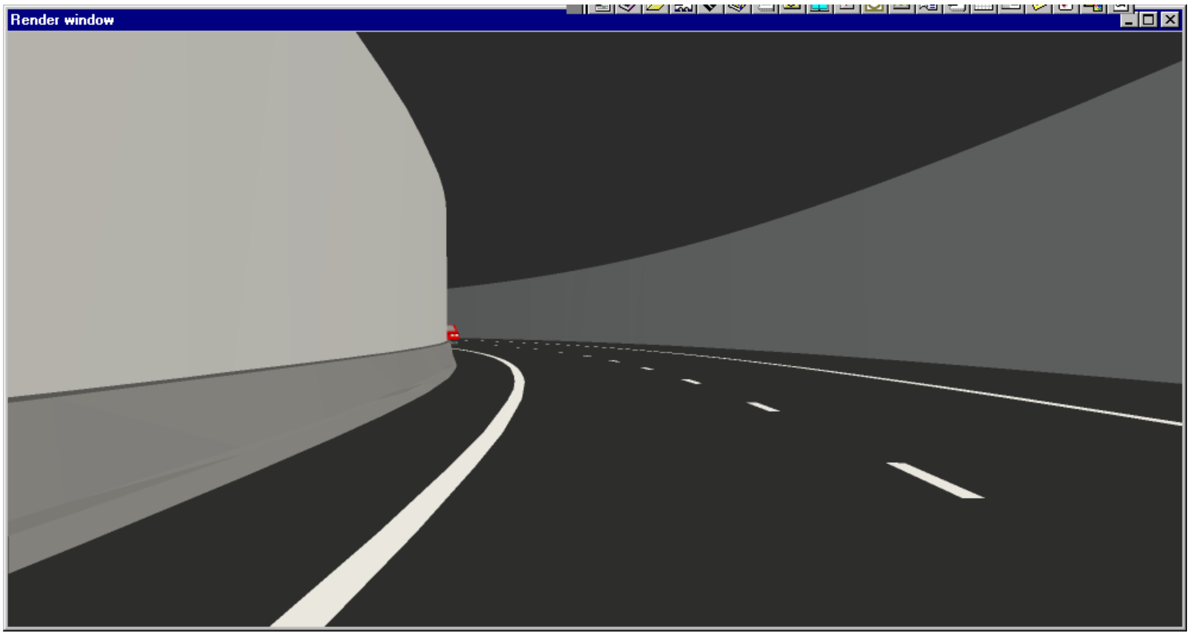

Figure 29: Obstacle 170m ahead of the driver (station 2200)

4.2.2 Vertical sight distance

4.2.2.1 Introduction

Sight obstruction in the vertical alignment is caused by too small a radius of a vertical curve. Figure 30 shows an example of a situation in which the visibility of the downstream road stretch is restricted by the radius of a crest vertical curve.

Figure 30: Sight obstruction caused by the radius of a crest vertical curve

For sag and crest vertical curves, the normative conditions in relation to the sight distance are different:

- If an overhead construction is placed in a sag vertical curve, e.g. a bridge, the construction may restrict visibility on a downstream obstacle.
- Adequate sight distance needs to be provided over crests to allow drivers to see a downstream obstacle.

4.2.2.2 Parameters

Figure 31 shows the parameters that are related to the available sight distance in vertical curves.

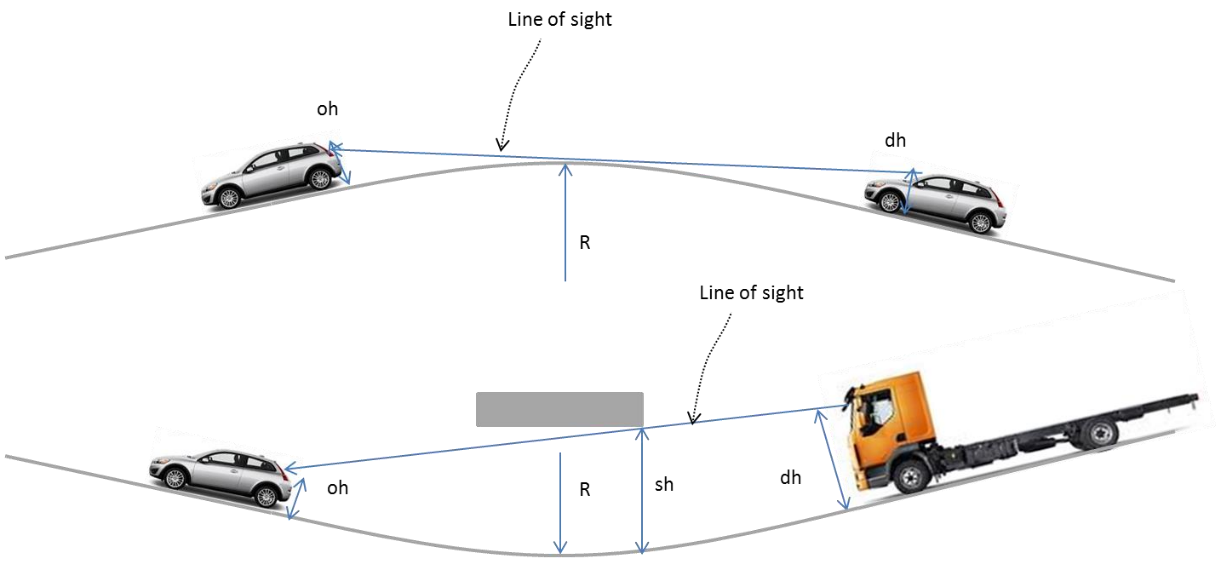

Figure 31: Sight distance parameters in relation to the vertical alignment

For both crest and sag vertical curves, the driver eye height (dh) and the obstacle height (oh), in this figure represented by the brake light, are relevant for the available sight distance. In the case of a crest vertical curve the eye height of a car driver is normative (a relatively low eye height); in the case of a sight intrusing object above a sag vertical curve, it is the eye height of a truck driver.

In crest vertical curves a higher obstacle height leads to a longer sight distance, in a sag vertical curve a lower obstacle height leads to longer sight distances.

For both crest and sag vertical curves a smaller curve radius (R) leads to a shorter sight distance. A relatively small overhead clearance (sh) in a sag vertical curve increases the chance of a sight obstruction.

4.2.3 Combination of horizontal and vertical sight distance

On road stretches where a horizontal and vertical curve are combined, the available sight distance is not equal to the the minimum sight distance based on the horizontal or vertical curve.

Figure 32: Example of combination of horizontal and vertical sight distance obstructions

In these situations the available sight distance needs to be calculated simultaneously for the horizontal and vertical curve. Because of the complexity of the calculation, this can be done best aided with a software evaluation tool that uses a 3D CAD-model.

For calculations for combined horizontal and vertical curves all the parameters that are relevant for the horizontal and vertical alignment are incorporated.

4.3 Driver eye height

Values
For the crest situation, most guidelines that were reviewed in WP2 (Van Petegem et al., 2014) specified a 1.00 to 1.10 m eye height above the road surface. For sag situations, when specified, a value of 2.0 to 2.5 m was given (trucks).

Capaldo (2012) reported experimental measures comparing actual (Italian) driver eye height with the standards of the Italian government. By cross examination of pictures, taking measurements from scale sketches and a fleet from 2004 to 2011, they were able to establish that the average driver eye height (125cm), as well as the 15th percentile of the data distribution (117cm), was higher than the value indicated by Italian standards (110cm). They sampled 200 passenger car drivers (35% women, 65% men), using a confidence interval of the mean of the Gaussian random variable at 95% with a probable error of

1.25cm. In a second experiment they used scale layouts of 70 passenger cars. In these layouts the height of similar features compared to the first experiment were measured.

Characteristic values	Men	Women	Total	Layouts
Mean	126.54	122.53	125.19	132.11
Standard Dev. Pop.	9.39	6.81	8.81	10.71
Standard Dev. Sample	9.43	6.86	8.84	10.81
Variation coefficient	0.07	0.06	0.07	0.08
10^{th}Percentile	117.09	116.01	116.44	120.35
15^{th} Percentile	118.40	116.85	117.81	123.62

Table 5: Characteristic distribution values (height in cm) (from Capaldo, 2012)

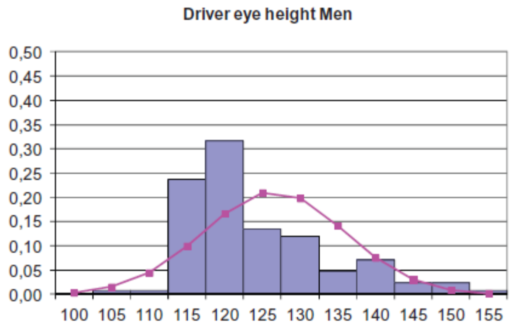

Fig. 7. Driver eye height men (cm)

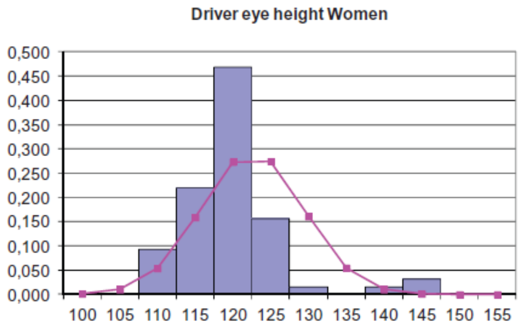

Fig. 8. Driver eye height women (cm)

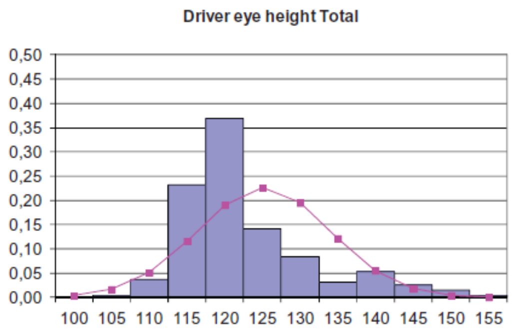

Fig. 9. Driver eye height total (cm)

Figure 33: Figures from Capaldo (2012) illustrating the distribution of driver eye height for men and women in Italy

A strong correlation ratio (0.82) between car height and driver eye height has been found (Capaldo, 2012). This means passenger car height can be considered a good parameter to estimate driver eye height. Dutch guidelines (Schermers et al., 2014) report passenger car height to be as follows:

	Average	Standard deviation	1%	5%	95%	99%
Passenger car height	1.63m (max 4m)	0.06	1.49	1.51	1.73	1.77

Table 6: Dutch guideline values of vehicle height

Fitzpatrick and collegues (1998) report an 1.08m driver eye height as the 10th percentile eye height for passenger car drivers in the USA. Note that this is considerably lower than the values presented above.

Guidelines
Values for different countries and differences among EU member states were reported in the literature review from WP2.1. The values reported from the guidelines are included below, extended with the values of a few other countries as reference.

Country	Driver eye height (observation point height)			Observed point height (obstacle height)		
	flat	Crest curve	Sag curve	flat	Crest curve	Sag curve
Denmark	1.0m	1.0m	2.5m	-	0.5m	0.5m
France	-	1.0m	-	-	0.6m	-
Germany	-	1.0m	-	-	1.0m	-
The Netherlands	1.1m	1.1m	-	0.5m	0.5m	-
Switzerland		1.0m	2.5m		0.15m	
United Kingdom	-	1.05m-2.00m	-	-	0.26m-2.00m	-
Austria*		1.0m				
Italy*, Sweden*		1.10m				
United States*		1.08m				
Canada*, Australia*		1.05m				
Japan*, Israel*		1.20m				

Table 7: Driver eye height and observed eye height per country, differentiated by vertical alignment characteristics (* from Capaldo, 2012)

Most countries take the driver eye height into account when checking the SSD in crest curves. No separate driver eye heights are mentioned for flat roads, where the driver eye height can be considered equal to the driver eye height in curves. Denmark and Switzerland specifically take the driver eye height of truck drivers into account at sag curves where tunnels or other vertical elements can block the vield of view of truck drivers. Ireland and the UK also take this situation into account, prescribing a check on the envelope of visibility from a driver eye height of 1.05m to 2.00m.

Further differences can be found in the way that road designers are prescribed to check the SSD for horizontal and vertical curves. Most of the guidelines provide designers with graphs and or formulas to check the SSD in curves. The combinations and used formulas and figures can differ however. Some also mention the checking of the alignment as a whole, taking changes in the horizontal and vertical alignment together into consideration. However, no tools or methods to do so are considered or prescribed.

Future developments
Stature (natural height in standing position) has increased throughout the period between 1950s-1980s in all countries in Europe. Growth in the southern European countries was larger than their Northern counterparts (whose residents were taller to begin with) (Garcia & Quintana-Domeque, 2007). Schönbeck and colleagues (2012) found that the height of Dutch children has stopped increasing in studies running from 1950s to 2009. Gohlke and Woelfle found a similar end of a trend of ever taller people (Gohlke & Woelfle, 2009)

Capaldo notes from their studies with vehicle layout pictures of current vehicle models, the changes of the vehicle height during five years (less than 1%) is not very large and may be due to variability of the random sample.

Conclusions
Values from Italy indicate that the eye height of more than 90 % off all drivers is higer than 1.16 m. Based on this result, setting drivers eye height to less than 1.16 m gives a conservative value.

People tend to get taller in Europe (altough the trend seems to be ending), even more so in southern Europe, whose inhabitants count among the smallest in stature in Europe anyway.

Vehicle height seems to be constant over the last few years, although there has been in increase in variation with SUV’s and other high seated vehicles. They have increased height which means their popularity is no reason to decrease driver eye height in the guidelines.

4.4 Obstacle definition including height

Values
Layton and Dixon (2012) report an appropriate obstacle height of around 450-600mm. At this height obstacles become dangerous to passenger vehicles (cattle, deer, other traffic).

In the literature review (Van Petegem et al., 2014), a height of 0.5 m has been identified as a traditional value for the ‘box’. This can be considered as the worst-

case situation. Smaller dimensions are considered to be irrelevant from a safety perspective because drivers will not initiate an emergency brake manoeuvre: a vehicle can drive over them without colliding, or they do not have sufficient mass to cause severe damage.
Visibility of the 'box' depends on the lighting (daylight/darkness) conditions, luminance, contrast and reflectiveness of the object. Weather (rain as well as sunshine) may influence these parameters.

Hall and Turner (1989) expressed their concerns about using a 6 inch (0.15m) obstacle in the criteria. Determining that at a distance of 600ft (180m) the obstacle should be 3.5 times larger (52.5cm) to be visible for a driver with 20/40 static visual acuity. "The small probability of a collision with objects of this size suggests that we may be designing for an event that almost never occurs". They also expressed concerns for merely measuring possibility of perception of the top of the object. Recognizing the obstacle requires more than being able to see the top of the obstacle.

Guidelines

Country	Obstacle	Observed point height (obstacle height)		
		flat	Crest curve	Sag curve
Denmark	-	-	0.5m	0.5m
France	Where the observed point concerns a vehicle, the observed point is the most effortlessly perceived of the two rear lights	-	0.6m	-
Germany	Stopping lights of a light vehicle	-	1.0m	-
Ireland	-	-	0.26m-2.00m	-
The Netherlands	The outer braking light on the inner lane	0.5m	0.2m (static) 0.5m (congestion)	-
Switzerland	-	-	0.15m	-
United Kingdom		-	0.26m-2.00m	-

Table 8: Obstacle definition and height per country, differentiated by vertical alignment characteristics

4.5 Brake performance (behaviour)

Values
In a study using an instrumented vehicle approaching a mock-up resembling a stopped vehicle (Van der Horst, 1990), maximum deceleration levels reached were around $6.5m/s^2$ for an initial speed of 30 km/h rising up to $7.5m/s^2$ when driving at 70 km/h. The results suggested that drivers followed a "constant minimum Time-To-Collision" strategy more than a "constant deceleration" strategy. Kusano and Gabler (2011) reported an average braking deceleration of 0.52 g's. It should be noted that all these manouvres ended in a collision, meaning that the braking was too little or too late. Fambro and colleagues (2000) found differences in individual driver performance in terms of maximum deceleration. They report that drivers generated maximum decelerations from

6.9 to 9.1m/s^2. The equivalent constant deceleration also varied among drivers. Based on the 90km/h data, 90 percent of all drivers without ABS chose equivalent constant decelerations of at least 3.4m/s^2 under wet conditions, and 90 percent of all drivers with ABS chose equivalent constant deceleration of at least 4.7m/s^2 on dry pavements. See Table *9* and Table *10* for the values Fambro et al. (2000) reported.

	Equivalent Constant Deceleration (g)		
	Study 2 ABS	Study 2 No ABS	Study 3 No ABS
Mean	0.63	0.62	0.55
75th	0.50	0.49	0.43
90th	0.42	0.42	0.37
95th	0.38	0.38	0.32
99th	0.28	0.29	0.24
AASHTO*	0.30	0.30	0.30

Table 9: Percentile estimates of equivalent constant deceleration to an unexpected object (Fambro et al., 2000)

	Equivalent Constant Deceleration (g)		
	Study 2 ABS	Study 2 No ABS	Study 3 No ABS
Mean	0.55	0.49	0.45
75th	0.46	0.44	0.36
90th	0.40	0.41	0.31
95th	0.37	0.39	0.27
99th	0.30	0.35	0.21
AASHTO*	0.30	0.30	0.30

Table 10: Percentile estimates of equivalent constant deceleration to an expected object (Fambro et al., 2000)

More information about driver braking behaviour is provided in the EUSight Driving Experiment Report, D5.2 (Broeren & Wools, 2015). The driving experiments showed that in situations which require immediate response and a significant decrease of speed (at least 40 km/h), a typical maximum deceleration rate of 3-4 m/s^2 was found. Only in situations with short times-to-collisions short peaks of higher deceleration rates up to 6 m/s^2 and higher were noted.

Guidelines
There are no values in the guidelines with respect to drivers braking behaviour except for the effects of friction on ranking itself.

Future developments
More and more cars will be equipped with better brakes, ABS, emergeny braking systems (AEB) etc. These systems will improve braking behaviour and therefore possibly shorten SSD. It will however still take some time before the entire fleet will be equipped with these systems. Especially the brake assist systems and

warning systems will improve braking behaviour from the drivers perspective as they will help the drivers brake maximally and respond earlier to emergency situations.

4.6 Perception reaction time

4.6.1 Perception reaction time

Values
In human factors research, PRT is classically measured using observed behaviour, taking the reaction time of the 85th percentile driver as 'the' reaction time (meaning that 85% of the drivers are able to react within that time). In the UK, SSD is based on a driver perception reaction time of 2 seconds. The American Association of State Highway and Transportation Officials recommends to use a PRT of 2.5 seconds (AASHTO, 2001, 2011).

Sohn and Stepleman (1998) recommended to use the 85th or even the 99th percentile value. In a a meta-analysis they concluded that that a PRT value of 1.92 s would be more appropriate (USA model, 85th percentile). See Table 11 for an overview of values found in different studies for the 85th and 95th percentile.

Study	85th Percentile (s)	95th Percentile (s)
Gazis et al.	1.48	1.75
Wortman et al.	1.80	2.35
Chang et al.	1.90	2.50
Sivak et al.	1.78	2.40

Table 11: Perception reaction time studies reported by Layton and Dixon (2012)

Green (2000) examined various factors that influence PRT: expectation, urgency, age, gender and cognitive load. He found expectation to be the dominant factor. He stated that with high expactancy and little uncertainty, the best PRT is about 0.70 - 0.75s. With normal signals such as brake lights, expected times are about 1.25s. For surprise intrusions, he reported 1.5s.

Other research shows that the current guidelines might be on the conservative side. Layton and Dixon (2012) give an overview of different studies checking the validity of the PRT of 2.5 seconds for the 85th percentile and report four studies that find lower reaction times, which supports the claim that 2 or 2.5 seconds is conservative (see Table 12).

	BRT (ms)	MT (ms)	PRT (ms)
Aware	4200 (1)	180 (2)	1300 (5)
	360 (2)		1290 (3)
			550 (4)
Partially Aware	390 (2)	175 (2)	1100 (5)
			632 (4)
Unaware	6300 (1)	170 (2)	1360 (3)
	420 (2)		739 (4)
			650 (5)
Young	350 (2)		2330 (6)
Mid-Age	390 (2)		
Older	430 (2)		2450 (6)

Table 12: Summary of driver response times from the literature review for driver factors (times are presented as mean in ms; source: Layton and Dixon, 2012)

(1). van der Hulst et al. (1999); slow deceleration condition.
(2). Warshawsky-Livne and Shinar (2002).
(3). Sohn and Stepleman (1998); 85th percentile non-US data.
(4). Schweitzer et al. (1995); 50 mph (80 kph) with 12 m gap condition.
(5). Dingus et al. (1998).
(6). Warnes et al. (1993); no warning or distraction condition.
BRT = brake reaction time; MT = movement time; PRT = Perception Reaction Time.

Durth & Bernhard (2000) showed that all drivers in their field study were able to stop in time within a total stopping time (prt + time elapsed while braking) of 2.0s. As a matter of fact the 95th percentile was below 1.8s, but as the researchers point out, these were drivers that participated in an experiment and may therefore have been more alert than ‘normal drivers’.

Guidelines

Table 13 provides a summarised comparison between countries of perception reaction time and the associated SSD. From these tables it is evident that there is some (small) amount of variation on SSD characteristics among these countries.

Country	Perception – Reaction time (s)	Stopping Sight Distance (SSD) (m)								
		50 km/h	60 km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h	120 km/h	130 km/h
Denmark	2	54	71	90	111	134	160	187	217	248
France	2	50		85		130		195		280
Germany	2	54	71	90	111	134	160	187	217	248
Ireland	-	70 50 50	90 70 50	120 90 70	160 120 90		215 160 120		295 215 160	
The Netherlands	Variable by design speed	60 (1.5s)			105 (2s)		170 (2.25s)		260 (2.5s)	
Switzerland	2		62		100		147		208	
United Kingdom (85 km/h instead of 80 km/h)	-	70 50	90 70	120 90	160 120		215 160		295 215	

Table 13: Stopping Sight Distance and Perception-reaction times per country

From Table 13 it can be seen that most countries prescribe a fixed perception reaction times of 2s. The Dutch guidelines deviate from other countries by prescribing different PRTs for different design speeds. Looking at the SSDs it can also be seen that the differences between the SSDs for most countries are small, except for Ireland and the UK where the preferred SSD requirements are about one third higher than for the other countries. Overall though there is a consensus about what the SSD requirements are. Taking into account that the oldest guidelines from this selection are the Swiss guidelines which are dated at 1983, it can be concluded that these requirements have not changed much over time.

The design guidelines in Ireland follow for the most part the UK design guidelines. Both countries recommend higher minimum SSDs than other countries. However the Irish and UK guidelines provide road designers with two steps of relaxations of the SSD. One step down resulting in equal SSDs compared to other European countries and two steps down being considerably smaller than the minimum SSDs from other countries. As the guidelines do not provide a background on the SSD design values, the differences cannot be explained based on these guidelines.

4.6.2 Situational complexity

Forbes et al. (1958) found that in tunnel downgrades, right curves, lower illumination, and psychological constriction flow tended to reduce, which they explained (deducing from photo material) by a larger time headway (THW, i.e. the time gap between the vehicle and and a lead vehicle) and more THW variations. This means that drivers drove with a larger gap between themselves and the cars in front of them and changed their relative speed (compared to predecessors). It seems that drivers do experience these situations differently and try to adjust their behaviour to compensate for the difference. A larger time headway suggests that drivers find the situation complex, difficult or dangerous and leave a larger gap to increase safety or decrease difficulty or give more time to deal with the complexity.

4.6.3 Obstacle visibility

In the NCHRP report 400 (Fambro et al., 1997), a commentary on the British and American design guidelines can be found. These guidelines state that an object is visible at the moment the top of the object comes into view. Hills comments that it is the part of the obstacle above the *object cut off height* that the drivers respond to, which is the portion of the obstacle above the defined obstacle height. Furthermore, he reports that obstacles with the same height but with different size and contrast are not equally visible. Therefore he concludes that line of sight should not be equated with visibility. Other factors influence visibilty next to height and size. For example, luminuance contrast, color contrast, ambient luminance level and glare. This makes visibilty of the object both an important and a complicated factor to take into account. But also the static visual acuity of driver should be taken into account. Sometimes 20/40 (Hall and Turner, 1989) and sometimes 20/20 (normal daylight vision) (Swedish Design Standards) static visual acuity are used.

The Swedish Design Standards (Trafikleder Pa Landsbygd, 1986), for example, define both the height and the angle to the road. Using the formulas of the Swedish Design Standards, some conclusions are reported in the NCHRCP report: 100mm of an obstacle must be above the line of sight to detect it at a distance of 65m. At 130m, 200mm must be above the line of sight. Germany used an object height that varies with design speed from 0.0m at low speeds to 0.45m at high speeds (Fambro et al., 1997) in earlier guidelines, but not in the current.

Visibility influences the time drivers need to interpret what kind of obstacle they see (or whether they see an obstacle at all or just a patch on the road). Therefore perception reaction time is influenced by obstacle visibility. The many factors playing a role in visibility have probably been the reason why there is little information on obstacle visibility in the guidelines.

4.6.4 ADAS

Abe and Richardson (2004) studied the effect of different alarm timings of forward collision warnings on the braking response of drivers. This study showed that an early alarm (0.05 s after the leading vehicle brakes) reduced the braking response by 0.25s. Alarms at 0.64 and 0.99 s did not result in a shorter braking response. In addition, Abe and Richardson (2005, 2006) found that speed and THW of the leading vehicle also influences braking response to forward collision warnings with different timings. Jamson, Lai and Carsten (2007) found that in unexpected events the brake reaction time went down from 6.1s to 4.8s. However, in case of expected events there was no significant effect of Forward Collision Warning systems (FCWs) on the brake reaction time.

Opposite to FCW, Adaptive Cruise Control (ACC) may increase brake reaction times, since the attentional level of drivers reduces. ACC is an extended version of cruise control that can also keep a constant distance to a car driving in front of the driver's own car. Rudin-Brown and Parker (2004) measured brake reaction times of drivers with and without ACC. When drivers were in control their brake reaction time 2s, while with ACC this was 2.6s and 2.8s for respectively time headways of 1.4s and 2.4s. Also Young and Stanton (2007) concluded that braking reaction times were substantially longer when using automated systems, drivers were about 1.0-1.5s slower.

Based on these findings it is not possible to define a common effect of ADAS on reaction times of drivers. Depending on the type of ADAS, this effect could be positive or negative. No studies were found that studied the effect of FCW and ACC together on drivers reaction time. Nowadays the penetration rates and actual usage of such systems is still relatively low, though it can be excepted that more cars will be equipped with ADAS systems in the future. Future research on this topic, which also takes into account the combined effects of multiple ADAS systems, is therefore desirable.

4.7 Lateral driver positions

Values

The lateral position of drivers in horizontal curves determines, among others, the sight distance through a horizontal curve. As mentioned in deliverable EUSight D3.1 many studies found that drivers tent to 'cut' the curve, and do not keep their vehicle in the middle of the lane. As a result, drivers have a decreased sight distance. Gunay and Woodward (2006) studied the lateral position of vehicles in three different horizontal curves on rural roads in Ireland. They found that most travelled wheel paths are shifted towards the inner side of the curve, and this shift increases with increasing radius. For horizontal curves the shift was about 30-40cm, with standard deviations in lateral position of 22-33cm. Ben-Bassat and Shinar (2011) found lateral shifts between 0.95-0.15m on 4.5m wide roads, with standard deviations of 40-50cm in shallow curves (design speed 90km/h).

Bella (2013) performed a driving simulator study and found that drivers tend to 'cut' the curve the most in sharp curves (design speed 70km/h). With an average lateral position of 1.26m on left curve and 2.24m on right curve (lane width of 3.5m). This, in both cases, resulted in a 0.49m shift towards the inner side of the sharp curve. The shallow curves (design speed 100km/h) resulted in an average shift of 0.17-0.30m, with SD of 0.21-0.31m.

However, lateral position is not only affected by the curvature. Studies also found effects of the presence of guardrails, herringbones, pavement markings and absence of a hard shoulder (Ben-Bassat & Shinar, 2011; Bella, 2013; Antonson et al., 2013). All these factors described a shift towards the centre of the road as a result. Bella (2013) found main differences of 5cm and 22cm for the presence of guardrails and hard shoulder respectively. Van der Horst and De

Ridder (2007) also studied the effect of trees on lateral position, though did not find significant differences. However, trees in combination with a guardrail did result in a 12cm shift towards the center of the lane.

Guidelines
Currently some guidelines already mention fixed observation points in curves based from which sight distance should be measured. The following table provides an overview of the values per country.

Country	Observed point position from edge marking
Denmark	1.5m
France	2.0m
Germany	Centre of lane
Ireland	-
The Netherlands	1.25m
Switzerland	Center of lane
United Kingdom	Center of lane

Table 14: Fixed observing points in curves based on which sight distance could be measured per country. Note: lane width may also differ per country

Conclusion
Based on literature, a shift of about 0.30m towards the inner side of the curve seems realistic. However, taking into account that a driver is not located in the center of the car, such a shift might mean that the drivers observing point is now located at the centre of the lane.

Taking into account the 85th percentile, based on an estimated standard deviation of 0.25m, the expected shift is about 0.55m. As such, assuming a 1.5m observe point position measured from the edge marking seems a reasonable and safe assumption (taking into account the 85th percentile and an assumed lane width of 3.5m).

4.8 Speed

The Literature Review Report produced under WP2 identified the key design parameters used in each member country in relation to determining SSD (Van Petegem et al., 2014). Chapter 6 reviewed in separate factsheets the design guidelines on sight distance requirements for motorways with a minimum configuration of 2x2 lanes, in the following European countries: Austria; Denmark; France; Germany; Ireland; The Netherlands; Switzerland; United Kingdom. These factsheets identified each of the key criteria by country and illustrated the relevant formula for calculating the appropriate SSD for a range of different speeds. These values are summarised in Table 6.14 which provides comparison of reaction time and SSD by country and speed. This table is reproduced here in Table *15* for ease of reference.

Country	Perception – Reaction time [s]	Stopping Sight Distance (SSD) [m]								
		50 km/h	60 km/h	70 km/h	80 km/h	90 km/h	100 km/h	110 km/h	120 km/h	130 km/h
Denmark	2	54	71	90	111	134	160	187	217	248
France	2	50		85		130		195		280
Germany	2	54	71	90	111	134	160	187	217	248
Ireland	2	70 50 50	90 70 50	120 90 70	160 120 90		215 160 120		295 215 160	
The Netherlands	Variable by design speed	60 (1.5s)			105 (2s)		170 (2.25s)		260 (2.5s)	
Switzerland	2		62		100		147		208	
United Kingdom (85 km/h instead of 80 km/h)	2	70 50	90 70	120 90	160 120		215 160		295 215	

Table 15: Stopping Sight Distance and perception reaction times per country(source: Table 6.14 from Van Petegem et al., 2014)

All countries except UK and Ireland refer to a single value of SDD for any particular speed.

UK refers to a desirable minimum value and a 1 step relaxation, whilst Ireland uses two steps of relaxation to create absolute minima for designers to consider at any particular location. These steps relate to one speed level reduction for each step (i.e. 215m = desirable minimum at 100km/hr or one step relaxation at 120 km/hr).

All other countries use a balanced approach to design to account for different speed characteristics and only require a single value of SSD to be considered. UK and Ireland define the whole route in terms of 'bendiness' to assess the appropriate level of SSD for each key component ie bend or junction where no relaxations in SSD are permitted. AS UK and Ireland use the same values for the 'desirable' value of SSD and 1 step relaxation they have been combined in the graph below.

Representing these variables graphically is shown in Figure *34* below.

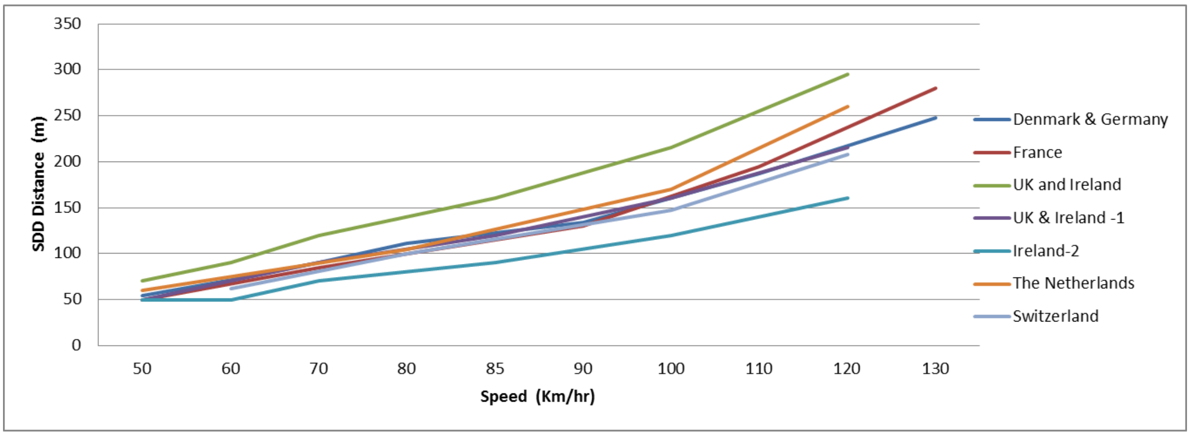

Figure 34: Plot af SSD for different speeds for each country

Whilst following similar profiles, there appears to be no common relationship between each of the SSD parameters used in each country.

The two extreme shapes in the above graph represent the desirable SSD adopted in the UK and Ireland (the higher value) and the 2 steps relaxation used in Ireland –the lowest value line ( ).

Removal of these two extremes from the chart gives a much closer relationship between the different countries determination of SSD and the possibility of specifying a single value for use in each country.

Within this table speed is not defined. However, with the exception of Switzerland and France, all other countries use a form of 'Design Speed' as the key variable in the equation for determining the appropriate SSD. A key definition for design speed and its relationship with other speed parameters is needed to relate these various curve equations to the same variables.

A study undertaken by Harwood et al. (1995) of SSD criteria in 11 countries in 1997 found that most used criteria based on the same model, but that assumptions about the model parameters varied. This has been verified in the literature report in WP 2.

Similarly Polus et al. (1995) in reviewing international design standards found inconsistencies in the application of this speed criteria. In summary they reported that for the European countries part of this study:

Germany

The German design guidelines use both design and 85th percentile operating speed for alignment design. Design speed is used to determine minimum radii of horizontal curves, maximum grades and minimum k-values for crest curves. 85th percentiles speed is used to evaluate design super elevation rates and SSD.

85th percentile speed is estimated from empirical relationships based on the curvature change rate and pavement width. The 85th percentile speed should not exceed the design speed by more than 20km/hr otherwise the guidelines require that the design speed is increase or the design modified to reduce 85th percentile speed.

NOTE: these guidelines were replaced in 2008 and now German guidelines use a road classification system to assign appropriate wet weather design speed to the road alignment. Each road category (EKA1 – EKA3) has a limiting speed value applied to its key design elements. This is regarded as the maximum permitted speed for that category of road that is specified at the planning stage. Where the appropriate limiting values cannot be achieved for a particular category of road, than consideration is given to the application of a speed limit. There is no indication that this limiting value is anything other than an assumed maximum operating speed. Even where no formal speed limit is applied, the maximum operating speed for design purposes is 130km/h.

However, this design approach is confused by a requirement that : *Motorways should ensure high-quality traffic flow and appropriate travel speeds and that quality is calculated on the basis of the specified target mean travel speed for the relevant road category in accordance with the Guidelines for Integrated Network Design (RIN).* (Section 2.2 RAA 2008) This conflicts with the detailed requirements in Section 3 and 5 relating to speed sensitive characteristices that rely on the maximum operating speed.**]**

Switzerland

The Swiss estimate the speed profile along an alignment and identify excessive speed differentials between successive highway elements. These were originally supposed to represent the observed 85th percentile speed, but more recent data (1997) showed increasing speed on sharper curves with corresponding increase in collisions. It is now based on an operating speed concept similar to the project speed used in Austria. This represents the maximum theoretical speed of a particular location on the road. It corresponds to 100 km/h on two lane rural roads and between 100 and 140 km/h on multilane roads.

France

Although not directly documented, the French do not believe SSD to be important when designing roads because their studies suggest that collisions with fixed objects are not common. The most common incidence is collision with pedestrians. These collisions typically occur at night when SSD is not believed to be the limiting factor.

UK

The UK emphasises the effects of alignment and layout (cross section and access control) on operating speed in developing an appropriate design speed, rather than defining design speed on a functional basis. Yet it still applies the same basic SDD relationship as many European countries.

5 Discussion and conclusions

5.1 Speed

The speed employed in the analysis of stopping sight distance is typically the design speed, in particular for vertical sight restrictions. As noted above some authorities allow the running speed or operating speed to be used. Since the design coefficient of friction element of the SSD equations is determined for wet pavements, and drivers were expected to slow on wet pavements this is believed to be more relevant for those countries. However research by AASHTO has demonstrated that drivers do not slow appreciably on wet pavement. Apparently, there is a need to determine a clear definition for selecting the determining factor.

The relationship between Design Speed and other key identifiers of the vehicle speed has rarely been fully documented: i.e. Mean speed, Operating Speed and 85th percentile speed.

In many instances there does seem to be interchangeability between Design Speed and Operating Speed, but no clear definitions or relationships are given.

Layton (1997) as well as Layton and Dixon (2012) present the following relationship (for all types of road):

> *The relationship between average speed, 85th percentile speed and design speed is not well defined. However, the approximate relationship can be defined as follows. The design speed has been defined as about the 95th to 98th percentile speed; therefore:*
>
> *Average operating speed = mean speed*
>
> *85th percentile speed = mean speed + 1 std. deviation*
>
> *Design speed (95% speed) = mean speed + 2 std. deviations*
>
> *Typically, the standard deviation for speeds is about 5-6 mph. Thus, if the standard deviation is not known, a rule-of-thumb is:*
>
> *85th percentile speed is operating speed + 5 mph*

Small variations in speed result in very large differences in stopping sight distance, since stopping sight distance varies as the square of velocity.

If this relationship is held as being true then design speeds should be developed in excess of operating speed and similarly speed limit. In Germany, they hold that operating speed is higher than 85%ile, taking instead the 95%ile. However, in many instances design speed, operating speed and speed limit are applied as an interchangeable value.

When considering the speed relationships defined in Table 6.14 of WP2 Literature Review Report considered in Section 3.1, the initial views were that there was little commonality between the various countries. This could be explained by the differences in application of operating speed and design speed. UK and Ireland practice of including 'stepped' alternatives for SSD could potentially take account of the situation above where Design and Operating speed are interchangeable. For consistency if a single value of 1 step relaxation for both these countries is used, their profile of SSD lies within the same grouping as other European countries.

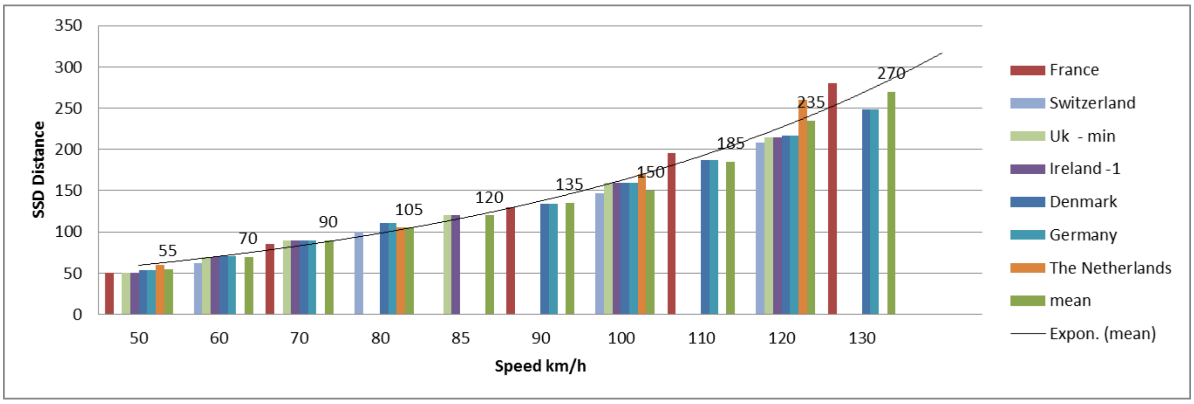

Figure 35: Trend line for mean of subset of values from each member state

Application of the mean of these values produces the above indicated exponential trend line.

In conclusion, the relationship between Design Speed, Operating Speed, v85 and v95 needs to be clearly defined and agreed to establish a common application of SSD.

5.2 Braking time

The braking time needed for drivers to stop in front of a stationary object or other obstruction in the highway, depends on a number of factors concerning (tangential) road friction, brake performance and human factors.

For the available road friction the road surface type, the road condition, the tyre type, the tyre tread depth, the brake system and the weather conditions are of relevance.

The (tangential) road friction coefficients from the road design guidelines studied in WP2 vary from 0.3 (Switzerland 80 km/h non-motorway) to 0.49 (Switzerland 60 km/h motorway). Most friction coefficients are in the range of 0.35-0.40. The majority of the guidelines do not contain background information about studies or assumptions which led to the chosen friction coefficients.

Test tracks measurements have given insight in the possible deceleration rates for various combitions of road, car, tyre and weather characteristics. The Mean Fully Developed Deceleration (MFDD) has a range from approximately 3.5-9 m/s^2. The lower range of the distribution of deceleration rates refers to cars without ABS, a poor road road surface condition, a small tyre tread depth and a wet road surface.

For several reasons it is desirable to use conservative deceleration rates and road friction coefficients for the SSD defintion:

- ABS is becoming increasingly common on new vehicles, but still a significant share of the EU vehicle fleet is not equipped with ABS.
- Because of the effect of climate change, the intensity of the rainfall is increasing in parts of Europe, resulting in increasing water layer depths.
- The share or road stretches with friction coefficients smaller than 0.4 is not to be neglected.

5.3 Obstacle definition

Not only the dimensions of the obstacle in relation to safety are relevant, but also the probability of encountering such an obstacle : the chance of a box on the road is very small compared to a stationary vehicle. When using a ‘worst-case’ approach, using a small box in the criteria, we may be designing for an event that almost never occurs.

5.4 Sight distance

Restricted sight distance can be the result of geometric characteristics of the road and objects in the verge (or median) of the road. The (available) sight distance depends on the position of the driver (both horizontal and vertical) in the cross section and the dimensions and position of the obstacle.

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7 References

AASHTO (2001). *A Policy on Geometric Design of Highway and Streets* (4th edition). Washington, DC: American Association of State Highway and Transportation Officials.

AASHTO (2011). A Policy on Geometric Design of Highway and Streets (6th edition). Washington, D.C.: American Association of State Highway and Transportation Officials.

Abe, G. & Richardson, J. (2005). The influence of alarm timing on braking response and driver trust in low speed driving. *Safety Science 43,* 639-654.

Abe, G., & Richardson, J. (2004). The effect of alarm timing on driver behaviour: an investigation of differences in driver trust and response to alarms according to alarm timing. *Transportation Research Part F: Traffic Psychology and Behaviour, 7* (4-5), 307-322.

Abe, G., & Richardson, J. (2006). Alarm timing, trust and driver expectation for forward collision warning systems. *Applied Ergonomics, 37* (5), 577-586.

Anfac (Asociacion Espanola de Fabricantes de Automoviles y Camiones). European Motor Vehicle Parc 2011.

Antonson, H., Ahlstrom, C., Wiklund, M., Blomqvist, G., & Mardh, S. (2013). Crash Barriers and Driver Behavior: A Simulator Study. *Traffic Injury Prevention, 14* (8), 874-880.

Bella, F. (2013). Driver perception of roadside configurations on two-lane rural roads: Effects on speed and lateral placement. *Accident Analysis and Prevention, 50,* 251-262.

Ben-Bassat, T., & Shinar, D. (2011). Effect of shoulder width, guardrail and roadway geometry on driver perception and behavior. *Accident Analysis and Prevention, 43* (6), 2142-2152.

Broeren, P., & Wools, T. (2015). *Driving Experiment Report* (Deliverable D5.2). European Sight Distances in perspective - EUSight, CEDR Transnational Road Research Programme.

Capaldo, F.S. (2012). Road Sight Design and Driver Eye Height: Experimental Measures. *Procedia - Social and Behavioral Sciences, 53,* 731-740.

Chang, M.-S., Messer, C.J., & Santiago, A.J. (1985). Timing Traffic Signal Change Intervals Based on Driver Behavior. *Transportation Research Record, 1027,* 20-30.

Durth, W., & Bernhard, M (2000). Revised design parameters for stopping sight distance. *2nd International Symposium on Highway Geometric Design.* Mainz, Germany: 2000-6-14 to 2000-6-17. 410-421.

EEA-JRC-WHO (2008). *Impacts of Europe's changing climate - 2008 indicator-based assessment* (EEA Report No 4/2008; JRC Reference Report No JRC47756). Copenhagen: EEA-JRC- WHO.

European Environment Agency
Average age of the vehicle fleet (TERM 033) – assessment published January 2011, Average age of passenger cars, light and heavy duty trucks, buses/coaches and two-wheelers, 1995-2009 from TREMOVE v3.1.

Fambro, D.B., Fitzpatrick, K., & Koppa, R.J. (1997). *NCHRP Report 400: Determination of Stopping Sight Distances.* Washington, DC: Transportation Research Board.

Fambro, D.B., Koppa, R.J., Picha, D.L., & Fitzpatrick, K. (2000). Driver braking performance in stopping sight distance situations. *Transportation Research Record,* (1701), 9-16.

Fitzpatrick, K., Lienau, T., & Fambro, D.B. (1998). Driver eye and vehicle heights for use in geometric design. *Transportation Research Record,* (1612), 1-9.

Flintsch G.W., McGee K.K., de Léon Izeppi E., & Najafi S. (2012). *The Little Book of Tire Pavement Friction* (version 1.0). Pavement Surface Properties Consortium.

Forbes, T.W., Zagoraki, H., Holshouser, E.L.S., & Deterline, W.A. (1958). Measurement of driver reactions to tunnel conditions. *Proceedings of the annual meeting of the highway research board, 37,* 345-357.

Gazis, D.R., Herman, R., & Madadudin, A. (1960). The Problem of the Amber Signal in Traffic Flow *Operations Research 8,* 112-132.

Garcia, J. & Quintana-Domeque, C. (2007). The evolution of adult height in Europe: A brief note. *Economics and Human Biology*, 5 (2), 340-349.

Gohlke, B., & Woelfle, J. (2009). Growth and puberty in German children. *Deutsches Ärzteblatt International, 106* (23), 377-382.

Green, M. (2000). "How long does it take to stop?" Methodological analysis of driver perception-brake times. *Transportation Human Factors, 2* (3), 195-216.

Greibe, P. (2007). *Braking distance, friction and behaviour. Findings, analyses and recommendations based on braking trials.* Lyngby, Denmark: Trafitec.

Groenendijk, J. (2013). *Starting point for a methodology for policy changes regarding wet road road friction, applied to the response intervals in case of exceeding threshold values.* KOAC-NPC, commissioned by Rijkswaterstaat.

Gunay, B., & Woodward, D. (2007). Lateral position of traffic negotiating horizontal bends. *Proceedings of the Institution of Civil Engineers: Transport, 160* (1), 1-11.

Hall, J.W., & Turner, D.S. (1989). Stopping Sight Distance: Can We See Where We Now Stand? *Transportation Research Record 1208,* 4-13.

Harwood, D.W., Fambro, D.B., Fishburn, B., Joubert, H., Lamm, R., & Psarianos, B. (1995). International Sight Distance Design Practices *International Symposium on Highway Geometric Design Practices* Boston, Massachusetts: August 30 - September 1, 1995

Henry, J. J. (2000). *Evaluation of Pavement Friction Characteristics: A Synthesis of Highway Practice,* (NCHRP Synthesis 291). Washington, D.C.: Transportation Research Board, National Research Council.

Jamson, A.H., Lai, F.C.H., & Carsten, O.M.J. (2008). Potential benefits of an adaptive forward collision warning system. *Transportation Research Part C: Emerging Technologies, 16* (4), 471-484.

Jansen, S., Schmeitz, A., & Akkermans, L. (2014). *Study on the safety-related aspects of tyre use, stakeholder information and discussion document.* MOVE/C4/2013-270-1, TNO and TML, commissioned by the European Commission, Directorate-general for Mobility and Transport, Brussels.

Kusano, K.D., & Gabler, H. (2011). *Method for Estimating Time to Collision at Braking in Real-World, Lead Vehicle Stopped Rear- End Crashes for Use in*

Pre-Crash System Design (SAE paper number 2011-01-0576). Warrendale: Society of Automotive Engineers, Inc.

Layton, R., & Dixon, K. (2012). *Stopping Sight Distance* (Discussion Paper #1). Oregon: Oregon State University.

Layton, R.D. (1997). *Stopping sight distance and decision sight distance* (Discussion Paper No. 8.A). Corvallis, Oregon: Transportation Research Institute Oregon State University.

Lenderink, G., & Van Meijgaard, E. (2008). Increase in hourly precipitation extremes beyond expectations from temperature changes. *Nature Geoscience, 1,* (8), 511-514.

Malda, D., & Terpstra, E. (2006). *Extreme precipitation curves for the 21st century, determination of the normative extreme precipitation curve for design* (commissioned by Bouwdienst Rijkswaterstaat). Wageningen: Meteoconsult.

Polus, A., Poe, C.M., & Mason, J.M. (1995). Review Of International Design Speed Practices In Roadway Geometric Design. *International Symposium on Highway Design Practices* Boston Massachusetts: August 30 - Sept 1 1995

Roe, P.G., & Sinhal, R. (1998). *The Polished Stone Value of aggregates and in-service skidding resistance* (TRL Report 322). Crowthorne, UK: TRL.

Rudin-Brown, C.M., & Parker, H.A. (2004). Behavioural adaptation to adaptive cruise control (ACC): implications for preventive strategies. *Transportation Research Part F: Psychology and Behaviour, 7* (2), 59-76.

Schermers, G., Stelling, A., & Duivenvoorden, C.W.A.E. (2014). *Maatgevende normen in de Nederlandse richtlijnen voor wegontwerp, Actualisatie van de norm-mens en het ontwerpvoertuig* (rapport R-2014-38). Den Haag: SWOV.

Schönbeck, Y., Talma, H., van Dommelen, P., Bakker, B., Buitendijk, S. E., HiraSing, R. A., & van Buuren, S. (2012). The world's tallest nation has stopped growing taller: the height of Dutch children from 1955 to 2009. Pediatric research, 73(3), 371-377. (,

Sivak, M., Olson, P.L., & Farmer, K.M. (1982). Radar-measured reaction times of unalerted drivers to brake signals. *Perceptual and Motor Skills, 55,* 594.

Sohn, S.Y., & Stepleman, R. (1998). Meta-analysis on total braking time. *Ergonomics, 41* (8), 1129 - 1140.

Stuiver, A., Hogema, J., Broeren, P., Schermers, G., Barrell, J., & Weber, R. (2015). *Scenario report* (Deliverable D3.1). European Sight Distances in perspective - EUSight, CEDR Transnational Road Research Programme.

Trafikleder Pa Landsbygd (1986). National Swedish Road Administration, Borlange, Sweden. In McLean, J.R. "Speeds, Friction Factors, and Alignment Design Standards." (No. 154, pp. 316-319). Research Report ARR.

V&W (2001). *ZICHT 1.0., software application for evaluation sight distances in road designs.* Apeldoorn, The Netherlands: Directorate-General of Public Works and Water Management, Civil Engineering Division, Road Design Department/Nedgraphics.

Van Petegem, J.H., Schermers, G., Hogema, J., Stuiver, A., Broeren, P., Sterling, T., Ruijs, P., & Weber, R. (2014). *Literature review report* (Deliverable D2.1). European Sight Distances in perspective - EUSight, CEDR Transnational Road Research Programme.

Van der Horst, A.R.A. (1990). *A time-based analysis of road user behaviour in normal and critical encounters*(PhD Thesis). Delft, The Netherlands: Delft University of Technology.

Van der Horst, R., & De Ridder, S. (2007). Influence of roadside infrastructure on driving behavior: driving simulator study. *Transportation Research Record, 2018,* 36–44.

Van der Hulst, M., Meijman, T., & Rothengatter, T. (1999). Anticipation and the adaptive control of safety margins in driving. *Ergonomics, 42* (2), 336-345.

Van der Sluis, S. (2002). Ableitung einer Wechselbeziehung zwischen Griffigkeit, Geschwindigkeit und Haltesichtweite anhand realer Bremsvorgänge [*Deriving a relation between friction, speed and stopping sight distance based on real deceleration events]* (Dissertation). Aachen, Germany: Fakultät für Bauingenieurwesen der Rheinisch- Westfälischen Technischen Hochschule Aachen.

Von Loeben, W-H. (2004). *Mögliche Bremsverzögerungen in Abhängigkeit von der Griffigkeit [Possible deceleration rates in relation to skid resistance].* Kolloquiem für Fortgeschrittene im Strassenwesen, Universität Karlsruhe, Institut für Strassen- und Eisenbahnwesen, 9-12-2004.

Welleman, A.G. (1977). *Water on the road.* Delft: Foundation Study Center for Road Construction.

Wortman, R.H., & Matthias, J.S. (1983). Evaluation of driver behavior at signalized intersections *Transportation Research Record, 904,* 10-20.

Young, M.S., & Stanton, N.A. (2007). Back to the future: Brake reaction times for manual and automated vehicles. *Ergonomics, 50* (1), 46-58.