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European Sight Distances in perspective – EUSight

Final Report

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EUSight
European Sight Distances in perspective

Final report

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Executive summary

Many aspects have to be taken into consideration when designing roads. Road capacity, traffic safety, construction and maintenance costs, the environment and how the road fits into the landscape, etc., are all factors that need assessment during the design process. None of these aspects should be considered separately. Designing roads is a complex task requiring an optimal balance between all relevant design elements. Sight distance is of great importance for traffic flow and traffic safety and consequently is an important parameter needing careful assessment during the geometric design process.

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 European countries. This research is considered to be necessary due to a number of changes that are relevant for the calculation of the Stopping Sight Distance, e.g. improvements of breaking systems, support and distraction of drivers by information technologies, aging driver population, etc.

This research considers Stopping Sight Distance from different (related) approaches: human factors (‘the driver’), road characteristics, vehicle characteristics and road conditions (like traffic, weather, lighting condition). In addition special infrastructure constellations like tunnels or overhead constructions are consider too. Consequently, this research considers Stopping Sight Distance from all of these interrelated aspects and focuses on these individually and/or collectively. Due to the fact, that many different related aspects has to be taken into consideration while analysing Stopping Sight Distance, multiple approaches and methodologies are needed to determine state-of-the-art parameter values.

Based on the results of the literature study, scenarios concerning the further development of selected relevant parameters are drawn and the impact those developments might have on Stopping Sight Distance are analysed. In addition, driving behaviour is analysed in the frame of a multi-national empirical field study. Grounded on these results, a parameter study has been conducted in order to provide an overview of the distribution of parameter values currently ’on the road’, differences among countries in Europe, and future developments. The determination of a recommended set of parameters and parameter values for the calculation of Stopping Sight Distance is the main finding of this project and the possible consequences of changes in the parameter set and/or the value of different parameters for the individual EU-countries. Before conducting the final conclusions, the results of all Work Packages are presented to and discussed with specialists from four different EU-Countries, Germany, Ireland, The Netherlands and United Kingdom.

This report summarizes selected results of the previous work packages of the EUSight project and contains tables with the recommended parameter and parameter values. Based on these proposals the resulting Stopping Sight Distance is calculated and the estimated impacts that such a uniform approach for selected countries might have is shown.

The results of the previous work packages are documented in the following reports in detail:

Petegem, v. J., Schermers, G., Hogema, J., Stuiver, A., Broeren, P.; Sterling, T.; Ruijs, P. & Weber, R. (2014). Literature review report. Deliverable D2.1, Final report. CEDR European Sight Distance in perspercetive (EUSight), Amersfoort, Netherlands.

UN/ECE, A., Hogema, J., Broeren, P.T.W., Schermers, G., Barrell, J., Weber, R. (2015). Scenario report. Deliverable D3.1. CEDR European Sight Distance in perspercetive (EUSight), Amersfoort, Netherlands.

Hogema, J., Stuiver, A., Kroon, L., Broeren, P.T.W., et al. (2015). Parameter Study report. Deliverable D4.1. CEDR European Sight distances in perspective (EUSight), Amersfoort, The Netherlands.

Broeren, P.T.W. (2015). Driving experiment report. Deliverable D5.2. CEDR European Sight distances in perspective (EUSight), Amersfoort, Netherlands.

Schermers, G., Broeren, P.T.W (2015). Representative parameter values study. Deliverable D6.1. CEDR European Sight distances in perspective (EUSight), Amersfoort, Netherlands.

List op 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)

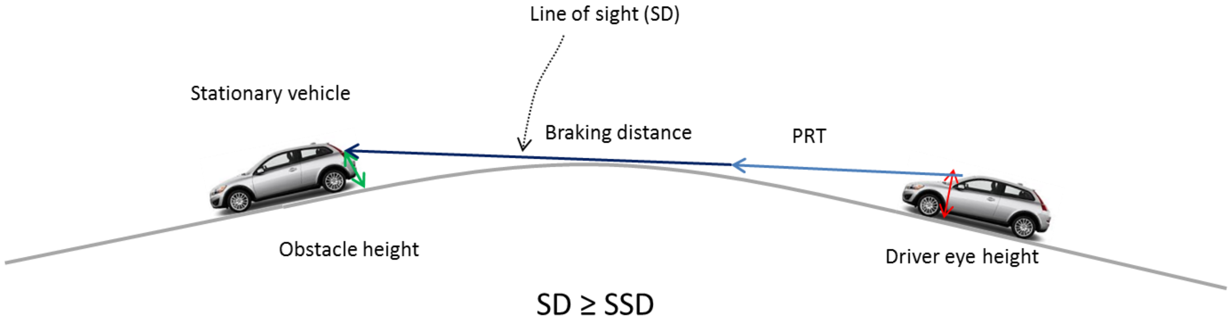
The time it takes for a road user to realize that a reaction is needed due to a road condition, decides what manoeuvre is appropriate (in this case, stopping the vehicle) and start the manoeuvre (moving the foot from the accelerator to the brake pedal).

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.



$$SD \geq SSD$$

1 Introduction

Many aspects have to be taken into consideration when designing roads. Road capacity, traffic safety, construction and maintenance costs, the environment and how the road fits into the landscape, etc., are all factors that need assessment during the design process. None of these aspects should be considered separately. Designing roads is a complex task requiring an optimal balance between all relevant design elements. Sight distance is of great importance for traffic flow and traffic safety and consequently is an important parameter needing careful assessment during the geometric design process.

In road design, sight distances are of great importance to, for example:

- avoid a collision with a possible obstacle downstream on the carriageway, the Stopping Sight Distance. The obstacle can be an object or a stationary vehicle on the road (because of lost load, a breakdown vehicle or a queue of vehicles);
- provide a clear line of sight on the road ahead, the sight distance. The sight distance is needed to enable drivers to steer the vehicle and to adapt speed to the alignment of the road ahead;
- overtake a slower vehicle on a carriageway with two way traffic safely, the overtaking sight distance;
- merge comfortably with or cross traffic at an intersection, the approaching sight distance;
- process roadside information given by the road itself, the road equipment or on traffic signs, the orientation sight distance;

Almost all handbooks for road design emphasise the importance of sight distance for traffic safety and extensive research has been conducted on the relationship between sight distance and crashes (traffic safety). These reveal two general but conflicting trends, increased sight distance leads to reduced crash risk and increased sight distances lead to more generous road design with larger horizontal and vertical curve radii which adversely affects speeds and thereby crashes and crash severity. This illustrates the necessity of applying appropriate sight and Stopping Sight Distances in geometric road design. Due to this, almost all design guidelines contains regulations concerning the calculation of Stopping Sight Distance. Within these guidelines considerable differences exist and not all necessary settings are documented in detail.

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 European countries. This research is considered to be necessary due a number of changes relevant for the calculation of the Stopping Sight Distance, e.g. improvements of braking systems, support and distraction of drivers by information technologies, aging driver population, etc.

This research considers Stopping Sight Distance from different (related) approaches: human factors ('the driver'), road characteristics, vehicle characteristics and conditions (like traffic, weather, lighting condition or infrastructure, e.g. tunnels). Consequently, this research considers Stopping Sight Distance from all of these interrelated aspects and focuses on these individually and/or collectively (Figure 1). Since many different related aspects have to be taken into consideration while analysing Stopping Sight Distance, multiple approaches and methodologies are needed to determine state-of-the-art parameter values.

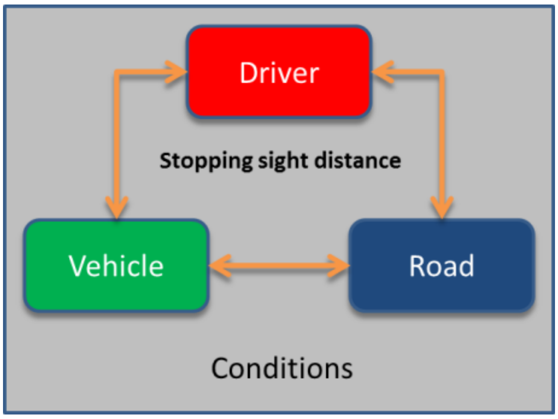


Figure 1: SSD-research in three aspects.

This report summarizes results from the previous work packages of the EUSight project (Petegem et al. (2014), UN/ECE et al. (2015), Hogema et al. (2015), Broeren (2015), Schermers & Broeren (2015)). Although it is not always explicitly mentioned, a lot of phrases are taken from the previous work package reports of this project. Based on the results of the literature study, scenarios concerning the further development of selected relevant parameters are drawn and the impact those developments might have on Stopping Sight Distance are analysed. In addition, driving behaviour is analysed in the frame of a multi-national empirical field study. The results of these work packages provide relevant input for the Work Package 'Parameter Study'. The result of this work package then provides an overview of the distribution of parameter values currently 'on the road', differences among selected European countries, and future developments. The overall target of this project to recommend a set of parameters for the determination of Stopping Sight Distance is developed in the Work Package 'Determination of representative parameter values', mainly for the design of motorways and high volume multilane highways. Again, this recommendation is based on the results of the previous work packages and, in addition, a value for each parameter is suggested. In order to support decision makers, possible consequences of changes in the parameter set and/or the value for different parameters are described, differentiated by selected countries. Before conducting the final conclusions, the results of all Work Packages are presented to and discussed with specialists from four different EU-Countries, Germany, Ireland, The Netherlands and United Kingdom.

2 Conceptual Model

Compared to the haptic (touch) and the acoustic (audible) cognition the optic (sight) cognition is the most important one in order to steer a motorized vehicle in a safe way. Around 90% off all information relevant for the driving task are received via the optic sense organ (Jainski (1985) / Kiegeland (1996)). While driving a vehicle, speed has a major impact on the size of the area, which is scanned for relevant information by the driver. The size, the distance and the position of an object have an impact on the visibility of an object as well as the lighting conditions (daylight/darkness), the luminance, the contrast to the surrounding and the reflectiveness of the object. Beside these aspects, weather (rain, fog as well as sunshine) may influence the visibility too. Depending on the result of the assessment of a potential obstacle and its relevance for the current driving task, a range of possible options on how to react may have to be assessed. After the assessment, a decision has to be taken and the chosen option has to be transformed into an action (or inaction). The possibility to execute this decision is influenced by both the vehicle and the road surface. This process points out the necessity to define a model, based on assumptions regarding the above-mentioned aspects.

Some international guidelines or handbooks (like AASHTO Green Book (AASHTO (2001)) not only distinguish explicitly between different types of sight distance, but also the type of obstacle: stopping in front of an object on the road is referred to as Stopping Sight Distance (SSD), stopping before a queue of vehicles is referred to as Decision Sight Distance (DSD). In this project both types of sight distance are considered although they are used synonymously since they have the same aim and are referred to as SSD (Schermers & Broeren (2015)).

Although the provision of sufficient sight distance is to avoid accidents, the conceptual model of this project does not take accident statistics into consideration. This decision was taken due to the limitations in accident statistics regarding the necessary information of a huge variety of relevant parameters. The conceptual model of this project is mainly based on three different sources of information:

- a literature study;
- a study of different road design guidelines; and
- a driving behaviour study.

Based on the results achieved from these study areas a parameter study was conducted and a set of parameters as well as parameter values were established, taking different conditions like traffic, weather, lighting condition or infrastructure, e.g. tunnels into consideration. The structure of the project approach is depicted in Figure 2.

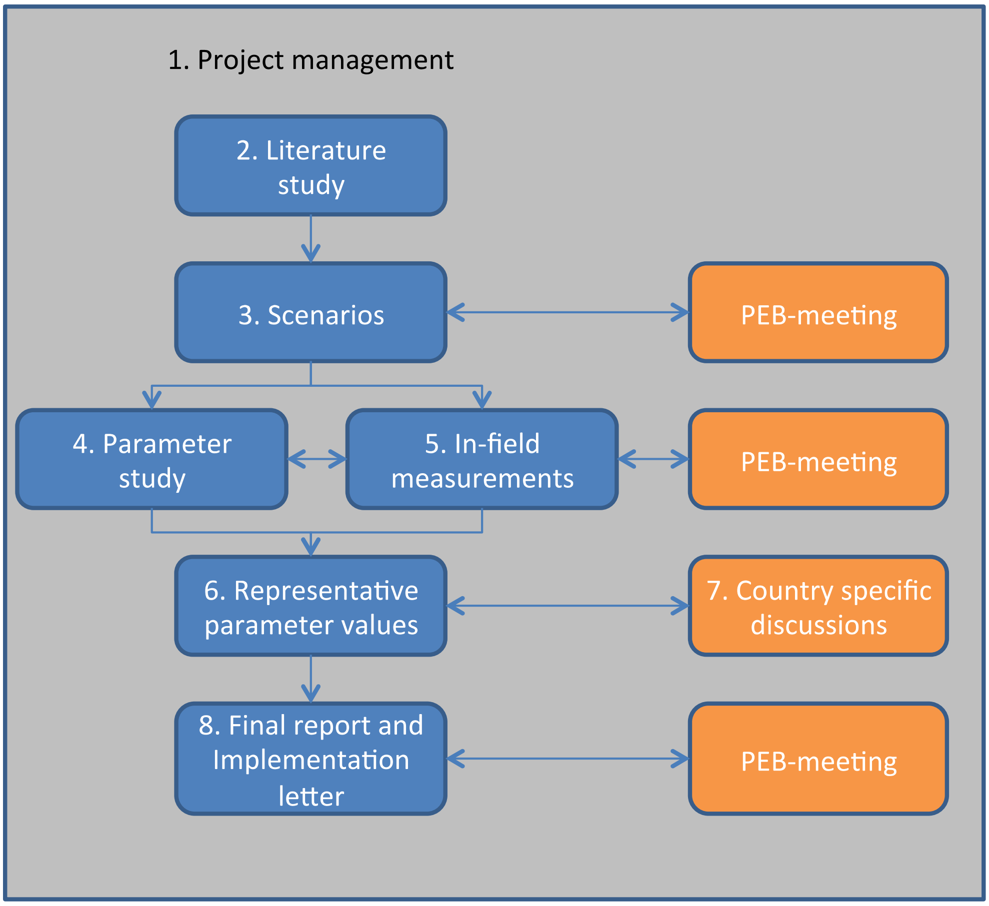
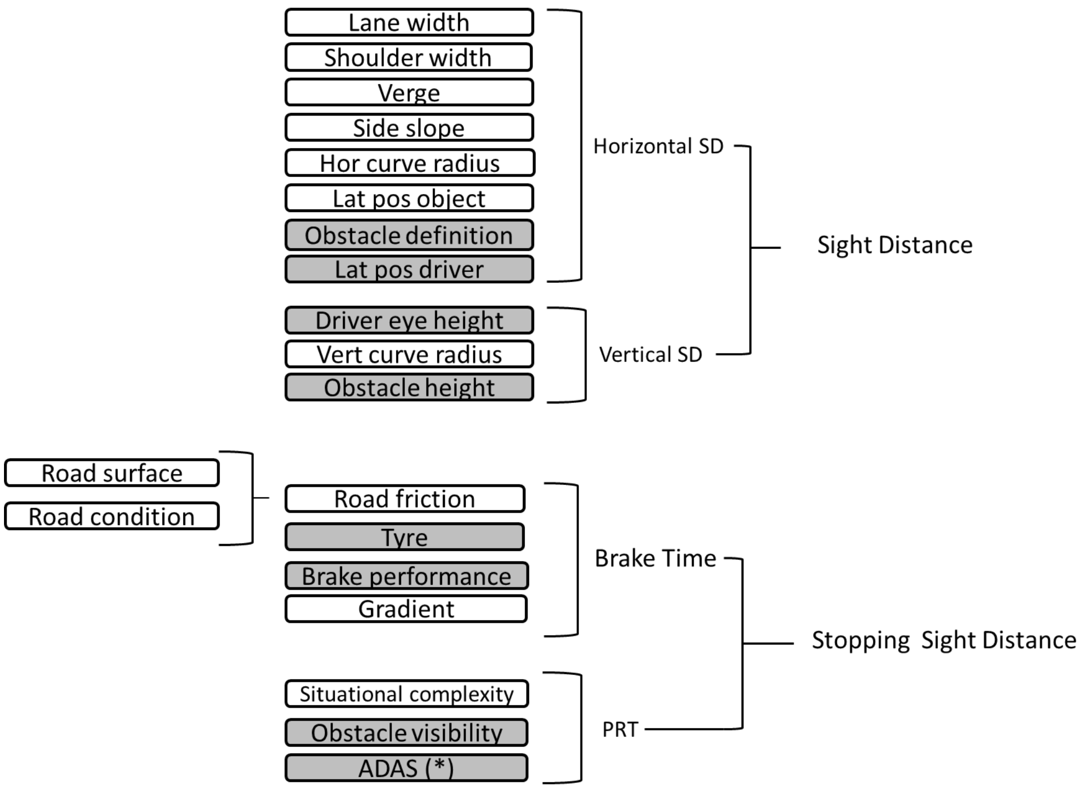


Figure 2: Structure of the project.

Work Package 2 (Literature study) presented human factor research concerning sight distances; traffic safety studies in relation to sight distances; pavement research and international highway geometric design symposia publications (TRB, TRA, etc.) and also discussed road design guidelines from selected European countries (Petegem et al. (2014)). In order to reduce the volume of guidelines to be reviewed and thus to reduce the variety of different settings, the analyses of guidelines was focused on those relevant for the design of motorways.

Based on the results of the literature study a conceptual model of Stopping Sight Distance (SSD) in which all the relationships between the various parameters affecting sight distance were defined was developed in the frame of Work Package 3 'Scenarios' (UN/ECE et al. (2015)). This structure is shown in Figure 3.



(*) Advanced Driver Assistance Systems

Figure 3: Parameters relevant for SD and SSD; parameters with white background are under direct influence of road design; parameters with grey background are not (UN/ECE et al. (2015)).

A 'Parameter study' constituted part of Work Package 4 with the aim to determine representative values for the various sight distance related aspects (Hogema et al. (2015)). In this work package, the actual distribution of parameter values used in the selected European countries, future developments and the impact of parameter value changes on road design elements were investigated.

Because sight distance is related to human factors, measuring speed and deceleration behaviour on the road is a major part of the overall project and this aspect was studied in Work Package 5 'Field measurements' (Broeren (2015)). Within these empirical field studies, conducted in 5 EU Member States (Belgium, Germany, The Netherlands, UK and Romania), about 400 hours of data provided by 37 drivers over 3 months were collected. 34 participants are male three are female. The age groups 30 to less than 40 and 40 to less than 50 consists of 14 respectively 15 persons. Out of the 37 five persons pertain to the age group of 20 to less than 30 and three to the age group 50 to less than 60. Although limitation concerning the representativeness of this field trial exists, these results are of interest and a valuable input for the foundation of the setting of the parameter values.

The process for determining values for the various parameters required for establishing Stopping Sight Distance (SSD) in geometric design (and in some cases also parameters relevant to Sight Distance) is shown in Figure 4.

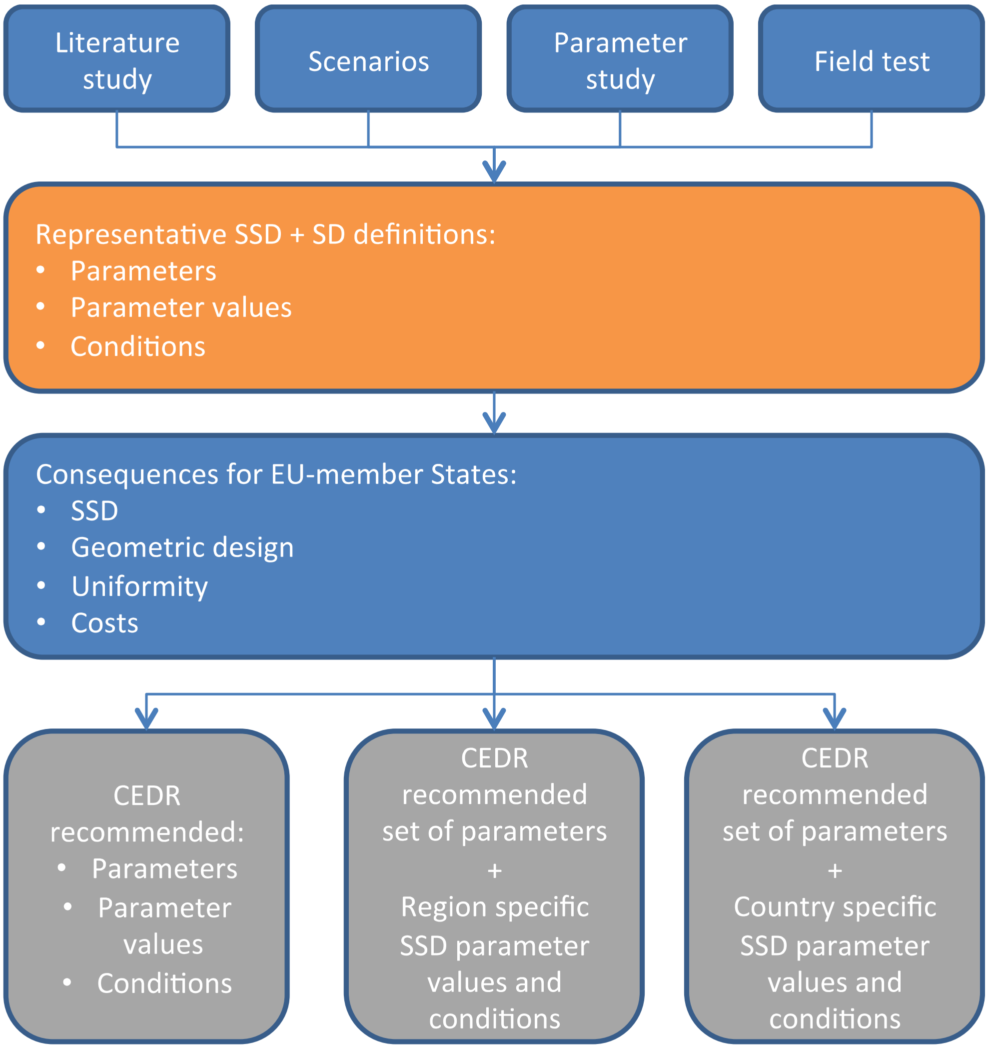


Figure 4: Process for determination of parameter values.

Although the research proposal makes regular reference to EU-member states, at the outset of the project it was decided to focus on those member countries that are making a financial contribution to this CEDR research programme, namely Ireland, The Netherlands, Germany and United Kingdom. Work Package 6 'Representative parameter values' brought together the results of the previous work packages and determined representative values (Schermers & Broeren (2015)). However, since the introduction of a uniform (new) set of SSD parameters and parameter values across EU member states may have significant impact, and may meet with resistance, countries other than only the funding countries are also included. Insight into the potential impact of changed SSD parameters and values on design practice in Denmark, France and Switzerland, have also been provided for illustrative purposes. Furthermore the impact those changes might have on road design as well as on construction costs were estimated at a general level using an Excel based tool developed within the framework of Work Package 3.

From these insights recommendations were developed regarding the definite SSD parameters and the values that should be used in future road design across Europe and taking into account the trade-off between optimal safeties versus realistic costs.

3 Parameters and Parameter Values relevant for the Calculation of Stopping Sight Distance

Because Stopping Sight Distance is an important basis for road design and is closely related to road safety, this subject has been studied intensively over the years. Most of these studies are based on analysis of road geometry, evaluating sight distance in the road design stage, driving simulator studies and equipped vehicle measurements.

Although the literature review done in Work Package 2 focused on relatively new material, from 2010 or later, some older work is incorporated where this was needed to fill elements that would otherwise remain empty, or for material that is judged to be fundamental.

3.1 Driver Aspect

In order to detect the information relevant for the driving task, drivers scan the area close to the road. In general, humans have a clear field of vision of about 10° in which they are able to see clearly enough to detect objects and interpret its meaning for the current situation. The time to shift to a new position (0.15-0.33s) combined with the time to focus on the object (0.1 – 0.3s) means a driver needs 0.5 seconds to focus on an object. A full cycle, scanning from left to right, takes therefore 1.0 second. An other relevant aspect is, that the visual system needs time to adapt when encountering glare (3.0s) or when changing from bright to dim conditions (6s) (Layton & Dixon (2012)).

Beside the time needed for focusing on objects, the visual acuity, the contrast sensitivity as well as the illumination of the object is of relevance. Corrected static acuity, the ability to resolve stationary details, declines with increasing age. This holds from the 20s to the 80s, although in the 30s and 40s acuity is relatively stable (Owsley, C., Sekuler, R. & Siemsen, D. (1983)). Beside the physical composition of the eye, the static visual acuity is dependent on the background, brightness, contrast and time for viewing. The dynamic visual acuity related to crash involvement is regardless of age. However, there is gradual deterioration of dynamic visual acuity with advancing age. For night time driving, safety and operation contrast sensitivity is more important than visual acuity because hazard perception-response time increases significantly with loss in contrast sensitivity (Horswill et al. (2008)). Older drivers have less contrast sensitivity than younger drivers.

Virtually all vision measures deteriorate with lower levels of illumination. This holds especially problematic for the elderly driver (see Staplin et al. (1997), for an overview). In addition elderly drivers have more difficulty selecting the critical information, and it takes them longer to process it (Staplin et al. (1997)). Due to the expectation that the percentage of elderly people (aged 65 years and over) is rising in the EU and expected to reach 24.1% by 2030 (EU (2015)), these aspects have to be considered. Even though huge differences between European Countries exist it has to be consider in addition that the percentage of elderly people having a driving licence is rising.

With regard to visual aspects, the definition of the obstacle is of utmost importance. The relevance of an obstacle for traffic safety is determined by its size and mass. A number of possible obstacles (e.g. lost cargo, animals, and aspects of relevance for judging whether a driver is able to detect this as an obstacle, such as colour and contrast) have not been considered in this study.

The literature review (Petegem et al. (2014)) revealed that there are many studies available on Perception–Reaction Time (PRT). Obviously, there are differences in PRT between and within drivers, due to driver's awareness, stage and age. In addition, the complexity of the situation might also have an impact. Hence, PRT is characterised by a distribution rather than by a constant value. Consequently for SSD, the common approach is to use percentiles of the PRT distribution. The 85th percentiles that have been reported range from 1.4s to 1.9s; 90th or even 99th percentiles may range from 1.8s to 2.5s. But *which* percentile should be used for SSD calculations does not follow from the literature review. Ultimately, this is a trade-off between safety and comfort on the one hand and cost/space, travel time and adaptation to landscape on the other. Even though shorter PRTs are observed, one should have in mind that not only the complexity of traffic is growing by an increase in the number of vehicle on the road but the proportion of elderly driver will also increase in the coming decades. This is of importance because the age of the driver has not only an impact on PRT but also on visual acuity.

Analyses of the effects of distraction by a secondary task and eyes-on/off-the-road revealed the significant slowing down of reaction times, secondary tasks by 16% and eyes-off-road by 29%. In addition, analyses of the driver's workload as a function of sight distance pointed out, that below a sight distance value of 150m drivers have no resources left for fulfilling a secondary task.

The analyses of the current guidelines for the design of motorways in Denmark, France, Germany, Ireland, The Netherlands, Switzerland, and United Kingdom (Petegem et al. (2014)) revealed that all these countries apply a PRT of 2 seconds.

A large part of the sight a driver has on the road is determined by the driver eye height. Therefore it is a relevant parameter for the determination of the SSD, both in horizontal and in vertical curves. Driver eye height depends on both the model of passenger cars or of trucks as well as on the length and the posture of the driver. Nevertheless, only few studies on driver eye height were found. On average, driver eye height decreased slightly over time with changing designs of vehicles (Layton & Dixon (2012)). However, in recent years the variation in driver eye height has also increased, due to the rise of the number of large vehicles, i.e. SUV's, and cars with higher seat height, designed for an easier entry/exit into the car (Layton & Dixon (2012)). Based on an empirical field study established in Italy, the 15th percentile value of the eye height distribution was 117cm (Capaldo (2012)). The difference between the mean eye height above seat level between the Dutch and the Italian population, which are regarded as representative for the extremes of the populations in this respect within the Europe, is about 3.5cm, based on the CAESAR database (Robinette et al. (2002)). Some studies point out that the differences in body height between countries are decreasing over the years (Garcia (2007)) and that in addition the trend to get taller in Europe seems to be ending (Gohlke & Woelfle (2009), Schönbeck et al. (2012)).

Within the literature study of Work package 2 no studies were found on changes in the average eye height for truck drivers. Normally truck driver's eye height is not of concern because they are significantly higher than passenger cars, which may even compensate for longer braking distance. However, truck driver's eye height may be an issue where the Stopping Sight Distance is limited by sight obstructions above the road, e.g. overhanging signs or constructions.

Analysing the guidelines, the eye height is specified to 1.00m to 1.10m above the road surface. For sag situations, when specified, a value of 2.00m to 2.50m is given, referring to the height of trucks (Petegem et al. (2014)).

Beside the driver eye height, the lateral position of the driver in the driving lane/on the roadway is also of relevance. The driver's position is influenced by the width of the carriageway, the horizontal curve radius and the transition of the curve. In addition, the presence of guardrails, chevrons pavement markings and absence of a hard shoulder as well as the combination of guardrails and trees have an impact (Antonson et al. (2013), Bella (2013), Ben-Bassat & Shinar (2011), Gunay & Woodward (2006), Van der Horst & De Ridder (2007)). Based on literature, a shift of about 0.30m towards the inner side of the curve seems realistic. Taking into account the 85th percentile, based on an estimated standard deviation of 0.25m, the expected shift is about 0.55m. Taking into account that a driver is not located in the centre of the car, such a shift might mean that the driver's observation position in a right bending curve is now located close to the centre of the lane, for left bending curves the drivers observation position is 0.75m from the inner edge lane (for countries driving on the right hand side and assumed a lane width of 3.50m and a vehicle width of 1.80m).

Based on the analyses of the current guidelines for the design of motorways in Denmark, France, Germany, Ireland, The Netherlands, Switzerland, and United Kingdom (Petegem et al. (2014)), differences concerning the driver observation position are apparent between countries. For left bending curves the range is 1.25m up to 2.00m and for right bending curves the range is 1.50m up to 2.25m.

Calculations of the minimum curve radius as a function of SSD points out, that increasing the observation point value beyond 1.50m has relatively little merit. On the other hand, a driver observation point of 0.70m would in most cases lead to significantly larger horizontal curves, with associated space and cost implications. Based on these calculations it is suggested not to differentiate between left and right bending curves. Therefore a constant value of 1.30m for the observation point position is recommended.

Studies focussed on the driver deceleration behaviour pointed out that the drivers follow a “constant minimum Time-To-Collision” strategy more than a “constant deceleration” strategy, meaning that drivers initiate strong deceleration rates only in case of emergency. Nevertheless, results show that drivers typically realise decelerations that are below the levels that are possible given the pavement's coefficient of friction: the average maximum deceleration was about 75 per cent of that level (Fambro et al. (2000)).

Results of the empirical field study, based on data of 400 driving hours, revealed a typical maximum deceleration rate of 3-4m/s^2 and that deceleration rates larger than 4m/s^2 seldom occurs. Only in situations with short times-to-collisions were short peaks of higher deceleration rates up to 6m/s^2 and higher noted. A value of 3-4m/s^2 can be interpreted as a comfortable deceleration rate.

Further information concerning the maximum deceleration rate is given in chapter 3.3 Road aspects.

3.2 Vehicle aspects

For passenger cars, the minimum requirements of the braking systems are given for the type approval by the ECE regulation (UN (2014)). There, a minimum deceleration rate of 4.82m/s^2 for a test speed of 100km/h is stated.

Brake Assist Systems (BAS)[1] and similar systems can help improve the response time of the vehicle and of the brake performance of the driver-vehicle system remarkably. Since 2009, all new cars have to be equipped with BAS and since mid-2004 all new cars have to be equipped with Anti-lock Brake Systems (ABS)[2] due to a commitment by the European Car Manufacturers Association.

Comparisons of brake performance between cars with and without ABS showed significant differences between the possible friction coefficients (Van der Sluis (2002), Von Loeben (2004)).

Figure 5 shows the differences between cars with and without ABS (vertical axis) on roads with different friction coefficients (horizontal axis with the friction coefficient increasing from left to right). Over all friction coefficients, the deceleration rate of a car without ABS is between approximately 1 and 3m/s^2 lower than for a vehicle with ABS.

[1] BAS: Increase of brake presure automatically in case of emergency braking.
[2] ABS: Prevention of wheel look-up. The vehicle remains steerable.

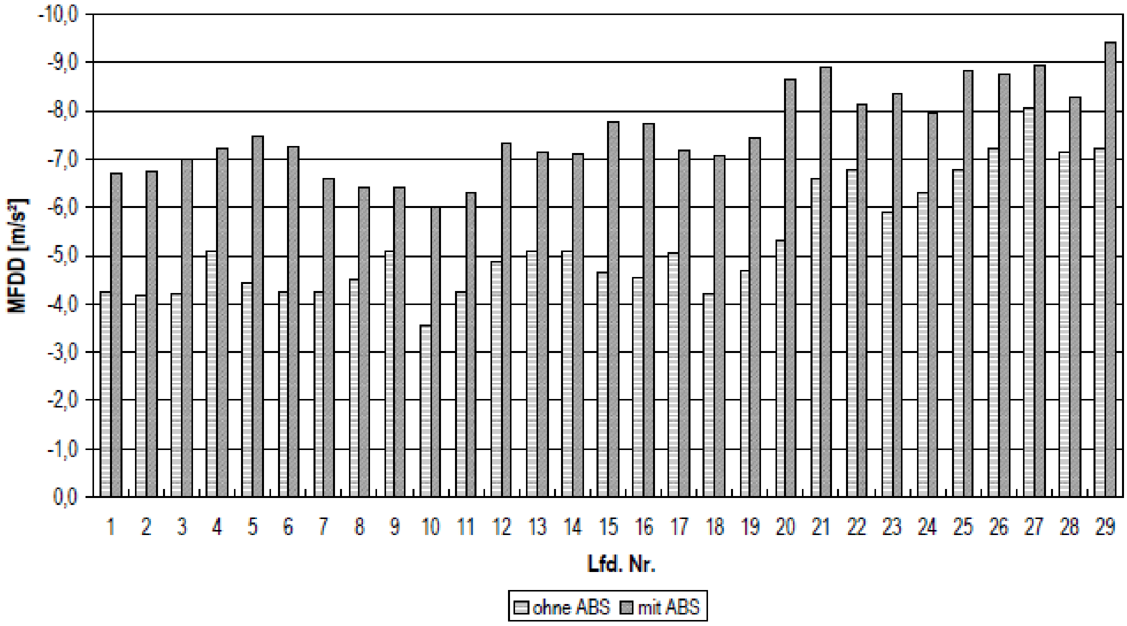


Figure 5: Deceleration rate with and without ABS (Van der Sluis (2002)).

Due to a publication of the European Automobile Manufacture's Association the average passenger car age within the EU could be estimated as 9,7 years (ACEA (2015)). The penetration level of vehicles with ABS will probably vary over the EU Member States. Countries with a relatively old vehicle fleet (e.g. in Poland around 55% of all passenger cars are older than 10 years (ACEA (2015)) will have a lower share of cars equipped with ABS than countries with a relatively modern vehicle fleet (e.g. in UK around 15% of all vehicles are older than 10 years, in Germany and in France the share of vehicles older than 10 years is around 20% and in The Netherlands around 25% (ACEA (2015)). Therefore, for the foreseeable future, SSD criteria will have to be based on a vehicle fleet containing vehicles *without* such systems. As a consequence friction is not only a lower level but in addition is speed dependent.

The classical road condition used in SSD calculations is a wet surface. As a consequence, the road friction should be considered as a function of speed and of water depth. Further, at higher speeds, the friction coefficient is a function of the tyre tread depth.

In the context of road surface and tyre interactions, dry grip and wet grip are distinguished but in terms of traffic safety effects, the focus is entirely on the wet grip level. Nevertheless, the legal requirement for passenger car braking performance according to UN/ECE Regulation No 13-H and UN/ECE Addendum 12-H: Regulation No. 13-H is defined for dry roads. The minimum grip depends on the category of vehicle. For passenger cars the minimum is 0.52 and for vans and light trucks as well as for trucks it is 0.50. According to literature, even the worst tyres (label F) for passenger cars and for vans and light trucks have higher wet grip levels. Only those tyres for trucks labelled C or better are having wet grip levels of higher than the required 0.5 on a dry road surface (Van Zyl et al. (2014)).

The tyre tread depth has a significant impact on the possible stopping distance on wet road surfaces. A comparison of 5 different tread depths on two different surfaces points out that the stopping distances increase dramatically at tread depths below 3mm (Figure 6). Comparing the results of the maximum tread depth of 6.7mm to the legal minimum tread depth of 1.6mm, the stopping distance is increased by 36.8% on the hot rolled asphalt and 44.6% on the smooth concrete (RoSPA (2005)).

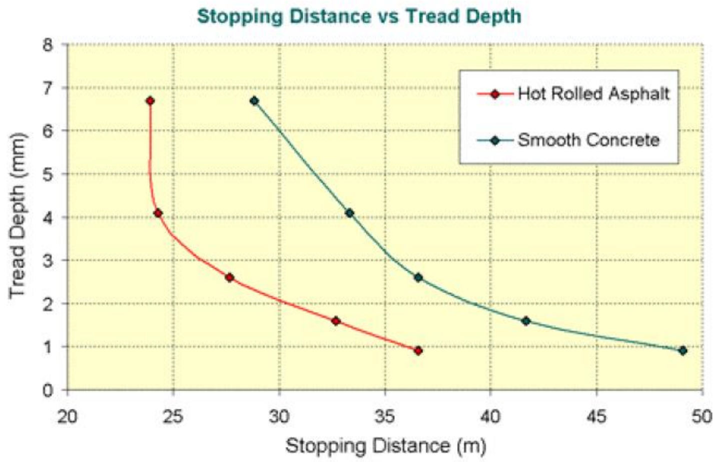


Figure 6: Stopping distance vs treads depth on wet roads (RoSPA (2005)).

A study by Van der Sluis (2002) using a car equipped with ABS on surfaces with a water layer depth of 0.5mm found the effect of the tyre tread depth (2mm or 4mm) was relatively small at lower speeds. At higher speeds the effect of this difference in tyre tread depth was in the range of 0.5 m/s^2 to 1.5m/s^2 (5-15%). Concerning the distribution of tyre tread depths of vehicle fleets there is very little information available. Therefore, and also from traffic safety point of view, using the legal minimum tyre tread depths is the preferred parameter. 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 2.5mm and 4.0mm (Jansen et al. (2014)).

3.3 Road aspects

A couple of aspects are of relevance concerning the possible wet friction coefficient on a road surface. It depends on

- the type of surface;
  On a high level, a distinction can be made between concrete and asphalt. Concerning asphalt, a further distinction is whether the asphalt is porous (or open) or dense. On asphalt, drainage of water is improved compared with a concrete surface (Elvik et al. (2009)). Porous asphalt has even better drainage

properties, reducing the splash and spray as well the likelihood of aquaplaning (Tromp (1994)).

- the scale of the texture;
  For road surfaces with rough macro textures the wet friction coefficient is almost independent of speed, but the level of friction coefficient is very much dependent on the micro texture. For roads with a smooth macro texture, the wet friction coefficient is strongly influenced by speed and also by the micro texture (Sabey et al. (1970)).
- the water layer thickness;
  On a wet road surface the friction coefficient strongly decreases with increasing vehicle speed and increasing thickness of the water layer. On a dry road surface the influence of the speed of the wheel (vehicle) on the friction coefficient in general is limited (Kane & Scharnigg (2009)/ Sabey at al. (1970)).

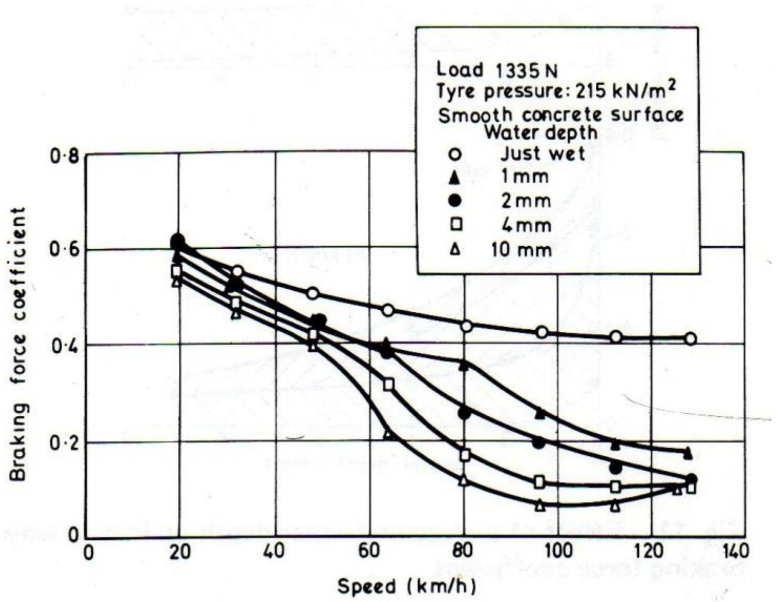


Figure 7: Effect of water depth on the braking force with a radial ply tyre (Kane & Scharnigg (2009)/ Sabey at al. (1970)).

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 be chosen that are on the conservative side 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.

Due to the fact that little is published concerning the actual distribution of friction coefficients of roads, the minimum friction coefficients according to the guidelines and legislation of European countries has to be considered.Table 1 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 column refer to the maintenance requirements (the need for an overlay/inlay).

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

Notes: * *measuring speed*
** *Based on revised German guidelines values (2013)*
*** *0.55 (corrected value for motorways where some braking regularly occurs, otherwise 0.5 (HD 36/06))*

Table 1: Minimum road friction coefficients (Van der Sluis (2002)).

Based on the various country road design guidelines, the friction coefficients vary from 0.30 (Switzerland 80km/h non-motorway) to 0.49 (Switzerland 60km/h motorway). Most friction coefficients are in the range of 0.35-0.40. Although the friction coefficient is decreasing with increasing speed, some countries use constant friction coefficients.

The values in table 1 refer to the minimum coefficients of friction used for validation of the quality of the road surface. The coefficient of friction used in the SSD definition is a calculation value enabling a safe stop in normative conditions.

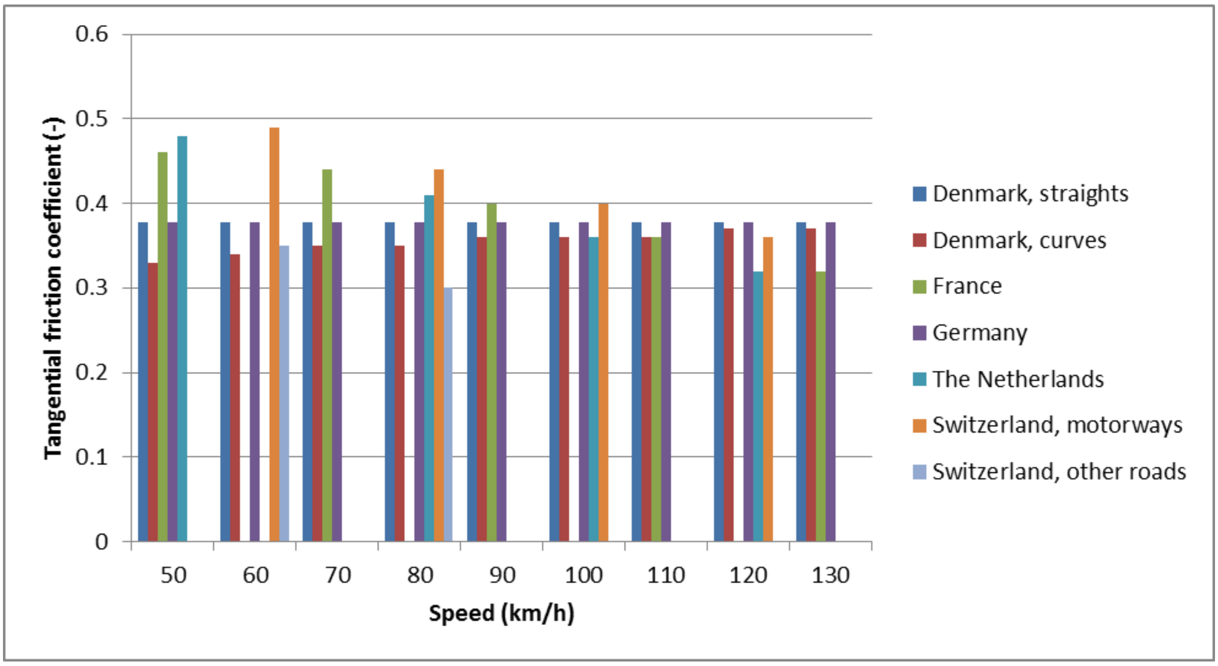


Figure 8: Tangential friction coefficients in road design guidelines (Hogema et al. (2015)).

The water layer depth, the tyre tread depth and the braking system come together in the (maximum) deceleration rate. On road stretches with low friction coefficients, a vehicle without ABS and a water layer thickness of 0.5mm, the maximum deceleration rate is limited to values of about 3.5m/s^2 - 4.5m/s^2 (Van der Sluis (2002)).

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. The effect of the gradient on the Stopping Sight Distance (speed 120km/h, road friction coefficient 0.37, Perception-Reaction Time 2.5 sec) is shown in Figure 9.

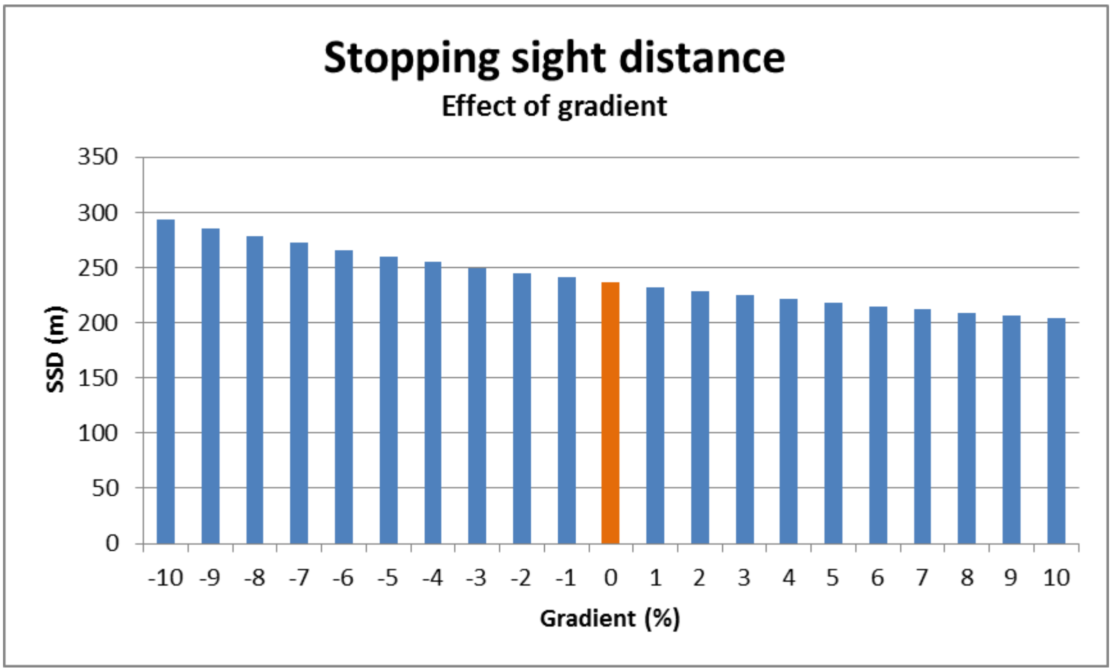


Figure 9: Effect of the gradient on the Stopping Sight Distance (Hogema et al. (2015)).

However, gradient is input by the road designer and is not a value to be chosen for the guideline definition of SSD. The same can be said for the cross section. Although vertical objects in the verge or median of the carriageway could cause sight obstruction in horizontal curves. Examples of sight obstructing objects are:

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

The impact that such elements might have on SSD is dependent on several parameters. In Figure 10 the impact of the driver eye position (dd), the obstacle position (bd) as well as the position of the sight restricting object (sd) is illustrated in a left curve of a dual carriageway road. The trees should symbolise sight obstructing elements in the central reserve of a dual carriageway. Figure 11 illustrates the possible impact of the driver eye height (dh), the obstacle height (oh) as well as the height of the sight restricting object (sh) and its position.

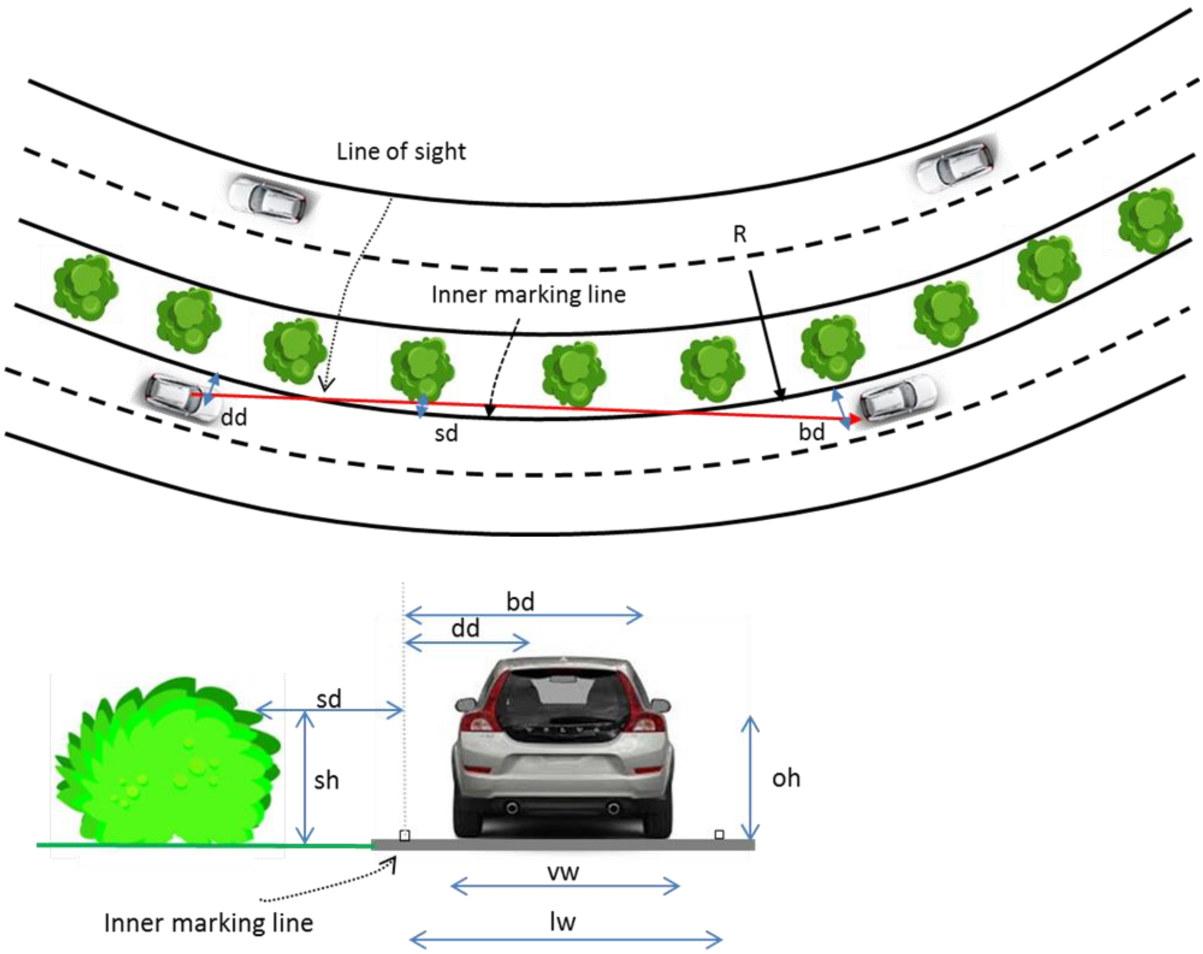


Figure 10: Factors affecting sight distance in horizontal curves (Hogema et al. (2015)).

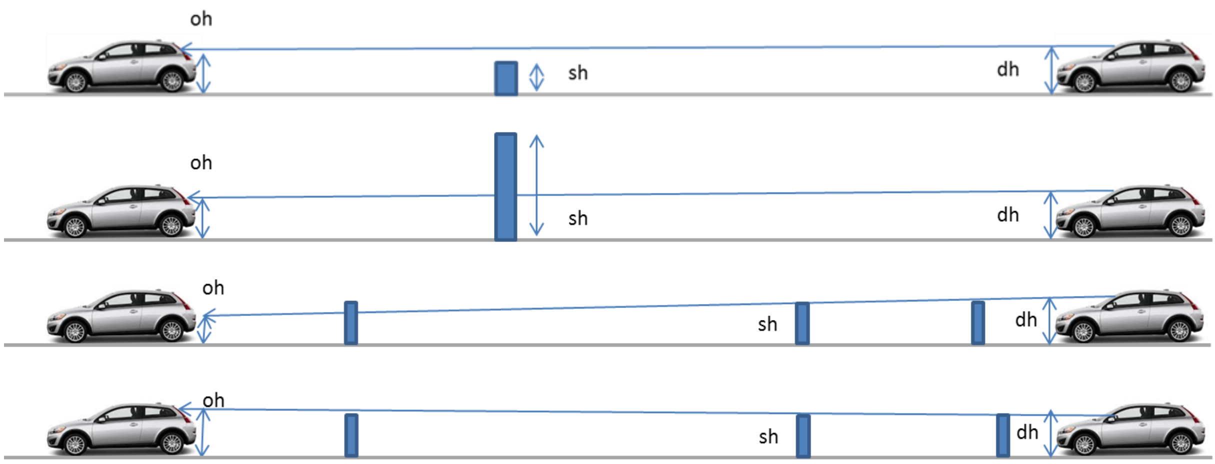


Figure 11: Factors affecting sight distance in horizontal curves (Schermers & Broeren (2015)).

Especially with regard to guardrails and safety barriers in the median, a decision about the size and the position of the obstacle is crucial.

Sight obstruction in the vertical alignment is caused by too small a radius of a vertical curve and in the same way as for horizontal curves depends on the definition of the obstacle. For sag and crest vertical curves, the normative conditions in relation to the sight distance are different (See Figure 12):

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

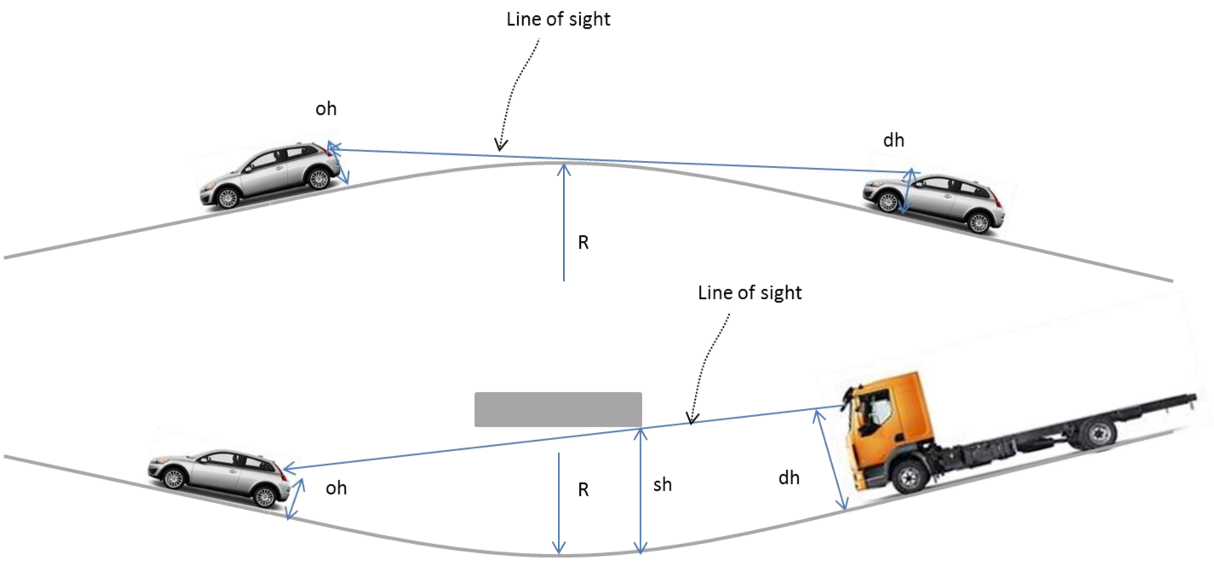


Figure 12: Sight distance parameters in relation to the vertical alignment (Hogema et al. (2015)).

On road stretches where horizontal and vertical curves are combined, the available sight distance is not equal to whichever is the minimum sight distance based on the horizontal curve or vertical curve. For calculations of combined horizontal and vertical curves all the parameters that are relevant for the horizontal and vertical alignment need to be incorporated together (with the help of 3D models and sight distance calculation software).

3.4 Obstacle

Guidelines should include a definition of the obstacle size in the road as this has a material impact on the design of horizontal and vertical curves. By definition, an obstacle is something that poses a risk to vehicles in the event of them being struck. The literature reveals that at a height of 450-600mm obstacles become dangerous to vehicles (Layton and Dixon (2012)). However, it is argued that smaller obstacles (150mm) do not pose sufficient risk for drivers to detect and stop for them (Hall & Turner (1989)) and that designing for these would be designing for situations that seldom or never occur (Hogema et al. (2015)).

Because car taillights fall into the 450-600mm height range, the guidelines of many countries define the obstacle as an object (often a 'box') with a height of 0.5m (Petegem et al. (2014)). The visibility of the object depends on the lighting conditions (daylight/darkness), luminance, contrast and reflectiveness of the object. Weather (rain as well as sunshine) may also influence the visibility of the box.

Within the current guidelines for the design of motorways in Denmark, France, Germany, Ireland, The Netherlands, Switzerland, and United Kingdom (Petegem et al. (2014)) the figure for the height of an obstacle differs. The height currently used ranges from 0.15m to 2.00m (The parameter values per country are shown in table 2.).

Some countries have adopted 1.0m as the obstacle height, that being the height of the third brake light, but still consider the potential for smaller obstacles (and even brake lights of sports cars) remaining undetected over the top of crest curves and thus the risk of crashes due to inadequate SSD's.

Concerning the obstacle position in the cross-section different approaches exist. In two countries a differentiation between left and right hand curves exist. Due to couple of guidelines the obstacle position is in the middle of the lane. Based on the definition that the taillight of a vehicle is the relevant obstacle to define the obstacle position in the middle of the lane is a definition on the safe side.

4 Conclusion of the analysis

Due to the related description of research needs, developed by representatives of road authorities from 4 different countries, the overall aim of this project is to define what is Stopping Sight Distance and why is it required. The analyses of the literature revealed that there is a lot of up to date information and knowledge available for the calculation of SSD and the relevant parameter necessary for the calculation (Petegem et al. (2014)). It is also evident that there is no single threshold value for many parameters although an appropriate value based on the various parameter distributions could be chosen. Ultimately, the background of these choices is a trade-off between safety and comfort on the one hand and cost/space, travel time and adaptation to landscape on the other. In addition, the analyses of the current guidelines for the design of motorways in selected countries points out that not only do differences concerning the parameters as well as the parameter values exist, but different approaches as well. Just to give some examples, in some countries

- a specific value for the eye height of a truck driver is given.
- the observation point position between right and left hand curves differs, range from 1.25m to 2.25m.
- the observation point height differs, range from 0.15m to 2.00m.
- the deceleration rate range from 3.13m/s^2 to 4.51m/s^2.
- a relaxation of SSD is possible.
- SSD has to be considered in the early design stage.

These differences may be due to the fact, that

- the driving behaviour in the different countries may vary, resulting in different speeds and deceleration rates.
- the vehicle fleets and driver population in the individual EU Member States may vary, which may result in different driver's eye height and acceleration/ deceleration rates etc.
- the physical geographical conditions differ per country; the impact of SSD on road design in mountainous countries (e.g. Austria) is bigger than in flat countries (e.g. The Netherlands), resulting in different vertical road alignments and thus in different design and construction costs.
- the road infrastructure differs per country, e.g. the width of the traffic lanes (and thus the position of the vehicle on the road), the width of the hard shoulders as well as the distance between both roadside obstacles and barriers to the traffic lane (and thus the visibility of obstacles in or behind horizontal curves), the minimum roughness of the surface required.
- the regulations could differ (e.g. the maximum speed allowed, the minimum tyre profile depth, the minimum friction coefficient of the road surface, ambient lighting, etc.).

Despite all these possible differences the general goal is equal for all countries. A road design should safely accommodate road users under the majority of conditions and in this case it would mean that a driver should be able to safely stop for an obstacle in the road allowing for an older driver, using an older vehicle with worn tyres, on a wet road and/or a worn (slippery) pavement with low skid resistance.

5 Uniform set of parameters and parameter values for Stopping Sight Distance calculation

Based on the results of the analysis conducted within this project a common approach for the definition of Stopping Sight Distance with representative parameters and parameter values has been developed. In order to develop this common approach:

- the current parameter and (distribution of) parameter values of selected European countries and the representative conditions were taken into account.
- these values were compared to the values in national road design guidelines of selected countries.
- the effects of the parameter and the parameter values for individual countries on SSD, geometric design elements (crest curves, combination of horizontal curves and cross-sections) and construction costs (only globally) were calculated and described.

To assess the impacts that changed parameter values could have on current guidelines in selected European countries, an Excel based tool (developed within the frame of work package 3) was applied. Taken the consequences for individual countries in terms of changes in values for SSD and geometric design elements (larger or smaller curve radii) into consideration a complete set of parameters, parameter values and conditions is developed.

Table 2 contains the parameter and the parameter values used in guidelines of different countries as well as the recommended parameter values based on this study.

Aspect	SSD default variables	Country values							Values based on	
		DK	FR	DE	IE	NL	CH	UK	Parameter study	Driving experiment
Road	Observation point position left curve (m)	1.5	2,0	1,8		1,25	2,0		1,3 - 1,5	
	Observation point position right curve (m)	1.5	2,0	1,8		2,25	2,0		1,3 - 1,5	
	Obstacle height (m)	0.5	0,5	0,5	0,26-2,0	0,5	0,15	0,26-2,0	0,4 - 0,6	
	Observed point height crest curve (m)	0.5	0,6	1,0	0,26-2,0	0,2-0,5	0,15	0,26-2,0		
	Observed point height sag curve (m)	0.5	0,6	1,0	0,26-2,0			0,26-2,0		
	Road Surface		wet	wet					wet	
	(Resulting) coefficient of friction	0.33 - 0.377		0,377		0,32-0,48	0,3-0,49			
	Tangential or braking coefficient of friction	0.377	0,46	0,25-0,32		0,32-0,48	0,3-0,49			
	Radial or side coefficient of friction			0,925* Ft						
Driver	Driver eye height Horizontal alignment (m)	1.0	1,0	1,0		1,1	1,0		1,10 - 1,16	
	Driver eye height Crest curve (m)	1.0	1,0	1,0	1,05	1,1	1,0	1,05	1,10 - 1,16	
	Driver eye height sag curve (m)	2.5		1,0			2,5			
	Perception-Reaction Time (s)	2	2	2	2	2	2	2	2	
Vehicle	Deceleration rate (m/s^2)	3.698	3,13-4,51	3,698	3,678			3,678	3,5 – 4,5	3,0-4,0
	Braking distance (m)									
	Design/ operating speed	Speed limit +20km/h	50-130	80-130	50-120	50-120	50-120	50-120	50-130	
Environment / Other	Light conditions	day		Day					day	
	Weather conditions	wet							wet	

Table 2: SSD parameter and parameter values based on WP2-5 (Petegem et al. (2014).

It is evident that nearly all parameters have recommended values covering a range, which in most cases accommodate the values currently applied by the selected countries. However, in some cases there are significant differences. Only Perception-Reaction Time is constant over all the countries reviewed in this study.

The comparison of parameter values for the driver eye height revealed that relatively little variation exists. In addition, empirical studies point out that a value of less than 1.16m is on the safe side and that this height will remain constant for the years to come. Further, the impact that a little change of this figure might have on SSD is limited. Considering the results of the parameter study 1.10m is recommended as an appropriate driver eye height figure.

Concerning the driver observation position, a range of 1.25m to 2.25m exists, depending on the direction of the curve. The effect on SSD of a driver observation position within a range of 1.50m to 2.00m is only 6%. For motorways in countries driving on the right hand side left hand curves are crucial, because of the hard shoulder normally applied on the right side of this type of roads. Assuming a standard lane width of 3.50m for motorways and given the driver position in a standard vehicle and the fact that most drivers tend to a shift towards the inner side of the curve, the observation point position should be 1.30m for left hand curves in countries driving on the right measured from the edge marking. Given this consideration, an observation point value of 1.30m is recommended for future use in assessing SSD.

With regard to the definition of the object/obstacle in the various design guidelines and literature, large variations exist and no uniform approach has been adopted across countries. Its effect on curve radius is however significant. Consequently, a decision regarding the definition of obstacle size in the road is required as this has a material impact on the design of horizontal and vertical curves. Based on the result of the literature study, it is currently recommended that 0.50m should be adopted as the definition of obstacle height or size.

Concerning the obstacle position in the cross-section it is recommended to define the outer braking light as a reference for the position of the obstacle in the cross section. For a 3.50m wide lane, the distance from the inner marking line to the outer braking light is assumed 2.47m. The analyses of the possible impact that sight obstructing elements close to the road may have on SSD revealed that a range of different combinations need to be considered. Due to this, not a single figure can be set for the guidelines. It is recommended that the designer make use of tools similar to that developed in Work Package 3 to calculate the minimum curve radius and SSD requirements for any set of obstructing parameters.

For the coefficient of friction, one has to bear in mind that this parameter deteriorates over time. Due to the fact that SSD is a critical safety component, it is preferable to adopt lower rather than higher values (i.e. the road is marginally overdesigned).

In road design one strives to provide a design that will operate safety throughout its life. It is advisable therefore, to base the SSD parameter values on at least average situations and, at best, on worst case conditions resulting in designs that allow for some human error. In Europe the minimum coefficients of friction, given the (design) speed and test methods, range between 0.40 and 0.55 for new roads and 0.25 – 0.50 for maintenance purposes. The coefficient of friction values applied in most of the selected countries ranged between 0.30 and 0.48 with 0.377 being the most commonly applied value.

The literature and parameter studies indicated 3.5m/s^2 - 4.5m/s^2 to be a representative deceleration rate. This was confirmed from the field study conducted in Work Package 5, which found 3.0m/s^2 – 4.0m/s^2 as a typical maximum deceleration rate. Applying 4,0m/s^2 as the norm, the Fambro model yields an SSD of between 105m and 235m at speeds between 80km/h and 130km/h. As shown in Table 3 this compares favourably with the (recommended design) situation with a friction coefficient of 0.377 (111m – 248m).

Speed	**SSD (based on recommended parameter values)**	**SSD (based on Fambro and using 4 m/s^2 deceleration rate)**
[km/h]	**[m]**	**[m]**
50	55	50
60	70	70
70	90	85
80	110	105
90	135	130
100	160	150
110	185	180
120	215	205
130	250	235

NOTE: values rounded to the nearest 5m.

Table 3: Effects of parameter values on SSD requirements (Schermers & Broeren (2015)).

Table 3 gives an overview of the recommended parameter and parameter values that have been derived from the literature, the parameter study, the field trials (see Table 2) and the considerations of the possible effects changed parameter values might have (see Table 5 and Table 6).

SSD parameter variables	Recommended parameter value
Observation point position left curve (m) RHD countries (LHD countries)	1.3[3]
Observation point position right curve (m) LHD countries (RHD countries)	1.3
Obstacle height (m)	0.5
Observed point height crest curve (m)	0.5
Observed point height sag curve (m)	0.5
(Resulting) coefficient of friction	0.377
Tangential or braking coefficient of friction	0.377
Driver eye height Horizontal alignment (m)	1.10
Driver eye height Crest curve (m)	1.10
Driver eye height sag curve (m)	1.10 (2.5 truck)
Perception-Reaction Time (s)	2.0
Deceleration rate (m/s^2)	4.0

Table 4: Summary of parameter and parameter values (Schermers & Broeren (2015)).

[3] With a lane width of 3.5m.

SSD parameter variables	Recommended value	Impacts			
		DK	FR	DE	IE
Observation point position horizontal curves (left curve in RHD countries) (m)*	1.3	1.5	2.0	1.8	
		Minor decrease in curve radius (3%)	Increase in resultant curve radius (6-10%), marginal increase in costs	Increase in resultant curve radius , marginal increase in costs	
Obstacle height (m) (based on the right tail of a vehicle positioned 2,5m from the inner edge line of the left lane in RHD countries)**	0.5	0.5	0.5	0.5	0.26 – 2.0
		None	None	None	Significant decrease in resultant vertical curve radii (18-30%), reduced costs
Observed point height crest curve (m)	0.5	0.5	0.6	1.0	0.26 – 2.0
		None	Marginal increase in vertical curve radii, increased cost	Significant increase in vertical curve radii (36%), increased costs due to flatter alignment	Variable depending on height applied, lower values result in increased radii and higher values in decreased radii
(Resulting) coefficient of friction	0.377	0.377		0.25 - 0.32	
		None		Higher coefficient of friction leads to lower SSD. Negligible effect on maintenance	
Tangential or braking coefficient of friction	0.377	0.377	0.46	0.377	
		None	Lower coefficient of friction leads to higher SSD. Positive effect for maintenance due to lower costs resulting from less frequent resealing	Higher coefficient of friction leads to lower SSD. Negligible effect on maintenance	
Driver eye height Crest curve (m)	1.10	1.0	1.0	1.0	1.05
		Marginal decrease in curve radius (5%), decreased cost	Marginal decrease in curve radius (5%), decreased cost	Marginal decrease in curve radius (5%), decreased cost	Marginal decrease in curve radius (2 %), decreased cost
Perception-Reaction Time (s)	2.0	2.0	2.0	2.0	2.0
		None	None	None	None
Deceleration rate (m/s^2)	4.0	3.698	3.13 – 4.51	3.698	3.678
		Marginal decrease in curve radius (5%), decreased cost	For values below 4, marginal decrease in curve radius (5%), decreased cost	Marginal decrease in curve radius (5%), decreased cost	Marginal decrease in curve radius (5%), decreased cost

Note: * - right curve for LHD countries

** - 2.5m from the inner edge line for right hand curves in countries driving on the left.

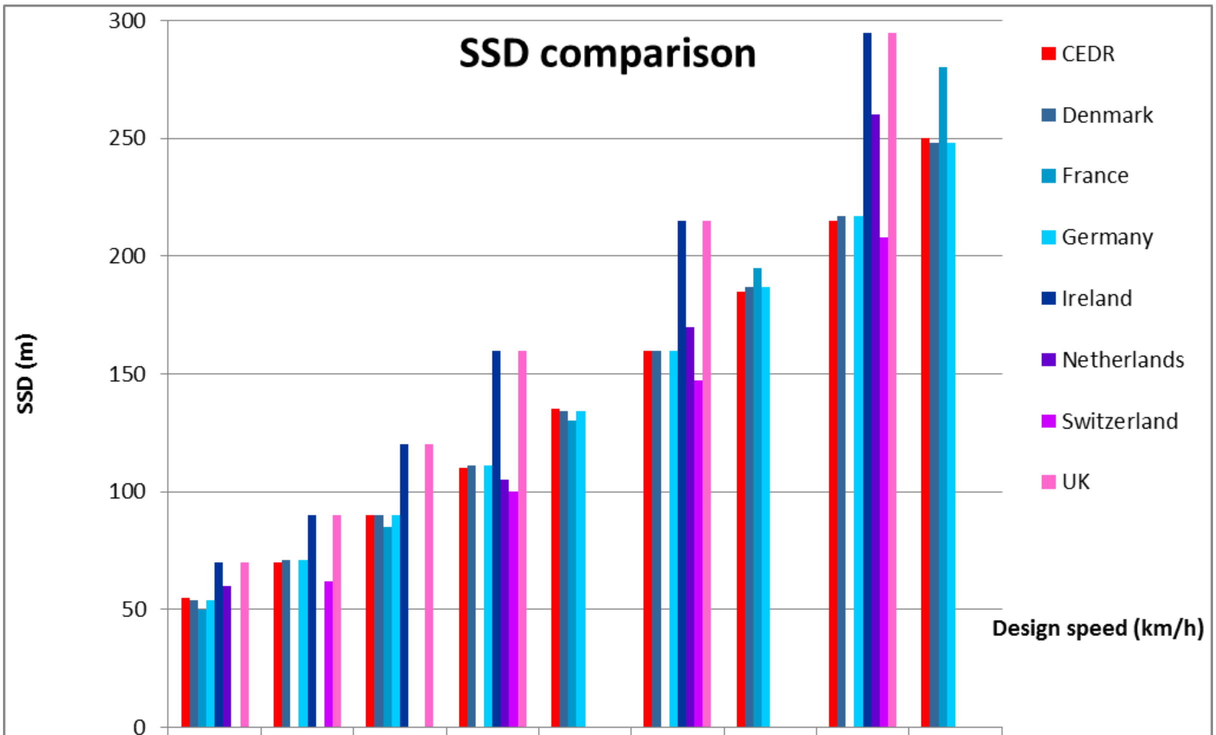
Table 5: Effect of changed parameter values for selected Countries (Schermers & Broeren (2015)).

SSD parameter variables	Recommended value	Impacts		
		NL	CH	UK
Observation point position horizontal curves (left curve in RHD countries) (m) *	1.3	1.25	2.0	
		Marginal decrease in curve radius (not significant)	Increase in resultant curve radius (6-10%), marginal increase in costs	
Obstacle height (m) (based on the right tail of a vehicle positioned 2,5m from the inner edge line of the left lane in RHD countries)* *	0.5	0.5	0.15	0.26 – 2.0
		None	Significant decrease in resultant vertical curve radii (30-50%), reduced costs	Significant decrease in resultant vertical curve radii (18-30%), reduced costs
Observed point height crest curve (m)	0.5	0.2 – 0.5	0.15	0.26 – 2.0
		Variable from no effect to decreased vertical curve radii (marginal effect on costs)		Variable depending on height applied, lower values result in increased radii and higher values in decreased radii
(Resulting) coefficient of friction	0.377	0.32 - 0.48	0.3 – 0.49	
		Lower coefficient of friction leads to higher SSD. Positive effect for maintenance due to lower costs resulting from less frequent resealing	Lower coefficient of friction leads to higher SSD. Positive effect for maintenance due to lower costs resulting from less frequent resealing	
Tangential or braking coefficient of friction	0.377	0.32 – 0.48	0.3 – 0.49	
		Lower coefficient of friction leads to higher SSD. Positive effect for maintenance due to lower costs resulting from less frequent resealing	Lower coefficient of friction leads to higher SSD. Positive effect for maintenance due to lower costs resulting from less frequent resealing	
Driver eye height Crest curve (m)	1.10	1.1	1.0	1.05
Perception-Reaction Time (s)	2.0	2.0	2.0	2.0
		None	None	None
Deceleration rate (m/s^2)	4.0	3.145		3.678
				Marginal decrease in curve radius (5%), decreased cost

Note: * - right curve for LHD countries
** - 2.5m from the inner edge line for right hand curves in countries driving on the left.

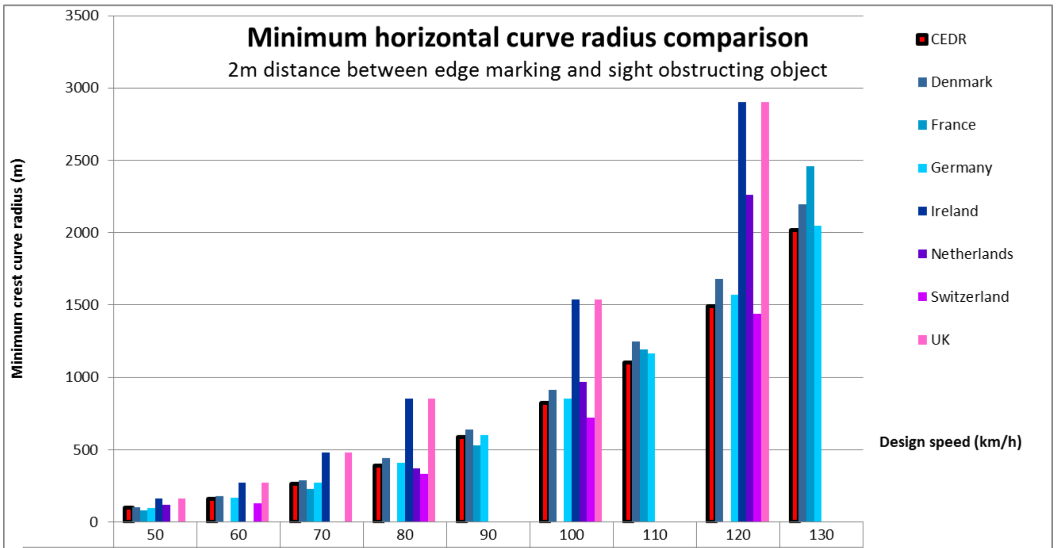
Table 6: Effect of changed parameter values for selected Countries (Schermers & Broeren (2015)).

The comparisons of SSD, minimum horizontal curve radius and minimum crest curve radius have been calculated based on the current national guidelines and the recommended values are shown in the Table 7, Table 8 and Table 9 below. The minimum horizontal curve radii in this study are based on a situation with sight limitations, while the minimum curve radii in some national guidelines are only applicable in situations without sight limitations (they are based only on vehicle dynamics, the skidding criterion).



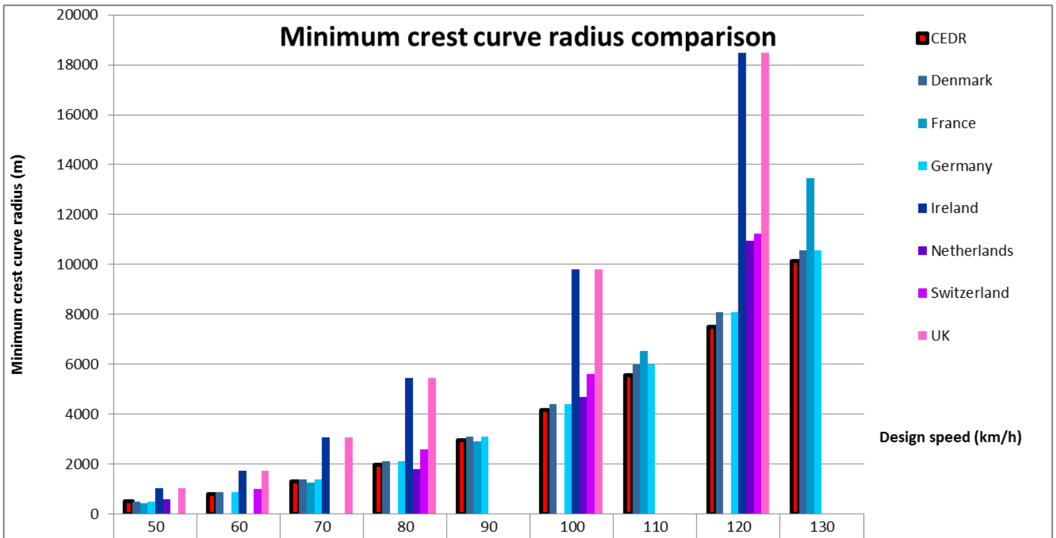
	50	60	70	80	90	100	110	120	130
CEDR	55	70	90	110	135	160	185	215	250
Denmark	54	71	90	111	134	160	187	217	248
France	50		85		130		195		280
Germany	54	71	90	111	134	160	187	217	248
Ireland	70	90	120	160		215		295	
Netherlands	60			105		170		260	
Switzerland		62		100		147		208	
UK	70	90	120	160		215		295	

Table 7: Comparison of SSD (Schermers & Broeren (2015)).



	50	60	70	80	90	100	110	120	130
CEDR	98	158	261	390	588	825	1104	1490	2015
Denmark	104	180	289	440	641	914	1249	1682	2197
France	78		227		530		1193		2460
Germany	97	168	270	411	599	853	1166	1570	2050
Ireland	163	270	480	853		1541		2901	
Netherlands	121			369		968		2263	
Switzerland		128		333		720		1442	
UK	163	270	480	853		1541		2901	

Table 8: Comparison of minimum horizontal curve radius (Schermers & Broeren (2015)).



	50	60	70	80	90	100	110	120	130
CEDR	491	795	1314	1962	2955	4151	5550	7496	10135
Denmark	500	865	1390	2114	3081	4392	6000	8079	10552
France	429		1240		2900		6524		13451
Germany	500	865	1390	2114	3081	4392	6000	8079	10552
Ireland	1040	1720	3057	5435		9814		18477	
Netherlands	584			1788		4687		10962	
Switzerland		999		2598		5614		11240	
UK	1040	1720	3057	5435		9814		18477	

Table 9: Comparison of minimum crest curve radius (Schermers & Broeren (2015)).

6 Conclusion

The results of the analysis conducted within the frame of this project leads to the conclusions that a common approach for the definition of Stopping Sight Distance could be developed and that due to a common definition of parameter and parameter values no significant changes in road design in different European countries are to be expected. Instead it could be expected that a common approach on Stopping Sight Distance might have a positive impact on traffic safety of cross border traffic.

One remarkable fact is, that a common approach concerning neither the initial speed nor the relationship between Design Speed, Operating Speed, v_{85} and v_{95} exists. Based on the impact the initial speed has on SSD it is suggested that this aspect should be analysed in the frame of future research projects. One further aspect is, that depending on the definition of the size of an obstacle, median barriers could become a sight obstructing object. With regard to further developments in areas relevant for the calculation of the SSD, e.g. brake performance of vehicles, driver assistant systems, it is advisable to periodically revise input variables that may change over time and thereby affect the resulting SSD parameter. To account for changes in driver, vehicle and/or pavement properties, these should be reviewed at least every five years.

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