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Representative parameter values study

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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)

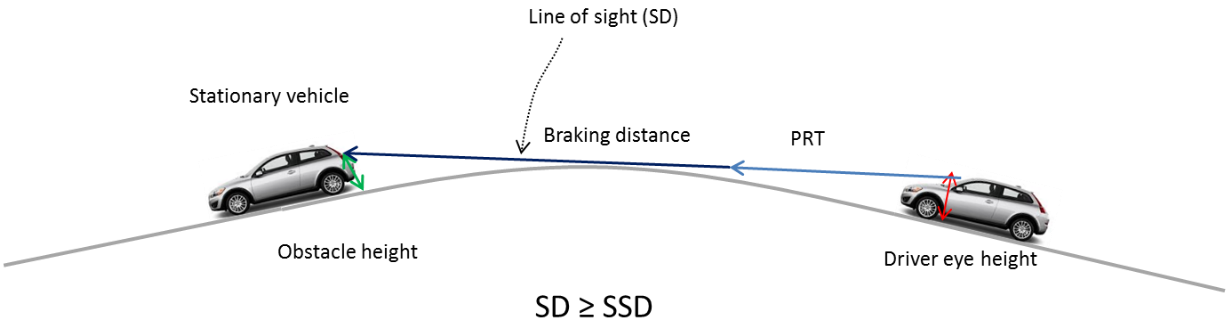
The time it takes for a road user to realize that a reaction is needed due to a road condition, decides what manoeuvre is appropriate (in this case, stopping the vehicle) and start the manoeuvre (moving the foot from the accelerator to the brake pedal).

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

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, it is of great importance to provide a clear line of sight of the road ahead in order to, for example:

- Avoid a collision with a possible obstacle downstream on the carriageway - the Stopping Sight Distance (SSD). The obstacle can be an object or a stationary vehicle on the road (because of a lost load, a breakdown or a queue of vehicles);
- Safely overtake a slower vehicle on a carriageway with two way traffic – the Overtaking Sight Distance (OSD);
- Comfortably merge with or cross traffic at an intersection;
- Process roadside information on traffic signs.

Some international guidelines or handbooks (like AASHTO Green Book (AASHTO, 2001)) explicitly distinguish between different types of sight distance and also the type of obstacle: stopping in front of a stationary 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 referred to as SSD.

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 large horizontal and vertical curve radii which adversely affects speeds and thereby crashes and crash severity. This illustrates the necessity for applying appropriate sight distances in geometric road design.

1.1 Background

A road design should provide sufficient sight distance over the entire length of the road. This sight distance is not only important to see and anticipate conditions on the road ahead but also to be able to detect and react/stop for potential hazards on the road.

In calculating sight distances it is necessary to distinguish between the minimum sight distance as set in road design guideline (SSD) and the available sight distance on the road (SD). Both are closely related to traffic safety and road design. For both SD and SSD, parameters such as perception reaction time, speed, vehicle deceleration rate, road surface and weather are essential input variables, which should be taken into account during road design.

Furthermore, these parameters should also be considered under different conditions to ensure that the design accommodates the widest possible range of conditions that a driver is likely to encounter whilst driving normally or when forced to take evasive action.

These parameters have been discussed at length in WP2 (Petegem et al., 2014) and WP4 (Hogema et al., 2015) and these will be discussed in varying detail in this and later chapters.

The literature review revealed that there are many studies available on Perception–Reaction Time (PRT)(Petegem et al., 2014). PRT is characterised by a distribution rather than by a constant value to describe the effects of factors such as age, mental state, task complexity and others on PRT. In most European countries a standard 2 s value based on the 85th percentile value has been adopted whereas the USA applies 2.5 seconds based on the 99th percentile.

Brake assist and similar systems can significantly improve braking performance and through higher deceleration rates reduce the overall brake-distance requirements. Such intelligent systems can compensate for prevailing conditions and negate the necessity for providing high levels of skid resistance under wet conditions. However, not all vehicles are equipped with such technology and in considering setting parameter values for SSD, consideration must also be given to the effect of these developments. It is likely that in the coming years that SSD criteria will remain based on a vehicle fleet containing vehicles *without* such systems (and therefore friction remains very much speed dependent).

Most SSD calculations are based on a design scenario with a wet road surface. 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. The existing surface types (concrete / dense asphalt / porous asphalt) are characterised by different micro and macro structures and by different water drainage characteristics.

The above illustrates that SSD is dependent on various (critical) parameters which all need careful consideration. Before developing a uniform set of parameters and setting their values, the impacts of these choices on current design practice must be carefully taken into account.

1.2 Overall Work Plan

Figure 1.1 shows the planned approach for the entire project. This report addresses Work Package 6 (Representative parameter values) and synthesises the results from the literature study (WP2), parameter study (WP4) and field measurements (WP5) which have been reported in detail earlier in the project (Broeren, 2015;Hogema et al., 2015;Petegem et al., 2014).

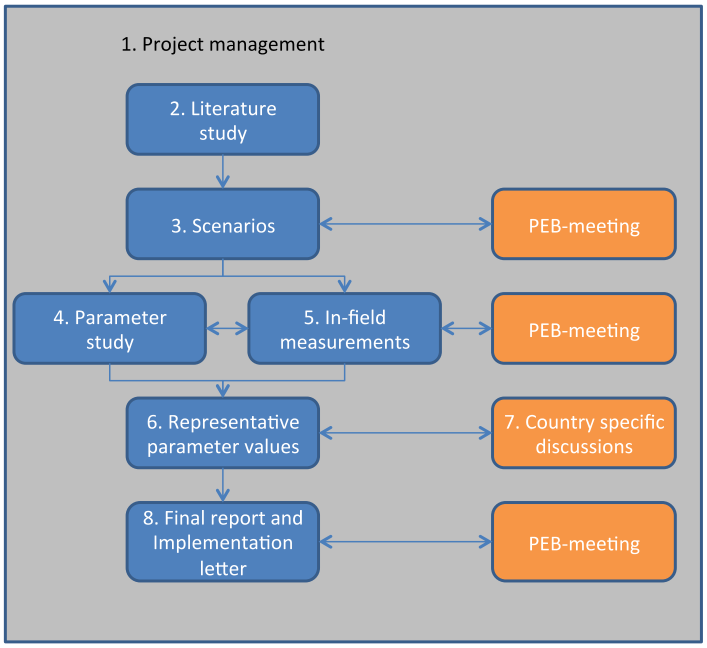


Figure 1.1 Outline of work plan

1.3 Objectives

The overall objective of this CEDR 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. Sight Distances (in their broadest sense), and specifically SSD, are the result of interactions between a driver, the vehicle and the road given a set of conditions (Figure 1.2). Consequently, this research considers stopping sight distance from all of these interrelated aspects and focusses on these individually and/or collectively.

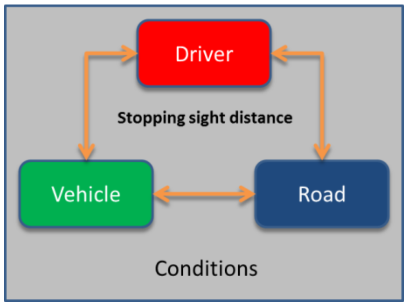


Figure 1.2 SSD-research in three aspects

The primary objective for this work package is to determine representative parameter values for stopping sight distances.
A secondary objective is to determine and assess country specific differences and consequences for adopting uniform parameters for stopping sight distance in EU member countries.

2 Methodology-project overview

The overall methodology is illustrated in Figure 2.1.

In Work Package 2, a literature review was carried out in which road design guidelines from the EU Member States, 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.) were studied and reported (Petegem et al., 2014).

In Work Package 3, the results of the literature review were utilised to develop a conceptual model of stopping sight distance (SSD) in which all the relationships between the various parameters affecting sight distance were defined.

In Work Package 4, a parameter study was carried out to determine the 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 EU Member States, 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.

Work Package 6 brings together these results and representative values are determined for the various parameters required for establishing Stopping Sight Distance (SSD) in geometric design (and in some cases also parameters relevant to SD). WP6 also provides an overview of expected impacts on current design practice and related costs.

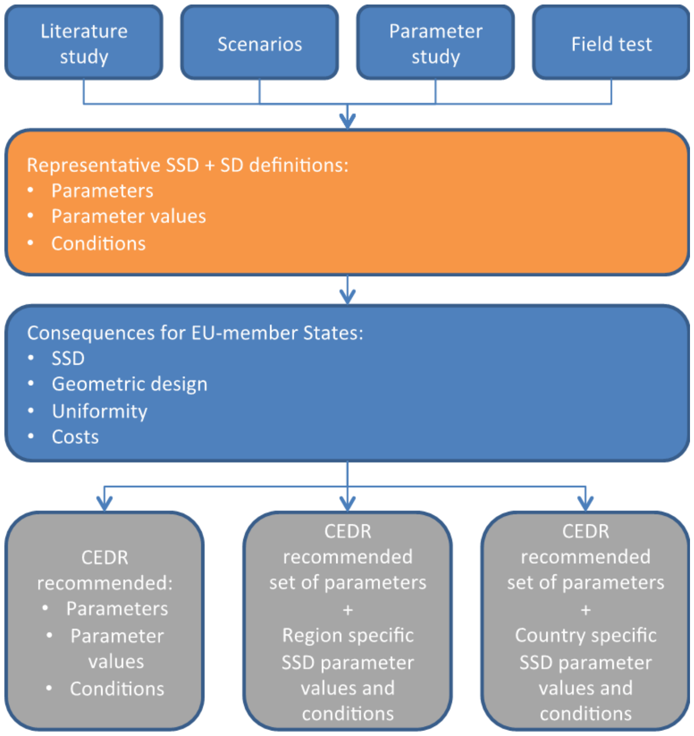


Figure 2.1: Process for determination of parameter values

2.1 Work package 6 methodology

The results of the literature study, conceptual model, the parameter study and the field measurements, were used to define representative parameter and parameter values. This was achieved by:

- Taking the (distribution of) actual parameter values of the individual EU Member States and the representative conditions;
- Comparing these values to the values in the National road design guidelines;
- Calculating and describing the effects of 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);

Depending on the consequences for individual countries in terms of changes in values for SSD and geometric design elements (larger or smaller curve radii); it was possible to determine one complete set of parameters, parameter values and conditions for the entire EU. If the consequences are too big for some countries, multiple sets of parameter values could be proposed. Depending on the national road, vehicle and driver characteristics, a country can use the most appropriate set of values. WP6 attempts to make clear if uniform EU criteria for SSD are possible.

In essence WP 6 has as its primary task the bringing together of results from primarily WP 4 and 5 (WP 4 having used the results from WP2 and 3) in a set of recommended parameter values for use in determining SSD in European road design. This presents 2 primary challenges; firstly defining the set of parameters required to calculate SSD and their respective values; and secondly how that impacts on current practice in the EU.

The first challenge has, to an extent, been overcome since WP4 has recommended certain parameters and their respective values. The list below shows the parameters originally identified in the proposal and to what extent these parameters have been dealt with in WP2, 3, 4 and (to an extent) 5.

1. SSD definition and purpose (covered)
2. SSD obstacle dimensions and conditions (covered)
3. SSD obstacle position and conditions (scenario's) (partially covered)
4. SSD observation points (indirectly covered in WP2 and 4)
5. Driver eye height (covered)
6. Common obstacle height (indirectly covered)
7. Effect of road side elements on SSD (not covered although this is not a SSD-parameter for which a road designer has to make choices: from the other parameters (eye height, obstacle definition) it follows when a roadside element is sight obstructing) (indirectly covered)
8. Deceleration rates (optimum/wet etc.) (indirectly covered)
9. Tyre tread depth standards (indirectly covered)
10. Obstacle definition and SSD in relation to design speed increases (covered)
11. Orientation sight description and effects on SSD (indirectly covered)
12. SSD in non-standard conditions (tunnels etc.) (partially covered)
13. Perception and reaction times (covered)

The parameters selected in WP6, and their values, will be based on the recommendations of WP2, WP4 and WP5. However, since it was not possible to cover all the parameters to the same level of detail for each country, an overview of all the original parameters by country will be provided. This comparison will, for each country, provide insights into the consequences of dropping certain parameters versus introducing others, which presently are not used. This introduces the second problem, namely the list of countries to be included in the WP6 report.

The research proposal makes regular reference to EU-member states (e.g. in WP6, milestone 6.2 on page 31) implying that EUSight will include an overview of all countries belonging to the EU. However, 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 England (UK). WP6 will primarily concentrate on these countries. 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 will also be included. Insight into the potential impact of changed SSD parameters and values on design practice in Denmark, France and Switzerland, will also be provided for illustrative purposes.

The parameter overview will, by country, reveal potential changes to SSD parameters and parameter values resulting from this study. The overview provides current parameters and values (from WP2), proposed parameters and values (from WP4 and 5) and indicates potential impacts (positive and negative). This will provide insight into the possibility of introducing one set of parameters and parameter values and indicate the implications and consequences on future design practice in each of the aforementioned countries. The basis will be an assessment of the impacts of the changed parameter values on current EU guidelines using an Excel based tool developed within the framework of WP 3.

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

3 Background to sight distance

3.1 Stopping sight distance

Stopping sight distance is the most basic requirement in geometric design since a design must at any single point along a road provide enough sight distance for a driver to be able to safely stop in front of an unexpected obstacle on the carriageway. SSD is nothing more than the distance that a driver must be able to see ahead along the road to detect a hazard or obstacle and to bring the vehicle to a safe stop. SSD is affected by both the horizontal and vertical alignment. Within curves the cross section and the roadside space might also have an impact.

SSD is the sum of the distance during the driver perception-reaction time and the vehicle braking distance. Essentially this is the distance required for a vehicle traveling with a specific speed to be able to stop before reaching the obstacle/hazard. SSD depends on:

- the time required for a driver to perceive and react to the stopping requirement; and
- the time needed for the driver to complete the braking manoeuvre

A basic SSD formula (Fambro, Fitzpatrick, & Koppa, 1997) is given in equation (1).

$$SSD = 0.27\,V\,t_{RT} + 0.039\,\frac{V^2}{a} \qquad (1)$$

Where :
V is the design speed (km/h),
t_{RT} is the reaction time (s) and
a is the average deceleration rate (m/s^2).

This initial formula is fairly basic in that the geometry and condition of the road are not considered as independent variables, mainly due to the fact that the model was developed for a range of roads covering a range of conditions. More complexity stems from the constants in the equation, which are correlated with other factors, and also stochastic in nature.

When considering all parameters concerning SSD, one has to distinguish the *minimum* SSD according to the road design guideline (usually referred to as SSD) and the *available* sight distance on the road (SD). Both are closely related to traffic safety and road design.

Table 3.1 shows the parameters relevant to determining SSD and SD.

Parameter	Influenced by	Relevant for
Speed	Driver (, condition)	SD, SSD
Perception reaction time	Driver (, condition)	SSD
Deceleration rate	Driver, vehicle, road surface, condition	SSD
Drivers' eye height	Driver, vehicle	SD, SSD
Drivers' lateral position	Vehicle, road design	SD, SSD
Stationary obstacle definition and position	Vehicle, condition, country definitions	SSD
Horizontal alignment	Road design	SD, SSD
Vertical alignment	Road design	SD, SSD
Cross section	Road design	SD, SSD
Road side obstacles	Road design	SD, SSD

Table 3.1 sight distance parameters

A parameter particularly relevant to SD and SSD is the definition of an obstacle and its position on the carriageway as well as of the situation requiring the stop to be made. This definition has a material effect on the outcome of the SSD required, generally the smaller the obstacle the bigger the SSD required. It is therefore important to base this definition on what really constitutes a threat to a driver and what must really be detectable at a given speed to allow the driver to safely come to a stop. In some countries the rear brake lights of cars define the obstacle height and in others an inanimate obstacle on the carriageway. However, in both cases there are factors that may affect the choice and definition, namely:

- The minimum size of a vehicle needs to be estimated and a decision concerning the position of the relevant brake light must be made.
- The impact that weather and visibility conditions may have on the visibility of the obstacle must be defined.
- Choosing a box as the relevant obstacle makes it necessary to define the minimum size of the box, based on assumptions concerning the visibility under different weather and lighting conditions (normally an imaginary box of 500mm high).

Certain parameter values may vary between EU Member States, since:

- 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.
- Design and construction costs may differ.
- The driving behaviour in the different countries may vary too, resulting in different perception reaction times, speeds and deceleration rates.
- 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.
- 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 deceleration rate of vehicles, the minimum tyre profile depth, the minimum friction coefficient of the road surface, ambient lighting.

3.2 Orientation Sight Distance or Orientation Visibility

In Germany a behaviour based approach called orientation sight distance has been introduced (Lippold & Schultz, 2007). The orientation sight distance supplements geometric parameters used in assessing sight distances with so called psycho-physiological criteria that allow for the extra demand placed on drivers (and their perception reaction times) by conditions on the road. This relationship was measured by looking at driving and viewing behaviour such as brake retardation, gazing at the road, and time spent on a secondary task. The study revealed that shorter SDs resulted in increased driver workloads.

Recently, German design guidelines have included a standard methodology to check the 3 dimensional alignment of a road during design. This takes into account the constraints mentioned previously with regards to sight distance and driver reaction/perception.

Work Package 5 (Broeren, 2015) provides some further insight into recommended Orientation sight distance (OSD) values for roads. For rural roads this revealed that visibility of at least 200m is needed to provide drivers with sufficient response and decision-making time. At lower visibility distances driver stress is increased and behaviour becomes more uncertain. These studies have resulted in the following recommendation for orientation visibilities:
- 100-120 km/h: 220-250m
- 80-100 km/h: 180-220m

These values are conservative, accounting for intra- and inter-individual differences among all the drivers in the pool.

3.3 Developments in relation to sight distance

Sight distances are impacted by many different aspects, and changes to any of these may result in the SD requirements changing. It is therefore important to regularly evaluate the criteria used in SD and SSD calculation to establish whether these are still relevant given the driver and vehicle population using the road network. Table 3.2 lists a number of factors that through change can impact on SD requirement from a driver, vehicle or road environment perspective.

Aspect	Driver	Vehicle	Road
Technological development of vehicles (ABS, ESP, brakes, etc.)	X	X	
Road surface characteristics (higher friction coefficient)			X
Quality of tyres (higher friction coefficient)		X	
Cross-border traffic in Europe (cars and especially trucks).	X	X	
Road safety equipment (managed roads, dynamic traffic management)			X
Third brake light		X	
Aging driving population (more elder drivers (60+) on the road)	X		
In-car technology (both assisting and distracting drivers)	X	X	
Increasing complexity of road configurations (self explaining roads versus special configurations)	X		X
Economic crisis in some EU-countries: less budget for maintaining road infrastructure and design of new roads as well as less budget for modern and well equipped vehicles		X	X

Table 3.2: Examples of sight distance related developments that may impact sight distance requirements

3.4 Accident factors and assumed relationship

Lower sight distances are reported to have a negative relationship with run-off road collisions and to a lesser extent with head-on collisions. The accident rate decreases as the sight distance increases. The relationship between collision rate and sight distance is not linear since the rate is seen to decrease rapidly until a certain critical distance is reached (Fambro, Fitzpatrick & Koppa, 1997).

On rural roads, sight distances less than 200m require a higher attention of drivers.
At sight distances less than 150m the impact is much higher (Lippold & Schultz, 2007), the critical sight distance is in the order of 90-100m.

Crashes related to sight distance are the result of the interaction between many factors and unfortunately most studies do not always correct for these influences. It is known that increasing the radius of horizontal curves leads to improved sight distance and that this in turn results in reduced crashes (Elvik et al., 2009). However, there is a fine balance between a safe sight distance and an unsafe one, too little leads to more crashes and too much also leads to more crashes.

4 Selection of relevant parameters for determining SSD

4.1 Parameters

Work packages 2 through 5 (Broeren, 2015; Hogema et al., 2015; Petegem et al., 2014) discussed the various concepts and definitions related to parameters relevant to determining stopping sight distances.

The following parameters were selected as being the most relevant for SSD (the number in brackets relate to the number in the original list developed in the research proposal, Section 2.1):

- The design or operating speed (1; 2; 8; 10;12)
- The point of observation (horizontal and vertical curves) (3; 4; 7 and 11)
- The obstacle height (2 and 6)
- The driver eye height (5)
- The road surface (8)
- The coefficient of friction (lateral and tangential) (8)
- The vehicle braking performance (8)
- The tyre tread depth (9)
- Environmental parameters (day/night and wet/dry/snow) (12)
- The driver perception-reaction time (13)

The majority of these are indirectly applied as input in a summary variable (for example deceleration rate is determined from vehicle braking performance, tyre tread depth, road surface and friction coefficients etc.) and therefore it is not essential to include these as SSD parameters in a guideline.

4.2 Parameter values

Table 4.1 provides an overview of the relevant SSD parameters and their values as determined from the literature study (Petegem et al., 2014), the parameter value study (Hogema et al., 2015) and the field measurements (Broeren, 2015).

A number of the parameter values recommended by the parameter study deviate significantly from the current design values applied by a number of countries. For instance, the parameter study recommends (Hogema et al., 2015) that the observation point for left horizontal curves should be 1.5 m (measured from the left lane edge line), where countries such as France and Switzerland currently apply 2.0 m. This has a material effect on the resulting curve radii (generally a larger distance of the observation point to the edge of the lane marking results in a lower curve radius).

Aspect	SSD default variables	Country values							Recommended values	
		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 (Ft)	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	50-130	50-130	50-130	50-130	50-130	
Environment/ Other	Light conditions	day		Day					day	
	Weather conditions	wet							wet	

Table 4.1: SSD parameter and parameter values based on WP2-5

Also the driver eye height and obstacle height in crest vertical curves have a significant impact on SSD and resulting curvature values. Adopting the German values would result in smaller radii whereas adopting the English values would result in much larger (flatter) crest vertical curves.

4.3 Effect of parameter value changes on SSD and curvature

Since SSD requirements dictate horizontal and vertical curvature, it is important to assess the impact of changes to SSD parameters on curvature. Since this study aims to recommend a uniform set of parameters and also to set the parameter values, it is important to gauge the impact of these changes on current design practice from both a space and cost perspective. Obviously the recommendations must take into account current practice and be realistic without imposing radical increases or decreases in SSD and consequently much more generous or much more fragmented horizontal and vertical curvature (implying higher or lower costs). It is the purpose of this report to establish the effect of changes to current parameter values on SSD and ultimately on horizontal and vertical curve radii in each of the selected countries. From Table 4.1 it is evident that only perception-reaction time is constant over all the countries reviewed in this study. All remaining 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 differences. In order to assess the impact of these on current design practice in each of the selected countries, the parameter values will reflect three conditions, a low, mid and upper range value.

4.3.1 Effect of PR and friction coefficient on SSD

SSD is the sum of the distance (time) travelled during the perception-reaction phase and the distance (time) covered during the actual braking phase. Obviously the SSD depends on the initial speed, the braking capability of the vehicle and the road surface (coefficient of friction, whether it is wet/dry and on a slope or not). Since this represents a worst case scenario (minimum value to be provided) road design practice is to adopt fairly generous values for PRT and deceleration, in that way ensuring that the provided SSD results in generally adequate horizontal and vertical road curvature for a given initial speed. However, providing excessive SSD can also result in expansive and expensive road designs (and possibly inappropriate and excessive operational speeds) and therefore it is important to keep reviewing, and where necessary revising, parameters affecting SSD to take into account technological and other developments.

The EUSight literature (Petegem et al., 2014) and parameter studies (Hogema et al., 2015) revealed that most countries in Europe apply perception reaction times of 2 s. This is lower than in the USA where 2.5 s is the norm. The coefficient of friction values applied in most of the selected countries ranged between 0.3 and 0.48 with 0.377 being the most commonly applied value. Applying high friction coefficients materially affects the resultant SSD with higher values obviously leading to lower SSD values (Figure 4.1).

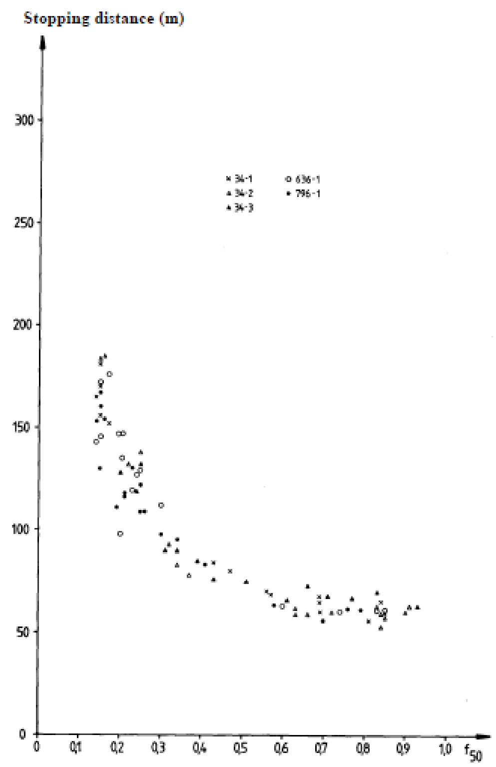


Figure 4.1: Actual stopping distance at different friction coefficients.

Passenger cars with unstudded tyres (Wallman & Aström, 2001).

Bearing in mind that SSD is a critical safety component and that the coefficient of friction deteriorates over time, it is preferable to adopt lower rather than higher values (i.e. the road is marginally overdesigned). Currently PRT values applied in European countries are already lower than in for example the USA, and the additional application of coefficient of friction values on the higher end of the (minimum value) scale (>0.7) could lead to critical SSD values allowing for little or no room for driver error in extreme emergency situations. Applying the principles of forgiving roads, a road should provide sufficient safety levels for an average driver to make a mistake without resulting in a serious (injury related) crash. By implication this means that given the PRT, the driver should be able to stop safely in most emergency situations without special remedial measures having been taken (e.g. lower speed limits, rumble strips etc.).

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 0.4 and 0.5 for new roads and 0.25 – 0.5 for maintenance purposes (Table 4.2).

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 4.2: Minimum road friction coefficients (Hogema et al., 2015)

The parameter study (Hogema et al., 2015) discusses the relationship between road surface, tyre and weather conditions in detail. It concludes that for determining SSD, road surface skid resistance values, and resulting maximum deceleration rates should be kept low, mainly because of the relatively large population of vehicles without ABS on EU roads.

The effect of friction coefficient on SSD is shown in Table 4.3. Given a fixed PRT of 2s this shows the effect of the friction coefficient values (between 0.3 and 0.74) as derived in WP2 and WP4 on total stopping distance required. Obviously the higher the coefficient the smaller the proportion of distance travelled during braking, resulting in significantly lower SSD's (and, should they be applied, significantly tighter horizontal and vertical alignments with little or no margin for error in the interaction between driver, road and vehicle).

Speed [km/h]	PRT [s]	Stopping sight distance [m] for a given friction coefficient 0.3	0.377	0.48	0.74
50	2	60.6	53.9	48.3	41.1
60	2	80.5	70.9	62.8	52.5
70	2	103.1	90.0	79.0	64.9
80	2	128.3	111.2	96.9	78.5
90	2	156.2	134.5	116.4	93.0
100	2	186.6	159.9	137.5	108.7
110	2	219.7	187.3	160.2	125.4
120	2	255.4	216.9	184.6	143.2
130	2	293.8	248.5	210.7	162.0

Table 4.3: Effect of PRT and friction coefficient on Stopping Sight Distances

For a road authority to continually maintain high levels of road surface friction is unlikely in view of the fact that previous studies (Hogema et al., 2015) have revealed that a realistic average value would be around 0.5-0.6 and with road authorities adopting minimum values between 0.25 (Poland) and 0.5 (Sweden) before undertaking preventative maintenance. Apart from road pavement wear, weather and vehicle tyres also have a strong influence on the resulting stopping distance. 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, an older vehicle with worn tyres, and a wet road and/or a worn (slippery) pavement with low skid resistance.

Given the applied design speeds and resulting SSD values in Table 4.3, deceleration rates under these conditions would range between 1.57 m/s^2 at 50 km/h and 2.4 m/s^2 at 130 km/h. Applying these deceleration rates to equation 1 in Section 3.1 (Fambro, Fitzpatrick & Koppa, 1997) reveals that such low deceleration rates would provide significantly larger SSD's (Table 4.4) than when applying PRT and friction coefficient values. Considering that the Fambro model was built using data collected at a range of sites representing typical conditions, its application is likely to be most reliable for the deceleration rates within 1 or 2 standard deviations of the mean. The literature and parameter studies indicated 3.5-4.5 m/s^2 to be a representative deceleration rate (confirmed by the field study in WP 5, which found 3.0-4.0 m/s^2). Applying 4.0 m/s^2 as the norm, the Fambro model yields an SSD of between 105 and 235m at speeds between 80 and 130km/h. This compares favourably with the (recommended design) situation with a friction coefficient of 0.377 in Table 4.3 (111 – 248m).

Speed (km/h)	PRT (s)	Stopping sight distance (m) for a given deceleration rate (m/s^2)				
		2	3	4	5	6
50	2	75.8	59.5	51.4	46.5	43.3
60	2	102.6	79.2	67.5	60.5	55.8
70	2	133.4	101.5	85.6	76.0	69.7
80	2	168.0	126.4	105.6	93.1	84.8
90	2	206.6	153.9	127.6	111.8	101.3
100	2	249.0	184.0	151.5	132.0	119.0
110	2	295.4	216.7	177.4	153.8	138.1
120	2	345.6	252.0	205.2	177.1	158.4
130	2	399.8	289.9	235.0	202.0	180.1

Table 4.4: SSD based on Fambro's model (Fambro, Fitzpatrick & Koppa, 1997)

4.3.2 Effect on vertical curvature

A vertical curve must provide enough sight distance for a driver to be able to identify and stop for an obstacle over the crest or past the sag of the curve. Apart from the speed, two other aspects, namely the driver eye height (h1) and the obstacle height (H2), and by definition also the type of obstacle are critical in this (Figure 4.2).

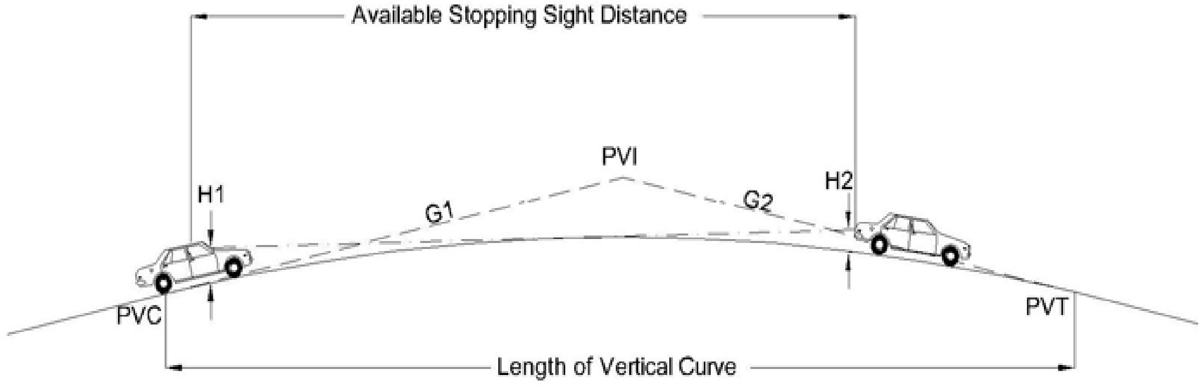


Figure 4.2: Factors affecting SSD on crest vertical curves

The crest vertical curve radius (in m) is calculated from:

$$R\min = \frac{SSD^2}{2.(\sqrt{h_d}+\sqrt{h_0})^2} \qquad (2)$$

Where:
SSD is the stopping sight distance in metres and
h_d and h_o are the driver eye height (in m) and the obstacle height respectively.

Work packages 2 and 4 revealed that there is significant variation between countries in especially obstacle and driver eye height in vertical (crest and sag) curves. Obstacle heights differ from 0.26 m to 1.0 m and driver eye heights from 1.0 m to 1.1 m (and 2.5 m for trucks in sag vertical curves). For the purpose of this report crest vertical curves are used to illustrate the effects of changes in the value of these two parameters on curve radius (Table 4.5). As with SSD, a lower, mid and upper range value for obstacle height has been used and a lower and upper value for car driver eye height.

This relationship shows the effect of obstacle height and driver eye height on resultant crest vertical curve radii with logically the lower the obstacle and driver eye height the flatter the required curve for the design speed and required SSD. Since driver eye height has remained relatively constant (at 1 – 1.1 m) over the years (Hogema et al., 2015; Schermers, Stelling & Duivenvoorde, 2014), this parameter has, and will have, relatively little impact on resultant curve radii. However, the definition of the object/obstacle in the various design guidelines and literature varies and no uniform approach has been adopted across countries. Its effect on curve radius is however significant.

Design speed (km/h)	SSD (m)	Driver Eye Height (m)	Crest Curve radius by obstacle height (m)		
			0.26	0.5	1.0
50	54	1	636	498	363
		1.1	597	470	346
60	71	1	1102	862	628
		1.1	1034	815	599
70	90	1	1777	1390	1013
		1.1	1667	1314	965
80	111	1	2712	2122	1546
		1.1	2545	2006	1473
90	135	1	3967	3104	2261
		1.1	3723	2933	2155
100	160	1	5606	4385	3195
		1.1	5260	4145	3044
110	187	1	7697	6021	4387
		1.1	7222	5691	4180
120	217	1	10316	8070	5880
		1.1	9680	7628	5603
130	249	1	13545	10597	7720
		1.1	12710	10016	7357

Table 4.5: Effect of Driver eye height and obstacle height on crest curve radii

Consequently, a decision regarding the definition of an obstacle size in the road is required 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 (Hogema et al., 2015; Petegem et al., 2014) that at a height of 450-600mm obstacles become dangerous to vehicles. It is furthermore argued that smaller obstacles (150mm) do not pose sufficient risk for drivers to detect and stop for them and that designing for these would be designing for situations that seldom or never occur (in Hogema et al., 2015).

Because car taillights fall into the 450-600 mm height range, these have been adopted by many countries as the standard definition for an obstacle. With regard to the third brake light some countries have adopted 1m as the obstacle height but considering the potential for smaller obstacles (and even brake lights of sports cars) remaining undetected over the top of crest curves and the risk of crashes due to inadequate SSD’s.

It is recommended that a height of 0.5 m be adopted as the definition of obstacle height or size.

4.3.3 Effect on horizontal curvature

Horizontal curves must provide adequate SSD for a driver to be able to see an obstacle on the road ahead and because of the curvature this means the line of sight should not be obstructed by obstacles in the verge (Figure 4.3).

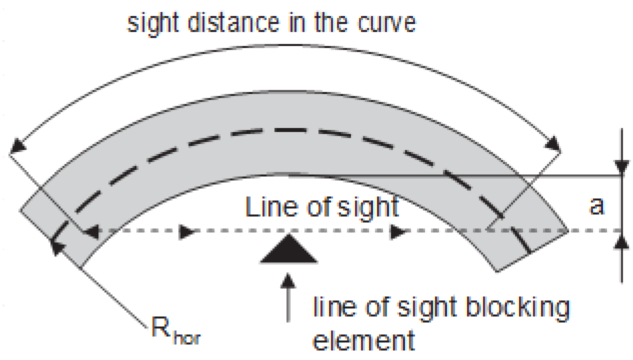


Figure 4.3: Concepts related to sight distance in horizontal curves

Minimum horizontal curve radius is determined by the required SSD, the lateral position of the driver and the vehicle on the road, the presence and location of any sight distance restricting elements and the lateral position and height of the obstacle on the road ahead (Figure 4.4).

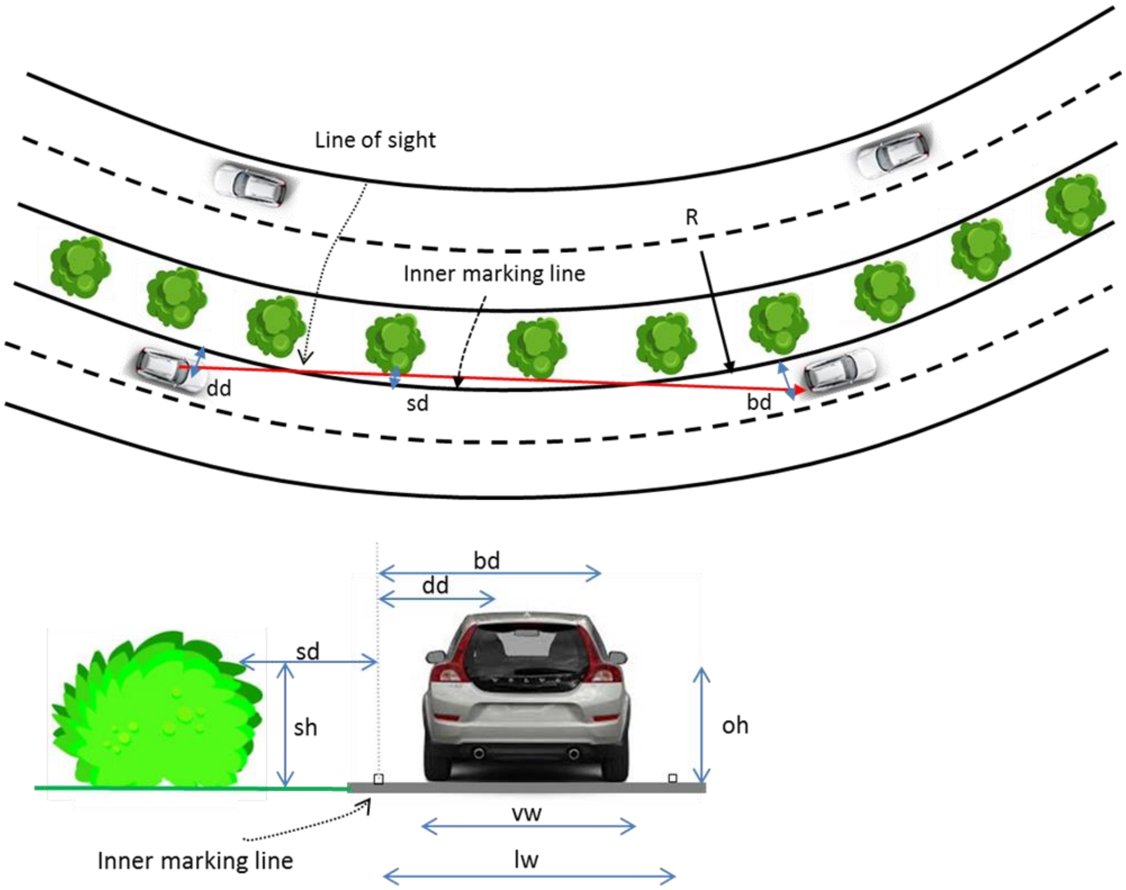


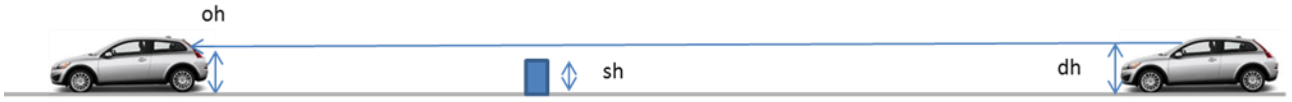
Figure 4.4: Factors affecting sight distance in horizontal curves (Hogema et al., 2015)

4.3.3.1 Sight restricting objects

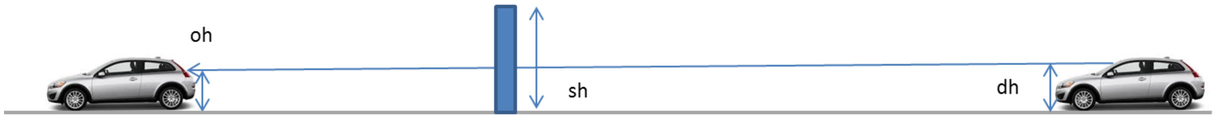
If (and how much) an object restricts the sight distance, depends on a number of factors, namely:

- Driver eye height (dh)
- Obstacle height (oh)
- Height of the sight restricting object (sh)

The following scenarios can be distinguished:

1. 

In this scenario both the driver eye height and the obstacle height are higher than the height of the sight restricting object. In this combination, there is actually no sight restriction: the driver is able to observe the obstacle over the top of the sight restricting obstacle:
Example: driver eye height of passenger car (1.10 m), obstacle is the third braking light of stationary passenger vehicle (1.50 m) and the sight restricting object is a crash barrier (height of 0.8 m) in the median of left-hand curve in a motorway.

2. 

In this scenario the driver cannot see over the top of the sight restricting object. Also the obstacle height is smaller than the height of the sight restricting object.
Example: driver eye height of a passenger car (1.10 m), obstacle is the taillight of a passenger car and the sight restricting object is a tunnel wall (height of 5 m) in the median of a left-hand curve in a motorway.

3. 

In this scenario the driver eye height is higher than the height of the sight restricting object. The obstacle height is lower than the height of the sight restricting object. In this case the driver is not able to see the obstacle over the entire stopping sight distance (Note, the extra elements illustrate the effect of the relative position of the sight restricting element). The available sight distance can be calculated:

$$SD = \frac{dh-sh}{dh-oh}.SSD \qquad (3)$$

With:
SD = sight distance
dh = eye height driver
sh = height sight obstructing object
oh = obstacle height
SSD = stopping sight distance

Example: a driver eye height of 1.10 m in combination with an obstacle height of 0.5 m (taillight) and a barrier in the median of a left-hand curve of a motorway.

4.

In scenario 4 the driver eye height is lower than the height of the sight restricting object and the obstacle height is higher than the sight restricting object. In this case the visibility of the obstacle depends on the ratio between the heights and the relative position of the sight restricting object to the driver position. The result is that the driver cannot see the obstacle over the entire stopping sight distance; when the sight restricting object is located close to the driver, the obstacle is not visible.

4.3.3.2 Calculating horizontal curvature

The horizontal curvature is calculated by:

$$R_{h,min} = \frac{SSD^2}{2(\sqrt{(sd+dd)} + \sqrt{(sd+bd)})^2} \qquad (4)$$

Where sd is the distance between edge marking and sight obstructing obstacle and dd and bd are determined from Figure 4.5.

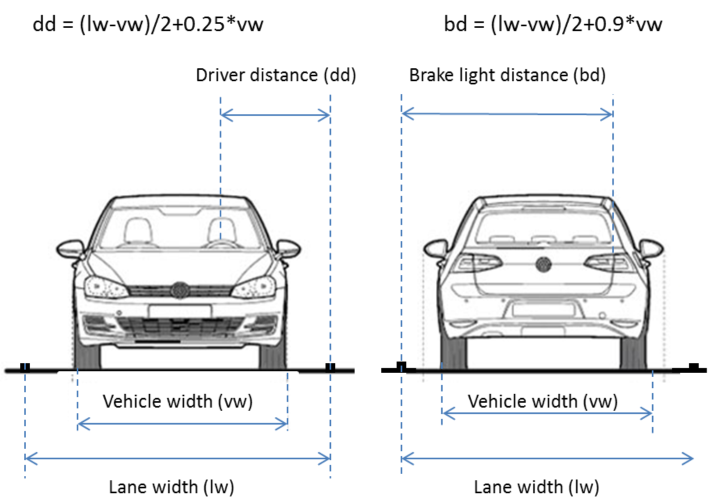


Figure 4.5 Driver and brake light positions

As revealed in Table 4.1, there are differences between the countries compared in this study with respect to the driver observation point (for left curves varying between 1.25 and 2 m and in right hand curves between 1,5 and 2.25m. Generally there are seldom SSD problems in right hand curves, mainly because of the presence of an emergency lane) and also with respect to the type (definition) and position of the obstacle on the road ahead (box vs rear brake light).

Since the driver observation point, design speed (and associated SSD value) and the distance between the edge marking and sight obstructing obstacle materially affect horizontal curve radii, these parameters were systematically varied to illustrate the effect on resultant curvatures (to illustrate this see Table 4.6 and Figure 4.6).
Not unexpectedly, this shows that for given SSD values and design speeds, a smaller driver observation point value combined with sight obstructing obstacles closer to the road edge lead to substantially larger horizontal curve radii. As expected, the effect of the distance of a sight obstructing obstacle on resulting curve radii is greater than the effect of the driver observation point. At a design speed of 100 km/h the curve radius required given a driver observation position of 0.7m with a sight obstructing obstacle at 2 m is 11% higher than an observation position at 1.5m. The difference between a 1.5 m and a 2 m observation position however is only 6%. The results in Table 4.6 and Figure 4.6 are illustrative and the SSD tool developed in WP3 can be applied to calculate the minimum horizontal curve radius for any combination of parameters.

Speed (km/h)	SSD (m)	Resulting horizontal curve radii *								
		Driver observation point (dd in m)								
		0.7 m			1.5 m			2 m		
		Distance edge and obstacle (sd in m)								
		0.1	2	10	0.1	2	10	0.1	2	10
50	61.3	301	133	41	228	118	39	202	111	39
60	79.3	512	226	69	388	201	67	343	189	65
70	100.7	813	359	110	616	319	106	544	299	104
80	123.6	1224	541	165	928	481	159	820	451	156
90	148.6	1770	782	239	1342	695	230	1185	652	226
100	175.7	2475	1094	334	1877	972	322	1658	912	315
110	205.0	3369	1488	454	2555	1327	438	2256	1241	429
120	236.4	4479	1979	604	3329	1759	583	2999	1651	571
130	269.9	5893	2580	787	4428	2293	760	3909	2152	744

** Note : curve radii for left curves in countries driving right and right curves for countries driving left*

Table 4.6: Effect of driver observation point and distance between obstacles and road edge on left hand horizontal curvature

In practice designers will strive to provide clear zones compliant with design speeds (the higher the design speed the larger the clear zone) and generally these are in excess of 6 m on motorways. Adopting a minimum value for the distance to sight obstruction obstacles in horizontal curves is therefore also not practical since these are very much case dependant and not one standard value can be applied. Only in situations where static obstructions limit the line of sight (e.g. guardrails and crash barriers, in a mountain cutting, historic tree or building etc.) will the designer need to account for this. Because this parameter is case dependant and will therefore not be considered as one of the essential SSD parameters. The designer can make use of tools similar to that developed in WP3 to calculate the minimum curve radius and SSD requirements for any set of parameters.

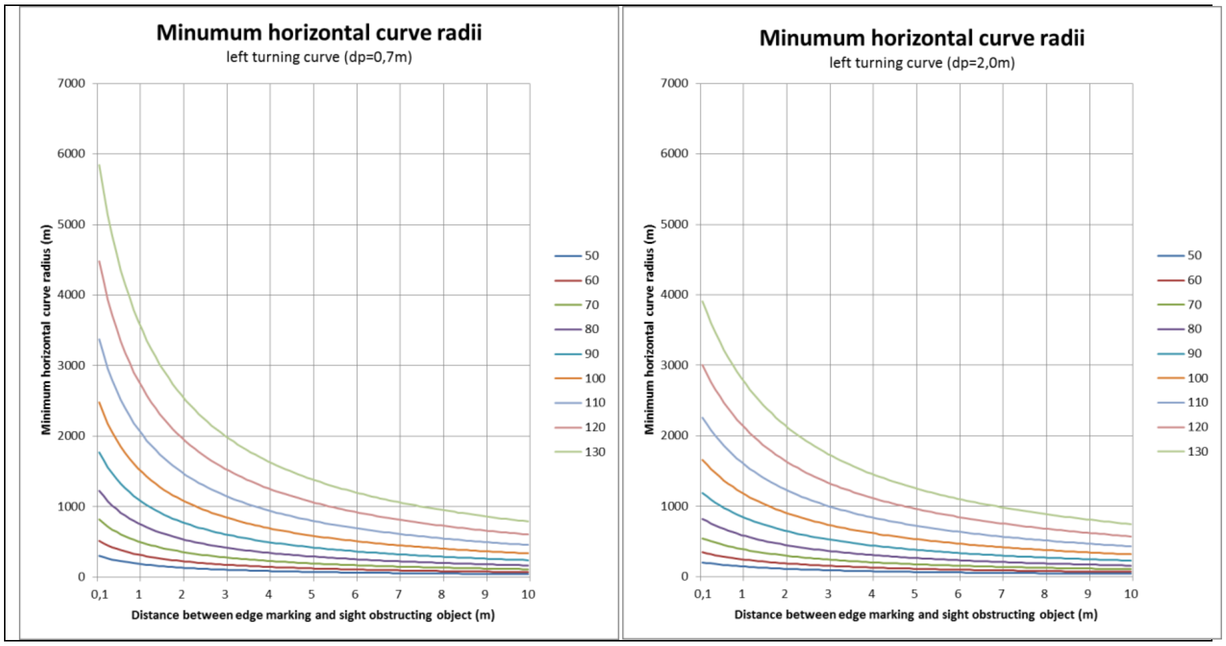


Figure 4.6: Effect of the driver observation point on horizontal curvature (left hand curve for countries driving on the right)

Note : SSD values range from 61m at Design speed 50km/h and 269m at design speed 130km/h

However, the driver observation point allows the designer some flexibility in providing adequate SSD. From Table 4.6, it is clear that increasing the observation point value beyond 1.5m has relatively little merit. However, assuming a standard lane width of 3.5 m and given the driver position in a standard vehicle and the fact that most drivers tend to drive in the centre of the lane, the observation position should be 1.3 m for left hand curves in countries driving on the right (see Figure 4.5). Given this consideration, an observation point value of 1.3 m is recommended for future use in assessing SSD.

A point of discussion is that applying a lower observation value of say 0.7 m for left hand curves is also likely (assuming 0.3 m offset from the lane edge to vehicle edge plus 0.45 m from vehicle edge to the driver in a left hand drive vehicle) because drivers tend to hug the inside of the curve, but this would in most cases lead to significantly larger horizontal curves, with associated space and cost implications. On the other hand, observation point values larger than 1.3 m will lead to tighter curvature (at lower space cost) but will not leave much margin for error should drivers fail to adopt that driving line (which is likely since most drivers tend to hug the inside of the curve rather than the outside).

5 Effect on current country standards

The following parameters were identified as critical for SSD and horizontal and vertical curve calculation:

- The point of observation (horizontal and vertical curves)
- The obstacle height
- The road surface
- The coefficient of friction
- The tyre tread depth
- The driver eye height
- The driver perception-reaction time
- The vehicle braking performance
- The design or operating speed
- Environmental parameters (day/night and wet/dry/snow)

Of these it was decided that road surface; tyre tread depth and environmental parameters were inherent in other parameters or not uniformly applicable due to country specific differences (e.g. rain layer thickness).

Table 5.1 provides an overview of the recommended parameter and parameter values that have been derived from the literature (See also Table 4.1), the parameter studies and the field trials and the considerations and effects tested in chapter 4.

SSD parameter variables	Recommended parameter value
Observation point position left curve (m) RHD countries (LHD countries)	1.3
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 (60km/h)	0.377
Tangential or braking coefficient of friction (60km/h)	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
Deceleration rate (m/s^2)	4.0

Table 5.1: Summary of parameter and parameter values

As previously illustrated in Section 2.1, a number of the parameter values recommended above deviate from the values currently adopted by a number of the countries reviewed in this study. Adopting the above values as a CEDR or EU norm could have implications for on current geometric design practice in certain countries. Because this will impact on not only standards but also on safety and on costs, an overview of these impacts has been prepared (Table 5.2).

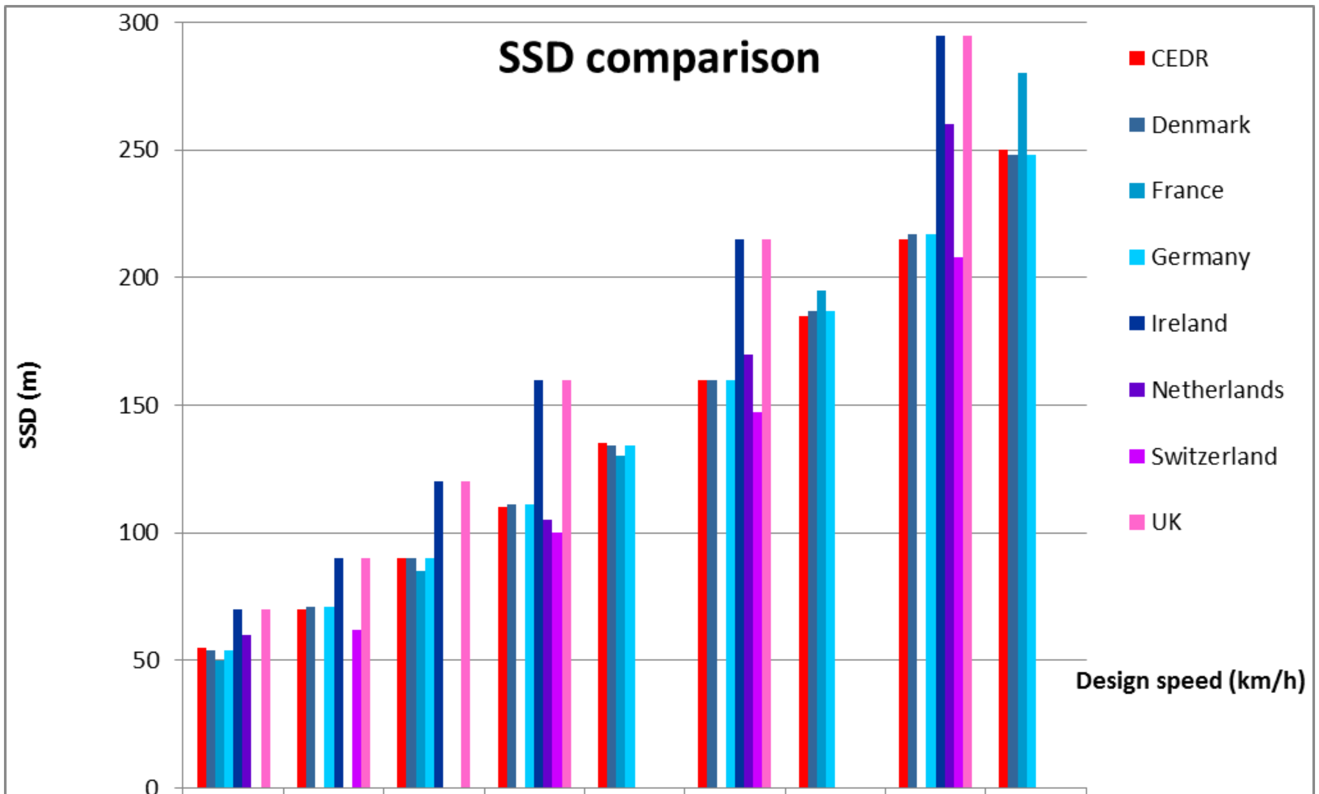
SSD parameter variables	Recom mended value	Impacts						
		DK	FR	DE	IE	NL	CH	UK
Observation point position horizontal curves (left curve in RHD countries) (m)	1,3	1,5 Minor decrease in curve radius (3%)	2,0 Increase in resultant curve radius (6-10%), marginal increase in costs	1,8 Increase in resultant curve radius marginal increase in costs		1,25 Marginal decrease in curve radius (not significant)	2,0 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 None	0,5 None	0,5 None	0,26-2,0 Significant decrease in resultant vertical curve radii (18-30%), reduced costs	0,5 None	0,15 Significant decrease in resultant vertical curve radii (30-50%), reduced costs	0,26-2,0 Significant decrease in resultant vertical curve radii (18-30%), reduced costs
Observed point height crest curve (m)	0,5	0,5 None	0,6 Marginal increase in vertical curve radii, increased cost	1,0 Significant increase in vertical curve radii (36%), increased costs due to flatter alignment	0,26-2,0 Variable depending on height applied, lower values result in increased radii and higher values in decreased radii	0,2-0,5 Variable from no effect to decreased vertical curve radii (marginal effect on costs)	0,15	0,26-2,0 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 None		0,25-0,32 Higher coefficient of friction leads to lower SSD. Negligible effect on maintenance		0,32-0,48 Lower coefficient of friction leads to higher SSD. Positive effect for maintenance due to lower costs resulting from less frequent resealing	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	
Tangential or braking coefficient of friction	0,377	0,377 None	0,46 Lower coefficient of friction leads to higher SSD. Positive effect for maintenance due to lower costs resulting from less frequent resealing	0,25-0,32 Higher coefficient of friction leads to lower SSD. Negligible effect on maintenance		0,32-0,48 Lower coefficient of friction leads to higher SSD. Positive effect for maintenance due to lower costs resulting from less frequent resealing	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	
Driver Eye Height Crest curve (m)	1,10	1,0 Marginal decrease in curve radius (5%), decreased cost	1,0 Marginal decrease in curve radius (5%), decreased cost	1,0 Marginal decrease in curve radius (5%), decreased cost	1,05 Marginal decrease in curve radius (2%), decreased cost	1,1	1,0	1,05
Perception reaction time (s)	2	2 None	2 None	2 None	2 None	2 None	2 None	2 None
Deceleration rate (m/s^2)	4,0	3,698 Marginal decrease in curve radius (5%), decreased cost	3,13-4,51 For values below 4, marginal decrease in curve radius (5%), decreased cost	3,698 Marginal decrease in curve radius (5%), decreased cost	3,678 Marginal decrease in curve radius (5%), decreased cost			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 5.2: Effect of changed parameter values

The tested parameter values have limited effect on SSD values and resulting curve radii in most instances. Figure 5.1 shows the SSD values proposed for CEDR (based on the parameter values in

Table 5.1) and the differences with current practice in the selected countries. With the exception of the UK and Ireland, the proposed SSD values are generally equal to or marginally lower than currently the case in most of the selected countries. In effect this will mean slightly tighter horizontal and vertical curvatures.

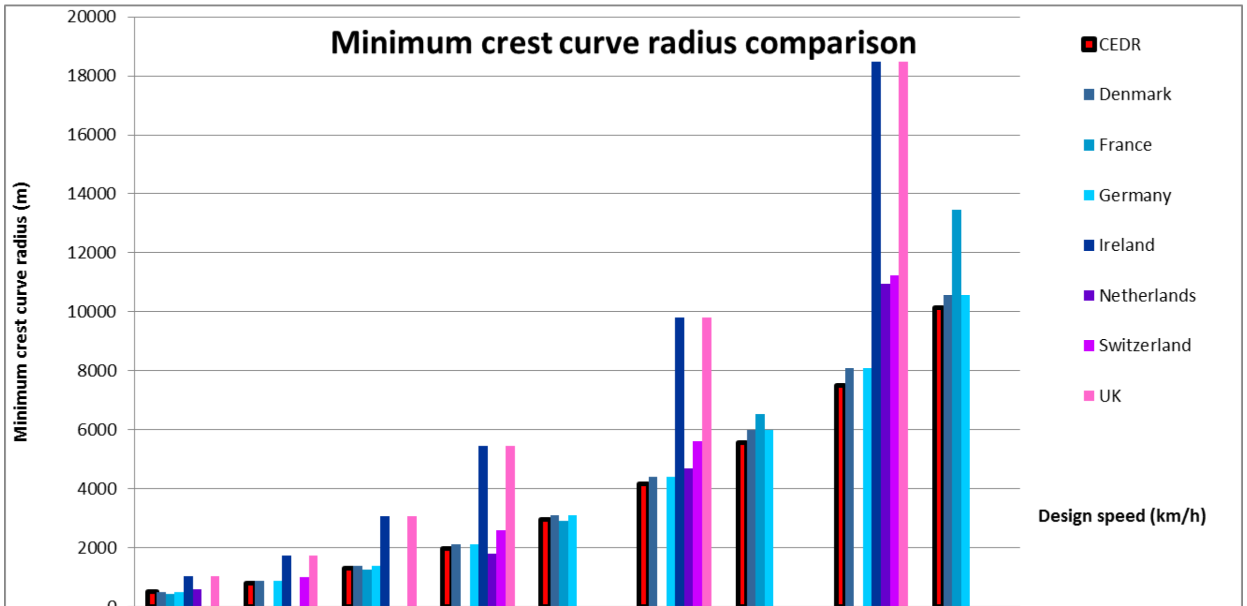


	50	60	70	80	90	100	110	120	130
CEDR	55	70	90	110	135	160	185	215	250
Denmark	54	71	90	111	134	160	187	217	248
France	50		85		130		195		280
Germany	54	71	90	111	134	160	187	217	248
Ireland	70	90	120	160		215		295	
Netherlands	60			105		170		260	
Switzerland		62		100		147		208	
UK	70	90	120	160		215		295	

Note: The UK and Ireland have options to calculate values below standard

Figure 5.1: SSD values based on proposed parameter values and consequences on current practice in selected countries

However, the adoption of a standard obstacle height based on the rear tail lights of passenger cars (positioned 2.5 m from the inner lane marking, see Figure 4.5) at a height of 0.5 m will have an impact of current design practice in some countries affecting observed point height definitions and resulting vertical and horizontal curvature (see Figure 5.2 and Figure 5.3).
In most countries the costs may be reduced due to curves being tighter or steeper. By adopting the recommended SSD values results in vertical crest curves that are typically 5-25% larger than currently applied at most design speeds in most of the selected countries (with the exception of France, the UK and Ireland). The recommended SSD values would result in vertical curves at all design speeds that are significantly lower than current practice in the UK and Ireland.



	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	

Note: The UK and Ireland have options to calculate values below standard

Figure 5.2: Effect of recommended parameter values and resultant SSD requirements on vertical curvature in selected countries

Horizontal curve radii based on the recommended SSD values (Figure 5.1) and given design speeds would generally be marginally lower than current practice in most of the selected countries (Figure 5.3), with the notable exceptions of the UK and Ireland, which apply significantly higher SSD values.

Note: The UK and Ireland have options to calculate values below standard

Figure 5.3: Effect of recommended parameter values and resultant SSD requirements on horizontal curves in selected countries

6 Recommended parameters and parameter values

The foregoing chapters have revealed that there is a lack of uniformity regarding the dimensioning of SSD relevant parameters. Especially variables relating to the size of the obstacle and the lateral position and height of the driver reveal differences between countries. Adopting a uniform value for these variables across countries may meet with resistance since there are cost implications for future design. On the other hand there are some marginal differences in applied friction coefficients and deceleration rates where a uniform value may be more readily acceptable.

From the results of this study the following parameter and parameter values are recommended as standard for use by CEDR members:

SSD parameter variables	Recommended parameter value
Observation point position left curve (m) (RHD countries) and right curve (LHD 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 (60km/h)	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
Deceleration rate (m/s^2)	4.0

Table 6.1: Recommended parameter values

Adoption of these values would result in the following SSD at various design speeds (Table 6.2). The resultant SSD values based on the recommended parameter values yield slightly higher SSD requirements than those based on Fambro (see also Table 4.4).

Speed (km/h)	SSD (based on recommended parameter values)	SSD (based on Fambro and using 4 m/s^2 deceleration rate (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

Table 6.2: Effects of parameter values on SSD requirements

NOTE: values rounded to the nearest 5m.

Finally, 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.

7 Acknowledgement

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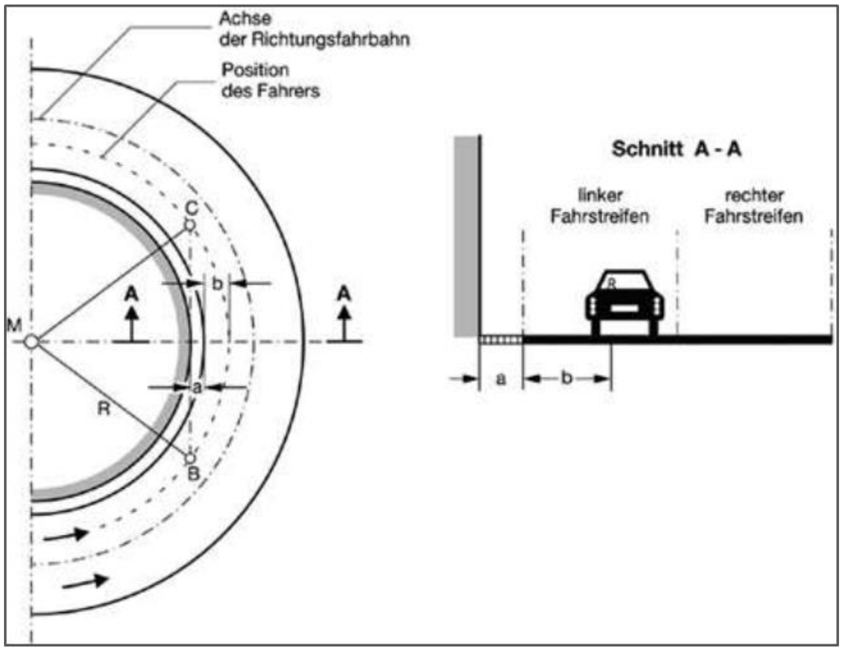
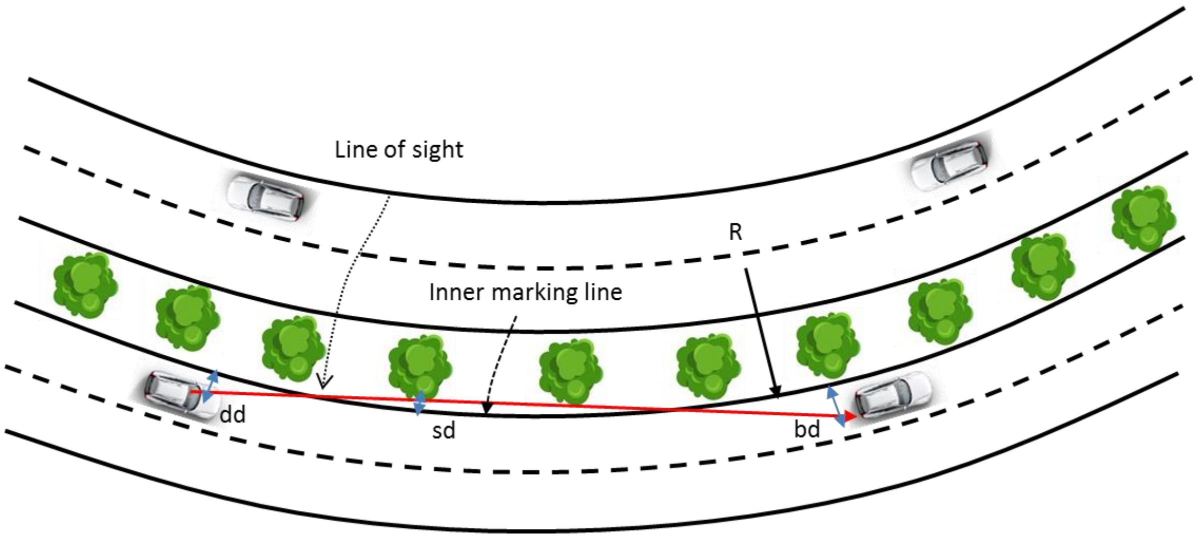
Appendix A : SSD determination in horizontal and vertical curves

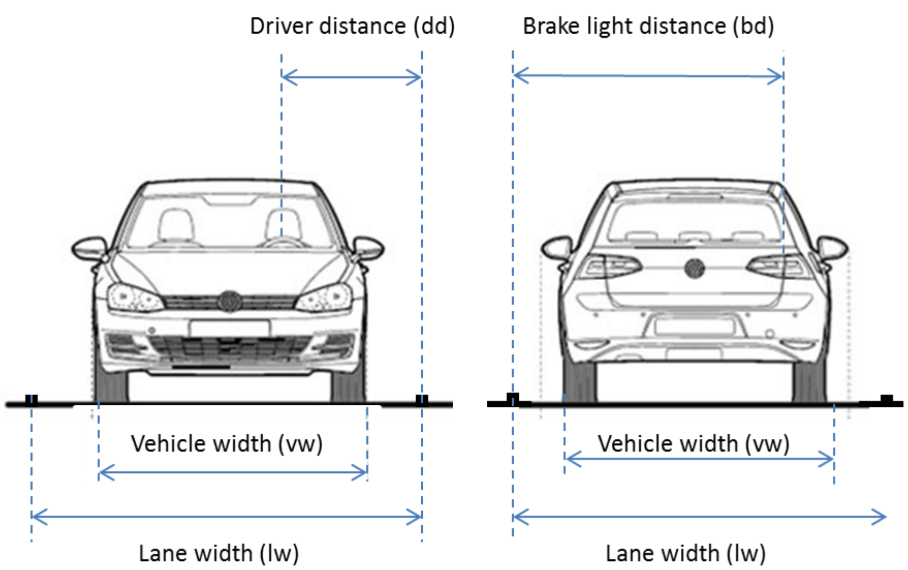
Considerations in horizontal curves





dd = (lw-vw)/2+0.25*vw

bd = (lw-vw)/2+0.9*vw



$SSD = 0.278\ Vt + 0.039V^2/a$

Where
SSD = stopping sight distance in m
V = (Design) speed (km/h)
t = brake reaction time
a = deceleration rate (m/s^2)

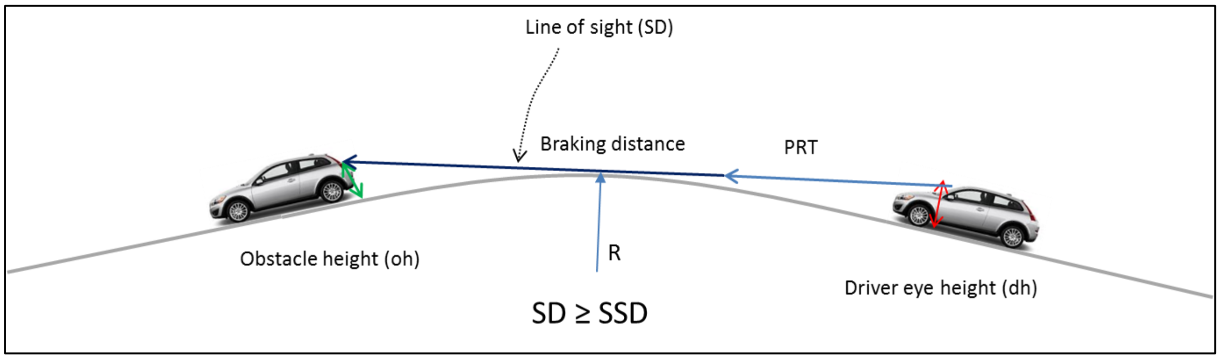
and

$$R_{h,min} = \frac{SSD^2}{2(\sqrt{(sd + dd)} + \sqrt{(sd + bd)})^2}$$

Where

Observation point (B)
Observed point (C)
Minimum horizontal curve radius (Rhmin)
Lane width (lw)
Vehicle width (vw)
Speed
Stopping sight distance
Distance between edge marking and and driver position (dd and b)
Distance between edge marking and braking light (bd)
Distance between edge marking and sight obstructing obstacle (sd and a)

Consideration in vertical curves



$$R_{min} = \frac{SSD^2}{2.(\sqrt{dh} + \sqrt{oh})^2}$$

Where

Eye height (dh)
Obstacle height (oh)
Stopping sight distance (SSD)
Minimum vertical curve radius (Rmin)