Passing Sight Distance Assessment on Rural Roads with Crest Vertical Curves

Stergios Mavromatis
Department of Transportation Planning and Engineering
School of Civil Engineering
National Technical University of Athens
5, Iroon Polytechniou str., GR-15773 Athens, Greece
Email: stemavro@central.ntua.gr

Konstantinos Markos
Department of Transportation Planning and Engineering
School of Civil Engineering
National Technical University of Athens
5, Iroon Polytechniou str., GR-15773 Athens, Greece
Email: kmarkos@mail.ntua.gr

Word Count: 4,099 words + 4 figures (250 words per figure) + 2 tables (250 words per table) = 5,599 words

Submitted February 2020

ABSTRACT
Passing sight distance (PSD) is a vital design element, which directly imposes economic as well as safety and operational considerations. The provision of PSD is highly prioritized, at least for rural road sections without additional passing lanes. The paper investigates areas with PSD inadequacy on rural roads with crest vertical curves. The research is based on the German (RAL, 2012) rural roads design guidelines, where PSD is currently dependent on the homogeneousness of the proposed road design classes and no longer on speed. Therefore, the required PSD for all the examined design classes was set to 600m. The interaction between the road surface and line of sight between the passing and the opposing vehicles was assessed through 6 different cases, while every case was associated with the resulting formulas. The analysis revealed that, excluding one situation for EKL4 design class, the boundaries of PSD inadequacy were concentrated in advance and inside the vertical curve, and do not depend on the grade difference of the vertical curve but only on the crest vertical curvature rate value. The paper delivers a ready-to-use tool for engineers in order to identify areas with inadequate PSD in the early stages of the design process, and avoid implementing costly additional passing lanes.
Keywords: Passing Sight distance, Crest Vertical Curves, Investigation

INTRODUCTION AND PROBLEM STATEMENT

Sight distance is the length of roadway ahead that is visible to the driver (1). Passing sight distance (PSD) is a critical sight distance parameter, which directly imposes economic as well as safety and operational considerations. PSD is the distance that drivers must be able to see along the road ahead to safely and efficiently initiate and complete passing maneuvers of slower vehicles on two-lane rural roads using the lane normally reserved for opposing traffic (2).

Unfortunately, vehicle collisions associated with failure during the passing process, generally result to high severity accidents, such as head-on collisions or collisions between the passing and the passed vehicle driving in the same direction (3, 4).

Road sections with limited passing opportunities (passing zones) besides safety impose also operational degradation. Such cases might motivate certain drivers to make risky passing attempts either late in a passing zone or on a portion of the road not intended for passing and therefore seem mostly critical (5).

The most effective mean to eliminate such accidents is to provide additional passing lanes, or at least protected passing zones through the provision of continuous 3-lane cross-section (2+1 roads). However, such arrangements are not always possible on 2-lane road sections due to economic, topographical or environmental protection constraints (6).

The provision of PSD is highly prioritized, at least for rural road sections without additional passing lanes. As stated in current design practice [e.g. RAL (7), OMOE-X (8)], the minimum requirements for PSD sufficiency on 2-lane rural roads is around 20%-25% of their total length.

More specifically, according to the recent German rural road design guidelines (7), PSD is currently dependent on the homogeneousness of the proposed road design classes and no longer on speed, where as a result the required PSD is set to 600m.

This value of 600m has evolved from the PSD requirement of a passenger car (vehicle 1) at 100km/h attempting to perform a passing maneuver to a truck (vehicle 3) driven at 70km/h, while at the same time, at the opposing traffic stream, another passenger car (vehicle 2) is running at 100km/h. The required PSD is the sum of the distances covered by vehicle 1 and vehicle 2 plus a safety margin distance of 100m (Figure 1).

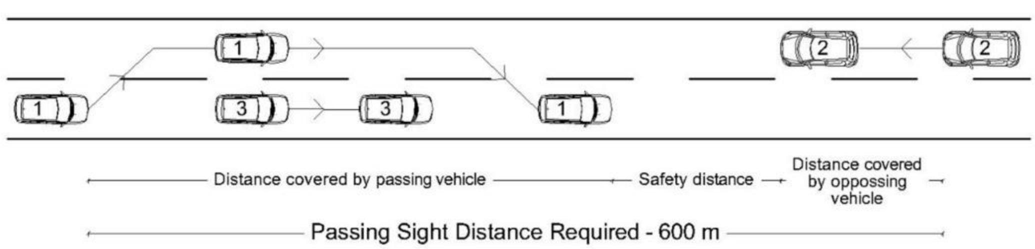


Figure 1 Required passing sight distance (RAL, 2012)

In road design the presence of crest vertical curves further obstructs the required PSDs. For this reason, in various design guidelines (1, 8, 9) amended crest vertical curvature rates based on PSD requirements are proposed as well. However, such costly arrangements are usually avoided, since in most road design guidelines, control crest vertical curvature rates are based on the critical case of stopping sight distance (SSD) provision, which delivers extremely limited passing opportunities. For example, control crest vertical curvature rates for serving PSD requirements are at least double (depending on the design speed) compared to the relevant rates for providing SSD requirements (1, 8, 9).

The paper investigates areas with PSD adequacy for 2-lane rural road segments where crest vertical curvature rates are selected according to the existing road design approach of SSD provision.

Such an assessment, although critical for identifying areas with inadequate PSDs in road projects, even during initial design stages, has not been analyzed adequately in terms of understanding thoroughly the interaction of the involved geometric parameters. Moreover, through this research the authors intend to quantify PSD availability and deliver a ready-to-use tool for practitioners.

METHODOLOGY

In order to utilize a uniform approach, in terms of PSD requirements, the investigation was performed in line with the design classes of the German rural road design guidelines RAL 2012 (7). It is evident that PSD sufficiency is granted when the line of sight between the passing and the opposing vehicle, set to 600m, is not obstructed by the road surface.

In RAL 2012 guidelines, four design classes are introduced; namely, EKL1, EKL2, EKL3 and EKL4 with varying design speeds and control design elements (Table 1). However, EKL1 design class, with design speed V=110km/h, was excluded from the present analysis, since the passing process is performed only through additional passing lanes.

TABLE 1 Control Values for RAL 2012

Design Class	Design Speed (km/h)	max s (%)	Crest Vertical Curvature Rate Hk (m)	Tangent length T (m)	Cross-section
EKL2	100	5.5	6000	85	RQ 11,5+
EKL3	90	6.5	5000	70	RQ 11
EKL4	70	8.0	3000	55	RQ 9

The objective of the assessment was to determine the parameters that impact the driver's sightline from vehicle 1 to vehicle 2. It is obvious that besides the relative position of the involved vehicles, the arrangement of the crest vertical curve is also critical.

Therefore, the areas with inadequate PSDs (<600m) were assessed as a function of crest vertical curvature rates and the algebraic differences between the entrance and exit grades, s_1 and s_2 respectively, with regard to the control design parameters of Table 1 per design class.

Throughout the analysis, the height of the driver's sightline height (h_A) as well as the height of the opposing vehicle - object (h_Z) were set to 1.00m (7).

The authors, in a previous research (10) have identified 6 different cases for addressing an unobstructed driver's sightline. More specifically, every case defined the boundaries in advance and beyond a single crest vertical curve where the elevation at any point along the above-mentioned line of sight, between the passing and the opposing vehicle, was found to be below the road surface. These boundaries of insufficient PSDs were drawn as a function of the position of the passing vehicle (vehicle 1). For every case, certain equations were derived which deliver the height difference between the elevation (h_{xline}) of every point along the line of sight (line of 600m from vehicle 1 to vehicle 2) and the respective projected elevation (h_x) on the road surface.

A brief outlook of the examined cases as well as the derived equations is provided in the following sub-sections.

Case 1

Both vehicle 1 and vehicle 2 are positioned in advance of the crest vertical curve (Figure 2).

The requested height difference for this case is given by Equation (1).

$$h_{xline} - h_x = h_A + \frac{(h_Z - h_A)}{x_{endline1}} x \quad (1)$$

where:
x: distance from vehicle 1 along the line of sight (m)
h_{xline}: elevation of line of sight at a random position x (m)
h_x: projected road elevation of h_{xline} (m)
h_A: driver's sightline height (1.00m),
h_Z: opposing vehicle - object height (1.00m)
$x_{endline1}$: distance between vehicle 1 – vehicle 2 (600m)

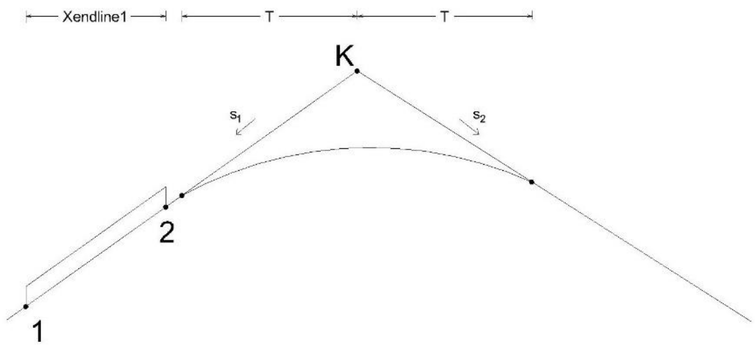


Figure 2 Overview of Case 1

Case 2

Vehicle 1 is positioned in advance of the crest vertical curve and vehicle 2 inside the curve (Figure 3). The following subcases apply:

*Subcase 2^A^*

The present subcase refers to the area between vehicle 1 and the beginning of the vertical curve.

The requested height difference for this case is given by Equation (2) as follows:

$$h_{xline} - h_x = h_A + \frac{\frac{x_{endline2}^2}{2H_K} + (h_z - h_A)}{D + x_{endline2}} x \qquad (2)$$

where:
$x_{endline2}$: distance between beginning of the crest vertical curve and vehicle 2 (m)
H_K: radius of crest vertical curve (m)
D: distance between vehicle 1 and the beginning of the curve (m)
x: distance from vehicle 1 along the line of sight (m)

*Subcase 2^B^*

Subcase 2^B refers to the area between the beginning of the vertical curve and vehicle 2.

The requested height difference for this case is shown through Equation (3).

$$h_{xline} - h_x = h_A - \frac{x^2}{2H_K} + \frac{\frac{x_{endline2}^2}{2H_K} + (h_z - h_A)}{D + x_{endline2}} (D + x) \qquad (3)$$

where:
x: distance from the beginning of the vertical curve (m)

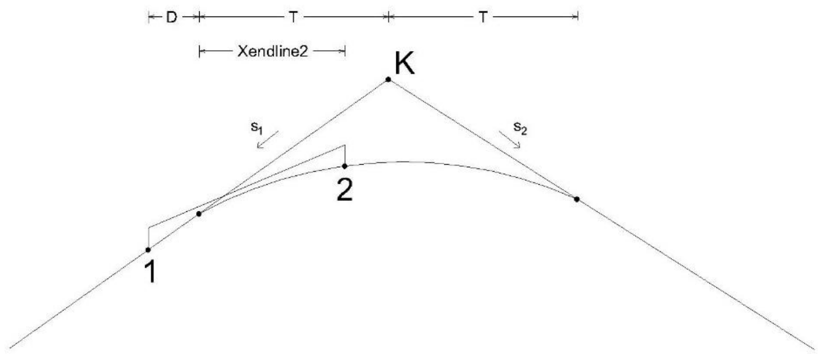


Figure 3 Overview of Case 2

Case 3
In Case 3, vehicle 1 and vehicle 2 are positioned in advance and beyond the crest vertical curve respectively (Figure 4). The following subcases apply:

*Subcase 3^A^*
Subcase 3^A refers to the area between vehicle 1 and the beginning of the vertical curve.
The requested height difference for this case is given by Equation (4).

$$h_{xline} - h_x = h_A + \frac{\frac{2T}{100H_K}(T+x_{endline3})+(h_z-h_A)}{D+2T+x_{endline3}}x \quad (4)$$

where:
x: distance from vehicle 1 (m)
$x_{endline3}$: distance between the end of the vertical curve and vehicle 2 (m)
T: tangent length of crest vertical curve (m)

Subcase 3^B
The above subcase refers to the area inside the vertical curve.
The requested height difference for this case is given by Equation (5).

$$h_{xline} - h_x = h_A + \frac{\frac{2T}{100H_K}(T+x_{endline3})+(h_z-h_A)}{D+2T+x_{endline3}}(x+D) - \frac{x^2}{2H_K} \quad (5)$$

where:
x: distance from the beginning of the curve (m)
D: distance between vehicle 1 and the beginning of the curve (m)

Subcase 3^C
Subcase 3^C refers to the area between the end of the vertical curve and vehicle 2.
The requested height difference for this case is given by Equation (6).

$$h_{xline} - h_x = h_A + \frac{\frac{2T}{100H_K}(T+x_{endline3})+(h_z-h_A)}{D+2T+x_{endline3}}(D+2T+x) - \frac{2T}{100H_K}(T+x) \quad (6)$$

where:
x: distance from the end of the curve (m)

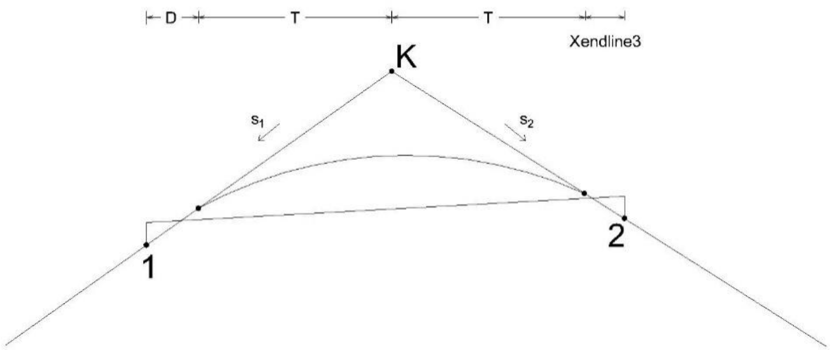


Figure 4 Overview of Case 3

Case 4

In Case 4 both vehicle 1 and vehicle 2 are positioned inside the crest vertical curve (Figure 5). The requested height difference for this case is given by Equation (7).

$$h_{xline} - h_x = h_A + \frac{D^2 - x^2}{2H_K} + \frac{\frac{(x_{endline4} + D)^2 - D^2}{2H_K} + (h_z - h_A)}{x_{endline4}}(x - D) \tag{7}$$

where:
x: distance from point 1 (m)
$x_{endline4}$: distance between vehicle 1 – vehicle 2 (600m)
D: distance between vehicle 1 and the beginning of the curve (m)

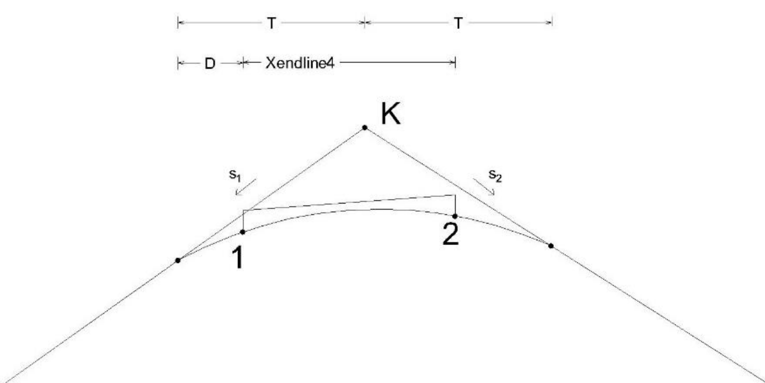


Figure 5 Overview of Case 4

Case 5

Vehicle 1 is positioned inside the crest vertical curve and vehicle 2 beyond the curve (Figure 6). The following subcases apply:

Subcase 5^A

Subcase 5^A refers to the area between vehicle 1 and the end of the vertical curve. The requested height difference for this case is given by Equation (8).

$$h_{xline} - h_x = h_A + \frac{2Dx - x^2}{2H_K} + \frac{-\frac{D^2}{2H} + (h_z - h_A)}{x_{endlines5} + D}x \tag{8}$$

where:
x: distance from vehicle 1 (m)
$x_{endline5}$: distance between the end of the curve and vehicle 2 (m)
D: distance between vehicle 1 and the end of the curve (m)

Subcase 5^B
Subcase 5^B refers to the area between the end of the vertical curve and vehicle 2.
The requested height difference for this case is given by Equation (9).

$$h_{xline} - h_x = h_A + \frac{-\frac{D^2}{2H}+(h_z-h_A)}{x_{endline5}+D}(x+D) + \frac{D^2}{2H_K} \qquad (9)$$

where:
x: distance from end of vertical curve (m)

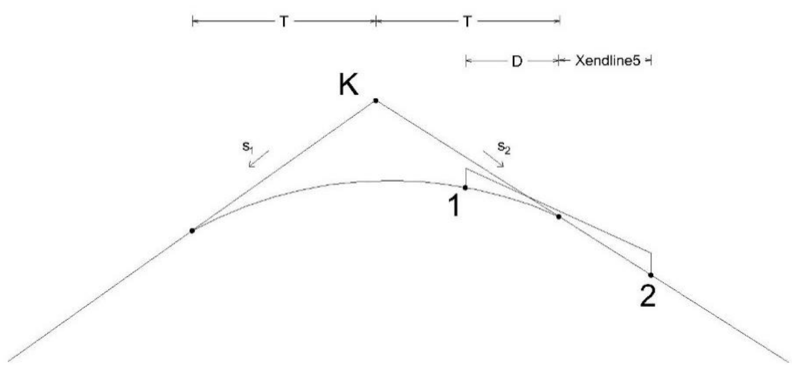


Figure 6 Overview of Case 5

Case 6
Both vehicle 1 and vehicle 2 are positioned beyond the crest vertical curve (Figure 7).
The requested height difference for this case is given by Equation (10).

$$h_{xline} - h_x = h_A + \frac{h_z-h_A}{x_{endline6}}x \qquad (10)$$

where:
x: distance from vehicle 1 (m)
$x_{endline6}$: distance between vehicle 1 – vehicle 2 (600m)

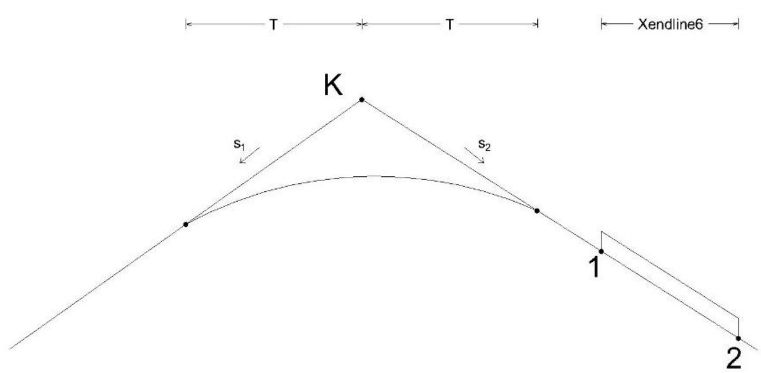


Figure 7 Overview of Case 6

Superelevation Impact Investigation

In order to investigate more realistic conditions, the roadway's cross-slope impact in terms of potential sight obstruction was further assessed, assuming crown superelevation configuration.

More specifically, vehicle 1 and vehicle 2 were positioned in the opposing traffic lanes in order the respective line of sight to form the hypotenuse of triangle 123 (Figure 8).

As expected the roadway's cross-slope delivers more conservative results. The requested height difference between h_{xline} along the line of sight (vehicle 1 to vehicle 2) and the respective projected elevation h_x on the road surface was performed based on the applied cross-section per assessed design class. The lateral distance d between vehicle 1 – vehicle 2 [line (2-3) in Figure 8] was assumed to be formed by the midpoint of each traffic lane, and depends on the utilized cross section type per design class (Table 1). However, for design class EKL4, although passing is generally undesirable, this additional assessment was not performed since the vehicles were assumed to travel along the centerline of the 6m carriageway.

The derived equations are as follows:

$$h_{xline12} - h_{x12} = \begin{cases} h_1 + h_A - h_x + \frac{e}{100}\frac{d}{2} + \left[h_2 - h_1 + (h_z - h_A) - \frac{e}{100}d\right]\frac{\delta x}{\Delta x}, \text{ if } \delta x \le \frac{\Delta x}{2} \\ h_1 + h_A - h_x - \frac{e}{100}\frac{d}{2} + \left[h_2 - h_1 + (h_z - h_A) + \frac{e}{100}d\right]\frac{\delta x}{\Delta x}, \text{ if } \delta x > \frac{\Delta x}{2} \end{cases} \quad (11)$$

where:

$h_{xline12}$: elevation of line of sight at a random position along line (12) (m)
h_{x12}: projected road elevation of $h_{xline12}$ (m)
h_x: road axis elevation at distance δx from vehicle 1 (m)
e: roadway's cross-slope (2.50%)
d: lateral distance between vehicle 1 – vehicle 2 (4.00m EKL2, 3.50m EKL3)
δx: random longitudinal distance from vehicle 1 (m)
δy: random lateral distance from vehicle 1, $\delta y = d\,\delta x/\Delta x$ (m)
Δx: longitudinal distance of required PSD from point 1 (vehicle 1) to point 3 (600m)

The above equations were used for every case in addition to the ones described in the previous sections, although their overall contribution is the extension of areas with insufficient PSD by only a few meters (below 2.5m).

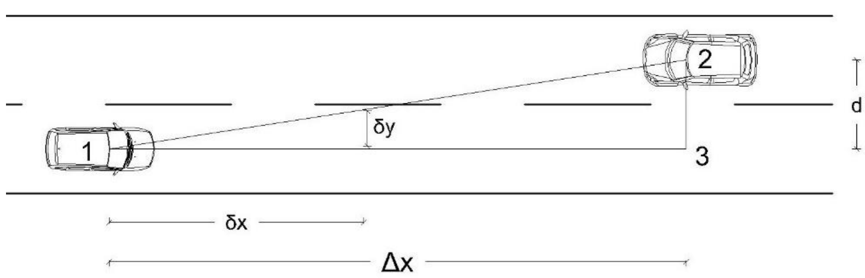


Figure 8 Cross-slope impact investigation on the line of sight between vehicle 1–vehicle 2

WORKFLOW DESCRIPTION

Using the above described equations, areas of inadequate PSD (PSD <600m) were identified based on the German rural road design guidelines (7).

The workflow of the overall algorithm, developed through VBA in MS Excel is as follows:

- Initially the PSD adequacy breakpoint (600m in the present analysis), the design class of the roadway, the crest vertical curvature rate (H_K) and the beginning (s_1) and ending (s_2) grade values are entered which are not necessarily symmetrical
- For a distance of at least 600m in advance of the starting point of the vertical curve vehicle 1 is positioned, where 600m after vehicle 1, vehicle 2 is positioned as well (line of sight)
- A calculation step is defined (1m in the present analysis) for which the difference $h_{xline} – h_x$ is calculated along the line of sight
- For $h_{xline} – h_x > 0 \rightarrow$ PSD >600m, where for $h_{xline} – h_x < 0 \rightarrow$ PSD <600m
- For cases where PSD <600m, the position of vehicle 1 is recorded
- Vehicle 1 and vehicle 2 are shifted ahead according to the calculation step and once again $h_{xline} – h_x$ is calculated along the line of sight through an iteration practice
- The process terminates when vehicle 1 reaches beyond the ending point of the crest vertical curve (Case 6)

For every set of parameters input, the algorithm delivers the area with inadequate PSD, between 2 distinct points; point A and point B respectively (Figure 9a). In other words, point A and point B represent the boundaries of insufficient PSD for vehicle 1 (passing vehicle).

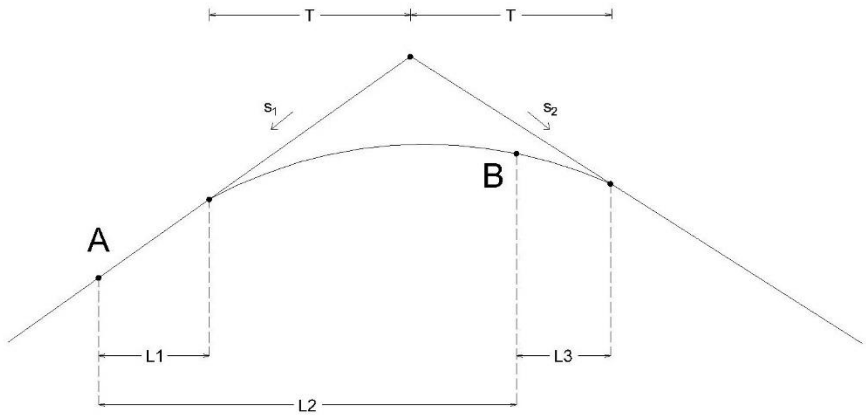
Moreover, for almost all the examined cases (excluding one referenced next) the area of inadequate PSD initiated and ended in advance and inside the vertical curve respectively, where 3 different lengths were identified (Figure 9a):

- L_1, distance of point A from the beginning of the curve
- L_2, area with PSD inadequacy (distance between A and B)
- L_3, distance of point B from the end of the curve

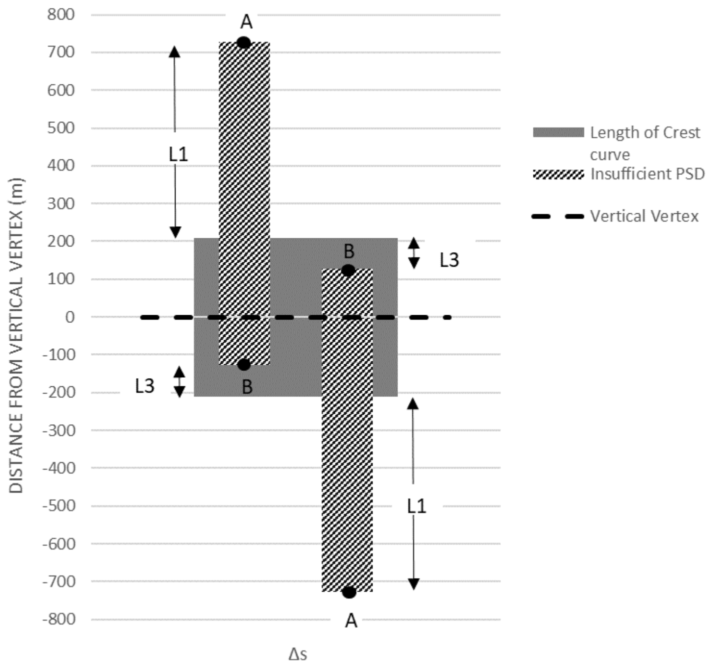
A more comprehensive representation of the passing process is also shown through Figure 9b. The solid box indicates the length of the utilized crest vertical curvature rate in advance and beyond the vertical vertex. Both traffic directions with inadequate PSD are shown as columns per direction of travel (the right column indicates the right traffic lane) and in accordance with the distances L_1 and L_3

A general remark for all the examined cases is that only Case 3 (where vehicle 1 and vehicle 2 are positioned in advance and beyond the crest vertical curve respectively) is grade dependent. More specifically, Equation 4 - Equation 6, besides the crest vertical curvature rate (H_K) include the tangent length of crest vertical curve (T) as well, the value of which depends on the grade difference Δs between the beginning (s_1) and ending (s_2) grade values ($\Delta s = s_2 - s_1$).

The investigation revealed that in all the examined points along the line of sight between vehicle 1 and vehicle 2 only for one situation (EKL4, Δs=2.00%) Case 3 delivered PSD adequacy. This means that for the exception where EKL4 is combined with Δs=2.00%, besides point A, point B as well was found to be positioned in advance of the crest vertical curve.



(a) representation of PSD inadequacy in accordance with L_1, L_2 and L_3



(b) representation of PSD inadequacy for both traffic directions

Figure 9(a,b) Areas with PSD inadequacy

OUTPUTS

For every examined design class, the critical lengths L_1 and L_2, essential in order to define the boundaries with PSD inadequacy, were calculated as a function of the (absolute) grade difference Δs between the beginning (s_1) and ending (s_2) grade values ($\Delta s = s_2 - s_1$) and curvature rate (H_K) of the crest vertical curve.

In Figure 10, a double graph is illustrated which provides a ready-to-use tool for practitioners. This graph can be implemented as follows:

By selecting a desired crest curvature rate at the right side of the graph and following the dashed red line, the length L_1 is defined. Then, depending on the selected Δs value, the length L_2 is determined. For example, for H_K=10000m, L_1 is determined 439m and assuming Δs=14%, L_2 is calculated to 1677m.

Figure 10 illustrates the outputs of the present research regarding acceptable values of crest vertical curvature rates (H_K) and grade differences (Δs) for all 3 design classes by RAL, 2012 (EKL2, EKL3 and EKL4). It is evident that one should select the above entrance parameters in accordance with the control values shown in Table 1. For example, during a PSD assessment for a road segment classified as EKL3, acceptable entrance parameters are $H_K \geq 6000$ and $\Delta s \leq 13.0\%$.

At the left section of Figure 10, excluding the line referring to Δs=2%, with respect to the above paragraph, all the other Δs values can be utilized per design class. In case of Δs=2%, the line splits in three parts, since the selected H_K parameter should also confirm the control tangent length T of Table 1. Therefore, by selecting Δs=2%, the control crest curvature rates for EKL2, EKL3 and EKL4 design classes are H_K=8500m, H_K=7000m and H_K=5500m respectively.

The most interesting finding was the fact that, per design class, for the same crest vertical curvature rate, the boundaries with insufficient PSD for the passing vehicle, formed between point A and point B in Figure 9(a,b), were found to have the same relative distances from the starting and ending point of the vertical curve, L_1 and L_3 respectively. This is because, since, as already mentioned, only for Case 3, PSD inadequacy is grade dependent, where Case 3 applies only for EKL4 combined with Δs=2%.

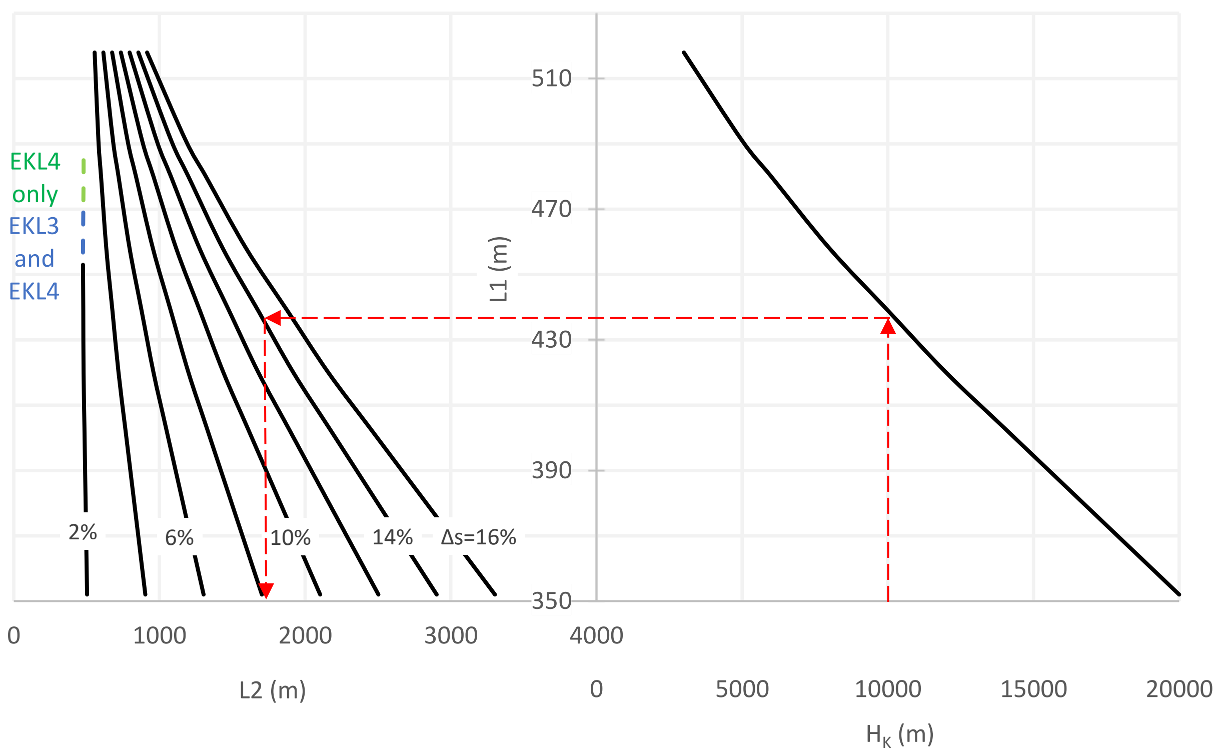


Figure 10 Arrangements and Values of Crest Vertical Curvature Rates for PSD Adequacy

The above outputs in terms of quantifying more accurately the values L_1 and L_2 for arrangements of H_K and Δs are shown through Table 2.

TABLE 2 Values of L_2 as a function of L_1, H_K and Δs

H_K (m)	Δs (%) / L_1 (m)	2	4	6	8	10	12	14	16
3000	518	-	555	615	675	735	795	855	915
5000	491	-	581	681	781	881	981	1081	1181
5500	485	479	589	699	809	919	1029	1139	1249
6000	480	479	599	719	839	959	1079	1199	1319
8000	458	475	635	795	955	1115	1275	1435	1595
10000	439	477	677	877	1077	1277	1477	1677	1877
12000	420	479	719	959	1199	1439	1679	1919	2159
14000	403	485	765	1045	1325	1605	1885	2165	2445
16000	386	491	811	1131	1451	1771	2091	2411	2731
18000	369	497	857	1217	1577	1937	2297	2657	3017
20000	352	503	903	1303	1703	2103	2503	2903	3303

CONCLUSIONS

The paper quantifies areas with PSD adequacy on road segments where crest vertical curvature rates are based on the existing and most common road design approach of SSD provision. More specifically, through the examined cases, the authors analyze the impact of the involved geometric parameters.

The stated methodology can be implemented for any road design guideline by introducing the required PSD and the respective control values (driver's eye height, object height, control crest vertical curvature rates, grade values, etc.), which in general depend on the examined roadway's design speed. The current analysis, aiming to utilize a uniform approach for PSD, was performed in line with the design classes of German (RAL, 2012) rural road design guidelines, where PSD is currently dependent on the homogeneousness of the proposed road design classes and no longer on speed, and as a result the required PSD is set to 600m.

The assessment was performed for the control values of three design classes, namely; EKL2, EKL3 and EKL4 with speed values of 100km/h, 90km/h and 70km/h respectively. EKL1 design class (V=110km/h) was excluded from the present analysis, since the passing process is performed only through additional passing lanes.

Aiming to define the boundaries in advance and beyond the crest vertical curve, where the elevation at any point along the line of sight between the passing and the opposing vehicle is below the road surface, 6 different cases were investigated. In order to assess realistic conditions, the roadway's cross-slope impact in terms of potential sight obstruction was also included in the analysis.

The analysis revealed that, excluding one situation for EKL4 design class, the boundaries of PSD inadequacy were concentrated in advance and inside the vertical curve, and do not depend on the grade difference Δs of the vertical curve but only on the crest vertical curvature rate value.

The paper delivered a ready-to-use tool for engineers in order to identify areas with inadequate PSD in the early stages of the design process, and avoid implementing costly additional passing lanes.

However, further analysis is required in order to cover more comfortable, in terms of curvature rates, vertical curves as well as assess the impact of combined horizontal and vertical alignment.

Moreover, future research is also necessary to link more closely the passing process to the traffic volumes in order to understand further the breakpoint for introducing additional passing lanes.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: SM, KM; literature collection: SM, KM; review and synthesizing: SM, KM; draft paper preparation: SM, KM. Both authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO), 2018. A Policy on Geometric Design of Highways and Streets, Fifth Edition. Washington, DC, USA.

2. Transportation Research Board (TRB), National Cooperative Highway Research Program (NCHRP), NCHRP Report 605, Passing Sight Distance Criteria, Washington, D.C., 2008.

3. Richter, Th. and S. Ruhl. Untersuchung von Maßnahmen zur Prävention von Überholunfällen auf einbahnigen Landstraßen, [examination of measures to prevent passing-related accidents on two lane highways]. Gesamtverband der Deutschen Versicherer, Forschungsbericht, No.24 [German Insurance Association, German Insurance Accident Research], Berlin 2014.

4. Clarke, D. D., P. J. Ward and J. Jones: Overtaking Road-Accidents: Differences in Maneuver as a Function of Driver Age. In Accident Analysis & Prevention, Volume 30, Issue 4, pp. 455-467, Great Britain, 1998.

5. Belz, N. Using Field and Simulation Data to Assess Passing Zone Behavior on Rural Two Lane Highways. *98th Annual Meeting of the Transportation Research Board*, Washington, DC., 2019.

6. Anne Vetters, Thomas Jaehrig, 53. Verification of the Existing Model for Passing Sight Distance on Single Two-Lane Rural Carriageways, Dresden, Germany, 2015.

7. Ed.German Road and Transportation Research Association, Committee, Geometric Design Standards, 2012. Guidelines for the Design of Rural Roads, (RAL), Germany.

8. Ministry of Environment, Regional Planning and Public Works, (2001), Guidelines for the Design of Road Projects (OMOE-X), Alignment, Part 3, Greece.

9. Ministero delle Infrastrutture e dei Trasporti, 2001, Norme Funzionali e Geometriche per la Costruzione delle Strade, n. 6792, Rome.

10. Markos, K., S. Mavromatis. Investigation of Passing Sight Distance Sufficiency on Rural Roads with Crest Vertical Curves. *Advances in Transportation Studies, XLIX Issue,* 2019.