



Coordination of horizontal and sag vertical curves on two-lane rural roads: Driving simulator study



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ABSTRACT

The highway geometric design guidelines for several countries provide suggestions for the coordination of horizontal curves overlapping with sag vertical curves (sag combinations) to avoid combined configurations that produce undesirable optical effects and reduced safety. Such suggestions are derived from studies based on the drawing of the perspective of the road. This drawing method is severely limited with respect to the simulation of the perspective view of the highway to the driver during the dynamic task of driving. Interactive driving simulation methods are deemed to be more efficient for these objectives.

This paper reports the results of a study carried out using an interactive driving simulator to evaluate the effects on the driver's speed behavior of different configurations of sag combinations and non-combined curves on a flat grade with the same features as the horizontal curves of the sag combinations (reference curves). The speed behaviors of drivers along the tangent–curve transitions of sag combinations and reference curves were recorded. The speed on the approach tangent, the speed at the midpoint of the horizontal curve and the maximum speed reduction (MSR), the difference between the maximum speed on the last 200 m of the approach tangent and the minimum speed on the first half of the horizontal curve, were analyzed. One-way repeated MANOVA was performed to determine if the driver's speed behavior on the horizontal curves was influenced by different configurations of sag combinations and reference curves.

The primary result was that on suggested sag combinations, the driver's speed behavior did not differ in any statistically significant way from that on the reference curves. Whereas the critical sag combinations (configurations that should be avoided) caused high values of maximum speed reduction along the tangent–curve transition, which pointed to the driver's reaction to an incorrect perception of the road alignment. Therefore, this result confirmed the effectiveness of the road design guidelines for the coordination of horizontal curves and sag vertical curves.

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1. Introduction

Curves are the geometric element of the road alignment characterized by a greater risk of accidents. According to the Fatality Analysis Reporting System (FARS), since 2005, approximately 5000 fatalities each year have resulted from single-vehicle run-off-road crashes on the horizontal curve sections of 2-lane rural roads in the United States [1]. Such statistics are attributed to the erroneous perceptions of the alignment features that induce drivers to assume a behavior inadequate to the geometric design of the curved section [2].

Several research studies have noted that the occurrence of erroneous perception increases as the complexity of the alignment increases and that erroneous perception could be a significant factor in the conditions of horizontal curves overlapping with sag vertical curves or with crest vertical curves [3–6].

In particular, Smith and Lamm [3] hypothesized that an overlapping crest curve may cause the horizontal curve to look sharper than it actually is, while a sag curve may cause the horizontal curve to look flatter than it actually is (called the driver perception hypothesis). In response, the driver may adopt a lower or higher speed, respectively, than if the radius was on a flat grade. Therefore, the erroneous perception of the horizontal curve may be particularly hazardous for the horizontal curve overlapping with a sag vertical curve (called a combined curve or sag combination) where the drivers may perceive a sharp curve as a flat one. Taking into account these findings, research has been undertaken to quantify the safety effects of combinations of horizontal curves and vertical curves for two-lane rural roads [7].

The road design guidelines of several countries (e.g., Italy, Spain, USA) [8–10], as a priority, encourage avoiding the overlapping of

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horizontal and sag vertical curves and, if not possible, affirm the need to overlap the vertices and to design vertical and horizontal curves with lengths of the same order of magnitude (referred to as a suggested sag combination in this study). In addition, the guidelines suggest avoiding a sag combination formed by a horizontal curve just after the end of the sag vertical curve because this configuration (referred to as a critical sag combination in this study) causes important undesirable optical effects. These suggestions come from studies based on drawings of the perspective of the road. This drawing method is considered to be heavily limited because it does not simulate the perspective view of the road to the driver during the dynamic task of driving. Therefore, in the last decade, numerous studies on the visual perception of the road used the most advanced computer animation techniques [6,11–14]. However, such visualization techniques are non-interactive and do not evaluate the driver's reaction to his perception of the road scenario.

The driving simulation is considered to be the most accurate method to study the driver's perception [e.g., 15,16]. Driving simulators offer several advantages, such as low costs to conduct experiments, easy data collection, safety for test drivers, and the ability to conduct experiments in controlled conditions. In addition to these important benefits, driving simulators are interactive. They allow the test driver to manipulate the pedals and steering wheel of the vehicle during the task of driving and record the effects of the road configurations on driver behavior in terms of speeds, trajectory, braking, etc. Such features are the reasons for the growing use of driving simulators for modeling driver visual demand on three-dimensional highway alignments [17,18], for testing the effectiveness of road treatments on rural roads with crest vertical curves [19–21], for analyzing the influence of sag vertical curves on car-following behavior [22], and for evaluating the effect of the interaction between overlapping horizontal and vertical alignments [23–25].

The experimental study at the driving simulator reported here was carried out to provide an additional and more reliable validation of the guideline indications for the coordination of horizontal curves overlapping with sag vertical curves. More specifically, the objective of the study was to assess if such suggestions are able to determine:

- on the suggested sag combinations, whether a driver's speed behavior is significantly different from that on the non-combined curves on a flat grade with the same features as the horizontal curves of the sag combinations (called the reference curve);
- on the critical sag combinations, whether a driver's speed behavior is significantly different (which is more critical for road safety) from that on the suggested sag combinations.

For this purpose, the speed behavior of each driver along the tangent–curve transition was recorded. More specifically, the maximum speed reduction (MSR), which is the difference between the maximum speed on the last 200 m of the approach tangent and the minimum speed on the first half of the horizontal curve, was analyzed.

According to the literature [e.g., 26–28,25], the maximum speed reduction along the tangent–curve transition is believed to be an efficient parameter for revealing undesirable optical effects or unclear and non-timely information provided by the road to the driver (MSR increases as the driver detects surprising events).

It should be noted that MSR (more specifically, the 85th percentile of the Maximum Speed Reduction) was proposed by McFadden and Elefteriadou [26] to study the speed differential in the tangent–curve transition. However, nothing prevents it from being used to study the speed differential between tangent and combined curves. This approach is used by Hassan and Sarhan [25]. These researchers carried out a driving simulation experiment to examine the operational effects of drivers' misperceptions of the horizontal curvature when overlapped with crest and sag vertical curves. For this effort, the maximum speed reduction from the tangent to the horizontal curve was used as the measure of drivers' speed behaviors. Such a parameter was believed to capture the full extent of the driver's response to the perceived

curvature. The authors found that the maximum speed reduction between the tangent and the curve was consistent with the perception hypothesis (the mean maximum speed reduction was higher for crest combinations and was lower for sag combinations). However, the differences between the flat horizontal curves and sag combinations were slight, indicating small differences among driver responses.

Described in Section 2 below are the road scenarios and the geometric configurations of the curves that were studied, the features of the driving simulator and the procedures that were used, the participants who were involved in the experiment and the measures used for statistical analysis. Section 3 presents the outcomes of the statistical analysis. In the final section, the obtained results are discussed, and the conclusions are presented.

2. Method

A within-subjects design was carried out using the fixed-base driving simulator of the Inter-University Research Centre for Road Safety (CRISS). Using speed data collected on the tangent–curve transitions of reference curves and sag combinations, one-way repeated MANOVA was performed to evaluate whether the driver's speed behavior on the horizontal curves was influenced by the type of curve (i.e., different configurations of sag combinations and reference curves).

It should be noted that driving simulators do have one important limitation. Drivers do not perceive any risk in a driving simulator. The driver's awareness of being immersed in a simulated environment might cause a behavior which is different than that on a real road. However, several simulator validation studies have afforded us sufficient guarantees regarding relative validity, which refers to the correspondence between the effects of different variations in the driving situations. Absolute validity, which refers to the numerical correspondence between behavior in the driving simulator and in the real world, is not essential when the research deals with matters relating to the effects of independent variables [29]. For the purpose of the present study, only relative validity is required and the CRISS driving simulator was previously validated as a useful tool for studying the driver's speed behavior on two-lane rural roads [30]. More specifically, the validation study of the CRISS driving simulator [30] was carried out to compare the speeds recorded on several measurement sites with different alignment configurations on a real two-lane rural road and the speeds measured on the same road reconstructed in the driving simulator. The results of the comparative and statistical analyses established the relative validity because the comparison of the speed profiles obtained from the data recorded in field at the measurement sites showed a good correspondence to driver behavior in the simulator. The absolute validity was also obtained for all of the measurement sites, except for two less demanding configurations, including a very long tangent (1100 m) and a curve with a high radius (500 m) coming after a long descending tangent. For these configurations, the higher speeds recorded in the simulator appeared to originate from the different risk perceptions on the simulated road as opposed to that on the real road. This evidence allowed us to successfully use the CRISS driving simulator for studying driver behaviors induced by road configurations and for providing insights that may help to guide road design of two-lane rural roads [e.g., 31–37].

2.1. Road scenarios, sag combinations and reference curves

Two two-lane rural roads, each approximately 15 km long, were designed. The cross-section was 10.50 m wide, formed by two 3.75 m wide lanes and two 1.50 m wide shoulders. The values of the circular curves' radii ranged from 118 m to 800 m. The length of the tangents ranged from 150 m to 2200 m, while the deflection angles of the horizontal curves ranged from 30° to 80°. The longitudinal grades were not over 6%. Italian guidelines for these roads recommend a design speed ranged between 60 km/h (on a curve with radius equal

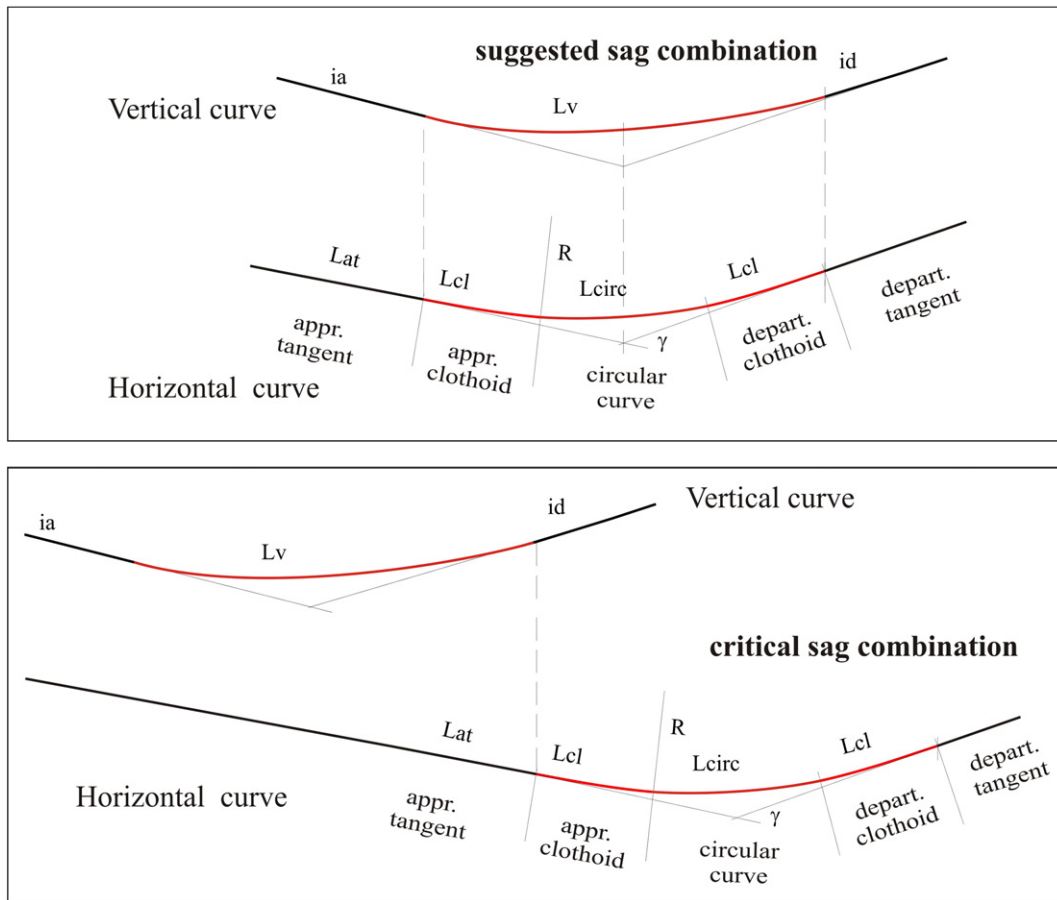


Fig. 1. Configurations of sag combinations: suggested and critical.

to 118 m) and 100 km/h (on a tangent). The posted speed limit is 90 km/h. These roads had the following types of sag combinations (Fig. 1):

- suggested sag combination: the sag vertical curve was overlapped on the horizontal curve such that the vertices of the two curves coincided and their lengths were the same order of magnitude, as required by design guidelines for the coordination of horizontal alignment and profile [8];
- critical sag combination: the horizontal curve begins just after the end of the sag vertical curve. Their lengths were the same order of magnitude. The guidelines [8] suggest avoiding this configuration

because it causes anomalies in the perspective of the road alignment.

Such sag combinations and reference curves (non-combined curves on a flat grade with the same features as the horizontal curves of the sag combinations) were the curves of interest. Half of these curves were on the first road and the other half were on the second alignment. This was done to:

- limit the order effect induced by the same sequence of presentation of the curves to the driver (the two road scenarios were driven by drivers in a counterbalanced order);

Table 1
Geometric features of the references curves and sag combinations.

	Horizontal curve								Vertical curve				
	R	L _c	L _{cl}	L _{circ}	L _{a.t.}	L _{d.t.}	γ	R _v	L _v	i _a	i _d	Δi	
Reference curves	252	480	140	200	400	400	77°	–	0	0	0	0	
	437	660	180	300	800	800	65°	–	0	0	0	0	
Suggested sag combinations	252	480	140	200	400	400	77°	11430	400	–2.0	1.5	3.5	
	437	660	180	300	800	800	65°	9566	660	–4.0	2.9	6.9	
Critical sag combinations	252	480	140	200	400	400	77°	11430	400	–2.0	1.5	3.5	
	437	660	180	300	800	800	65°	9566	660	–4.0	2.9	6.9	

R = radius of horizontal curve
L_c = length of horizontal curve in m (L_{cl} + L_{circ} + L_{cl})
L_{cl} = length of clothoids in m
L_{circ} = length of circular curve in m
L_{a.t.} = length of approach tangent in m
L_{d.t.} = length of departure tangent in m

γ = deflection angle
R_v = radius of vertical curve in m
L_v = length of vertical curve in m
i_a = approach grade in percent
i_d = departure grade in percent
Δi = |i_d - i_a|

- limit the duration of tests in the driving simulator to limit driver fatigue (see also Section 2.3).

The geometric parameters of the curves are shown in Table 1; while Fig. 1 shows the configurations of the two types of sag combinations.

2.2. Apparatus

The CRISS simulation system is an interactive fixed-base driving simulator. The system allows the simulation to represent the infrastructure scenario, traffic conditions, configurations of horizontal and vertical alignments, cross section features, and simulates the friction between tires and road surface and the vehicle's physical and mechanical characteristics. The hardware interfaces (wheel, pedals and gear lever) are installed on a real vehicle. The driving scene is projected onto three screens; one in front of the vehicle and one on either side.

The usual field of view is 135°. The scenario is updated dynamically according to the traveling conditions of the vehicle, and depending on the actions of the driver on the pedals and the steering wheel. The resolution of the visual scene is 1024 × 768 pixels and the update rate is 30–60 Hz depending on scene complexity. The system is also equipped with a sound system that reproduces the sounds of the engine. This setup provides a realistic view of the road and surrounding environment.

The system allows the intensity of driver actions on the brake, accelerator pedal, and steering wheel to be recorded and provides many parameters to describe travel conditions (e.g., vehicle barycenter, relative position in relation to the road axis, local speed and acceleration, steering wheel rotation angle, pitching angle, and rolling angle). Data can be recorded at time or space intervals of a fraction of a second or a fraction of a meter, respectively.

Fig. 2 shows an example of a road scenario as observed by the driver during the driving simulation.

Past studies stressed the important role that landscapes and roadside elements such as vegetation, trees and guardrail barriers play in a driver's perception of the road and a driver's speed [38–41]. For this reason, to avoid confounding factors, the background pictures were the same in each driving course and the roadside configurations were the same in all sections (combined curves and reference curves) that were analyzed.

2.3. Procedure

The experiment was carried out using pavement under dry conditions and in a good state of maintenance, and with the free vehicle on its own driving lane. On the other driving lane, modest traffic was distributed randomly to discourage the driver from changing lanes. The vehicles in the opposite lane were always present in sections separated from the curves of interest. The simulated vehicle was a standard medium class car, in dimensions and mechanical performance,

with an automatic transmission. The data recording system acquired all parameters at spatial intervals of 5 m.

The driving procedure was broken down into the following steps: (a) communicate to the driver the duration of the driving trial and the use of the steering wheel, pedals, and automatic gear selector; (b) train the driver to use the driving simulator on a specific alignment for approximately 10 min to allow the driver to become familiar with the simulator's control instruments; (c) execute the first test scenario; (d) have the driver vacate the car for approximately 5 min to reestablish a psychophysical state similar to the one at the start of the first test scenario and to fill out a form with personal data (e.g., years of driving experience and average annual distance driven); (e) execute the second test scenario; and (f) have the driver answer a questionnaire regarding discomfort perceived during the driving procedure, including the type (e.g., nausea, giddiness, daze, fatigue, or other) and the intensity (e.g., null, light, medium, or high). Participants were instructed to drive as they normally would in the real world.

The sequence of the two scenarios was varied for each driver, to avoid any influences that might result from the repetition of the experimental conditions in the same order. The participants completed the procedure in less than 60 min.

2.4. Participants

Thirty-five drivers were selected to drive in the simulator according to the following characteristics: no experience with the driving simulator, at least four years of driving experience and an average annual driven distance on rural roads of at least 2500 km. The participants, male (63%) and female (37%), ranged from 23 to 60 years of age (average 26). From the analysis of the questionnaires completed by the drivers after their tests, no participants experienced any discomfort. Therefore, no participant was excluded from the sample.

2.5. Data collection

The drivers' local speeds were recorded along the sections formed by the last 200 m of the approach tangents and the horizontal curves. More specifically, for each sag combination and for each reference curve, the following local speeds of each driver were collected:

- speed (V_T) at the point (T) on the approach tangent located 200 m from the beginning of the horizontal curve;
- speed (V_C) at the midpoint (C) of the horizontal curve;
- the maximum speed reduction (MSR) between T and C (i.e., maximum speed on the last 200 m of the approach tangent minus the minimum speed on the first half of the curve).

Table 2 shows a summary of the mean values of the measures V_T , V_C and MSR and their standard deviations for the 6 studied curves.



Fig. 2. Driving phase from the simulator.

Table 2
Mean values and standard deviations of V_T , V_C and MSR.

curve	Measure	Mean (km/h)	Std. deviation
Reference curve #1	V_T	114	17.4
	V_C	97.4	18.8
	MSR	20.1	14.0
Reference curve #2	V_T	122.3	15.3
	V_C	104.6	17.7
	MSR	20.1	14.1
Suggested sag combination #1	V_T	117.6	17.6
	V_C	102.4	15.6
	MSR	16.1	11.8
Suggested sag combination #2	V_T	127.2	16.7
	V_C	108.7	20.3
	MSR	20.1	17.1
Critical sag combination #1	V_T	111.3	13.4
	V_C	93.8	20.1
	MSR	19.6	12.7
Critical sag combination #2	V_T	125.2	16.8
	V_C	98.7	16.9
	MSR	27.8	12.7

3. Data analysis and results

The objective of the paper was to analyze the driver's speed behavior on a range of combined curves and reference curves with geometric features that are typical of Italian two-lane rural roads. In other words, the analysis of the driver's speed behavior as affected by specific geometric features of the curves (e.g., radius of horizontal curve, length of horizontal curve, radius of vertical curve, and length and longitudinal grades of approach and departure tangents) was not among the objectives of the study. Therefore, the statistical analysis was performed by aggregating the 6 curves under 3 groups based on the type of curve (reference curves, suggested sag combinations and critical sag combinations), regardless of the specific geometric features of the curves.

V_T was analyzed to ascertain whether the driver's speed at point T was unaffected by the type of the following curve. It should be noted that the selection of this point is consistent with the results of Fitzpatrick et al. [42] who found that the speed along the approach tangent does not begin to drop until the driver is at a point less than 200 m from the point of curvature. Should it be confirmed, as expected, that V_T does not depend on the type of curve, the possible difference between the values of V_C and MSR on the different successive curves (sag combinations and reference curves) shall exclusively depend on the conditioning induced by the type of curve.

V_C and MSR were analyzed to determine whether the drivers' speed behavior on the section of tangent–curve transition was affected by the type of the curve.

To evaluate the effects on the driver's speed behavior induced by the 2 types of sag combination and reference curves, a repeated measures MANOVA was performed. More specifically, a one-way repeated measures MANOVA was conducted to investigate the effects on the two dependent measures (V_T and MSR) due to the independent variable (or factor) type of curve (3 types: reference, and 2 types of sag combination: suggested and critical).

V_C was not used as a dependent measure in the MANOVA test to avoid redundancy in the dependent variables. Fig. 3 shows the mean values of the dependent measures V_T and MSR and their 95% confidence intervals for every type of curve. The V_C values are also shown.

The MANOVA revealed a significant effect for the type of curve ($F_{(6,272)} = 3.198$, $P = 0.005$, Wilk's lambda = 0.873, partial Eta squared = 0.066, observed power = 0.923). Univariate statistics showed that the type of curve did not affect the dependent measure V_T ($F_{(1,749, 120,710)} = 1.886$, $P = 0.161$, partial Eta squared = 0.027, observed power = 0.360), while it significantly affected the dependent measure MSR ($F_{(2, 138)} = 3.592$, $P = 0.030$, partial Eta squared = 0.049, observed power = 0.657) as shown in Table 3. The assumption of sphericity was tested by Mauchly's test. For the measure V_T , this assumption

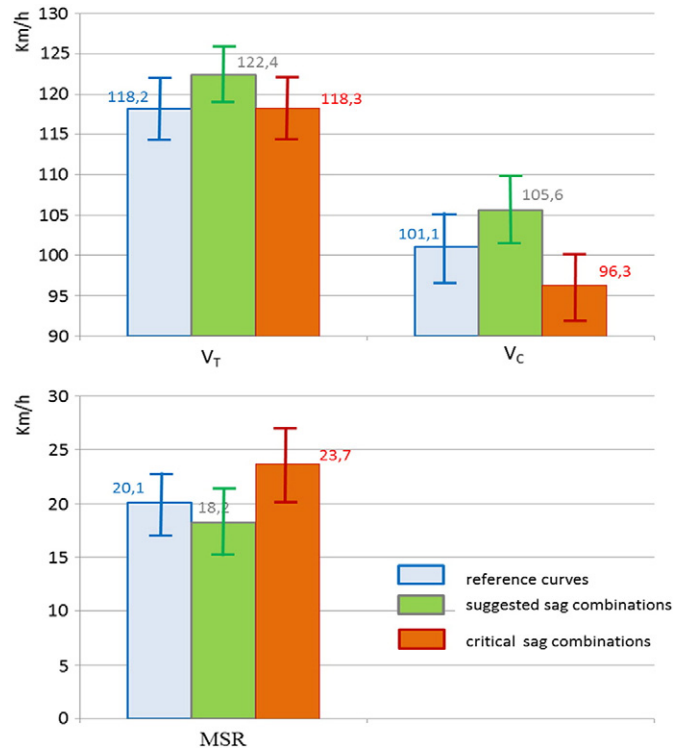


Fig. 3. Mean value of V_T , V_C and MSR for reference curves and sag combinations.

was violated. Therefore, the degrees of freedom were adjusted by using the Greenhouse–Geisser correction factor.

Having ascertained that V_T is not affected by the driver's perception of the type of curve, it is possible to affirm that the difference between the values of MSR depends entirely on the conditioning induced by the type of curve.

Post hoc tests using the Bonferroni correction revealed that the mean value of MSR (20.1 km/h) on reference curves was not significantly different than that (18.2 km/h) on suggested sag combinations (mean difference = 1.9 km/h; $P = 1.000$). The mean value of MSR on reference curves (20.1 km/h) was less than the mean value (23.7 km/h) on critical sag combinations, however the difference was not statistically significant (mean difference = 3.6 km/h; $P = 0.362$). The difference between the mean value of MSR on suggested sag combinations and that on critical sag combinations was statistically significant (mean difference = 5.5 km/h; $P = 0.020$).

The high value of MSR for the critical sag combinations could be due to the longitudinal grade at the midpoint of the curve (at this point, the road is uphill).

However, the values of the longitudinal grade are low (1.5% and 2.9%) and, in accordance with the literature, they do not lead to any appreciable conditioning of the drivers' speeds on the curves. Multiple studies [e.g., 43–47] showed that longitudinal grades less than 5% do not affect passenger car speeds on curved sections. On these sections, the driver's speed is only highly correlated to curve parameters such as the radius or the curvature change rate.

Table 3
Multivariate and univariate statistics.

Variable	F	p
MANOVA		
Type of curve (df = 6, 272)	3.198	0.005
Univariate		
V_T (df = 1, 749, 120, 710)	1.886	0.161
MSR (df = 2, 138)	3.592	0.030

This inference (i.e., the low longitudinal grades do not lead to any appreciable conditioning of car drivers' speeds) is also supported by the result obtained for V_T : the mean value of V_T was not significantly different ($F_{(1,749, 120,710)} = 1.886, P = 0.161$) for the types of curves: reference (curves with longitudinal grades on the approach tangents equal to 0%), suggested and critical (curves with longitudinal grades on the approach tangents equal to -2% and -4%).

From Table 2, the difference between the value (114 km/h) of V_T measured on the approach tangent 400 m long and longitudinal grade 0% for reference curve #1 and the average value (114.45 km/h) of V_T measured on the approach tangents 400 m long and longitudinal grade -2% of suggested sag combination #1 and critical sag combination #1 was equal to 0.45 km/h. Similarly, the difference between the value (122.3 km/h) of V_T measured on the approach tangent 800 m long and longitudinal grade 0% of reference curve #2 and the average value of V_T (126.2 km/h) measured on the approach tangents 800 m long and longitudinal grade -4% of suggested sag combination #1 and critical sag combination #1 was 3.9 km/h.

These values (0.45 km/h and 3.9 km/h) of the differences between V_T on level tangents and the values of V_T on tangents with longitudinal grades equal to -2% and -4% , respectively, show the null or negligible effect of the low values of longitudinal grades (1.5% and 2.9%) at midpoints of the horizontal curves of the critical sag combinations.

Therefore, considering the evidence above, there is a reasonable guarantee that the reduction in speed on the critical sag combinations is due entirely to the configurations of the combined curves.

4. Discussion and conclusions

The data analysis demonstrated the following:

1. a driver's speed behavior on reference curves and suggested sag combinations is similar (V_T and MSR did not show a statistically significant difference between the 2 curve types);
2. a driver's speed behavior on critical sag combinations and on suggested sag combinations is different (V_T did not show a statistically significant difference, but MSR on the critical sag combinations was significantly higher (+5.5 km/h) than MSR on the suggested sag combinations). A similar result was obtained from the comparison of the driver's speed behavior on critical sag combinations and reference curves. However, in this case, the difference in MSR was not statistically significant; although the value (+3.7 km/h) was not practically different than that recorded between the critical sag combinations and suggested sag combinations (+5.5 km/h).

The first result (point 1) does not support the hypothesis according to which on the sag combinations, because the horizontal radius is perceived as being greater than it actually is, the driver reduces speed significantly less between the approach tangent and the curve than the driver does on reference curves. The result (point 1) is consistent with a previous study carried out at CRISS driving simulator [23] which did not confirm the perception hypothesis for the sag combinations and is in line with the findings of Hassan and Sarhan [25], who found slight differences in drivers' responses on sag combinations and flat horizontal curves.

The obtained results (points 1 and 2) confirm the effectiveness of the road design guidelines for the coordination of horizontal curves and sag vertical curves. The suggested sag combination does not determine an anomalous driver's speed behavior, whereas the critical sag combination causes a high reduction in speed along the tangent–curve transition, which indicates the driver is reacting to an incorrect perception of the road's alignment.

These suggestions come from studies based on drawings of the perspective of the road and are not based on the analysis of the driver's speed behavior induced by the driver's perception of the road while driving. Consequently, the findings of this driving simulator study, that are based on the analysis of the driver's speed behavior induced

by the road configurations, provide an additional and more reliable validation of the guideline indications for the coordination of the sag combinations.

The speeds on the reference curves and sag combinations, while consistent with those obtained in previous studies of drivers' speed behaviors on combined curves using driving simulators [24,25], are higher than those typically recorded for free vehicles on real two-lane rural roads. For purposes of this study, absolute validity is not essential. It is only necessary to have the relative validity according to Tornos [29] because the research deals with the effects of independent variables and does not determine absolute numerical measurements of driver behavior. The relative validity of the CRISS driving simulator for speed research analysis on two-lane rural roads similar to those used in this research was previously proven [30]. For these reasons, sufficient guarantees are provided concerning the validity of the methodological approach used in this study.

The findings of this study are valid only for the configurations of combined curves studied. Further research should focus on enlarging the sample of curves in terms of longitudinal grades of the approach tangents and departure tangents, as well as horizontal radii. Moreover, besides the effects of the types of combined curves on the driver's speed behavior, the effects of the geometric features of combined curves (e.g., radius of the horizontal curve, length of the horizontal curve, radius of the vertical curve, and length and longitudinal grades of approach and departure tangents) should be analyzed.

Acknowledgments

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