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EVALUATION OF HORIZONTAL CURVE RADIUS EFFECT ON DRIVING SPEED IN TWO LANE RURAL ROAD. PILOT STUDY

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Abstract. This paper presents a case study of driving speed at horizontal curves in the regional road. The literature review of operating speed at horizontal curves in regional roads expresses the difference between design speed and driving speed. Driving speed was measured in ten horizontal curves on regional road No. 2610. Collected data was compared to the design speed, various design standards, and Operating Speed Prediction Models for traffic in low-volume roads. Based on result analysis, was proposed initial adjusted minimum radius of the horizontal curve based on operating speed. It is justified that proposed corrections based on operating speed ensure a credible speed limit effect on road safety. The performed experiment showed different tendencies comparing measured driving speed with permitted and design speeds. It was determined that dependent on specific curved section drivers tend to exceed posted

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speed limit from 17% to 98% of cases, and from 41% to 100% – the design speed in the horizontal curve. This research led to identifying the limitations of experimental research methodology. These limitations are related to experimental Site selection with different combinations of alignment elements, traffic, and accident data. A pilot study showed significant results and gave essential insights into the full-scale research plan. The results are expected to benefit both other researchers and the organisations responsible for the development and implementation of normative technical documents for road design.

Keywords: design speed (V_d), horizontal curve, low-volume road, operating speed (V_{85}), regional road.

Introduction

In most countries, design guidelines of the road alignment include permissible speed (V_{perm}), design speed (V_d) and 85th-percentile speed (V_{85}). The permissible speed is defined by general regulation or local maximum speed limit. Individual alignment design elements are unrelated to V_{perm}. For road safety reasons, the goal is that V_d of the horizontal curve always be no lower than V_{perm} – posted speed. Limiting and standard values for most of the design elements are determined conforming to the V_d: maximum tangent lengths, minimum radii of the horizontal curve, minimum parameters of clothoids, maximum longitudinal grades and vertical curves. Constant V_d must be applied consistently on longer sections or at least on longer connected roadway sections (Lamm, Psarianos, & Mailaender, 1999). It is desirable that the driving speed of a large proportion of drivers be lower than the V_d (AASHTO, 2018). Significant differences in speed results in an increase in the frequency with which vehicle drivers pass one another, increasing the number of opportunities for multivehicle crashes. Vehicles travelling the same speed in the same direction withholds overtaking one another. Therefore, it is impossible to collide if the same speed is maintained.

As reported by the Elliott, Dawson, & Edwards (2006) research report, the relationship between speed variance and safety were not entirely conclusive. Moreover, it is incompletely clear what the relationship exactly means. In most studies, speed differences reflect the range in speeds over 24 hours of measurements (Elliott, Dawson, & Edwards, 2006). The measured speed differences must include the variation between peak and off-peak periods, traffic volume and indefinitely speed between vehicles at a particular moment.

Elvik (2014) reviewed thirteen studies, which evaluated the effects of speed variance on crash rates, based on loop detector data. Although almost all these studies found that a large variance in speed increased

the risk of crashes, the numerical estimates of the effect varied greatly. It is nevertheless clear that increased driving speed variance increases the risk of crashes. However, most of these crashes are probably property-damage-only crashes. Dense traffic characterised by frequent and sudden changes in speed is associated with an exceptionally high risk of crashes (Elliott, Dawson, & Edwards, 2006).

As widely characterised in literature, the drivers must understand what speeds they are expected to drive. Road design should be self-explaining, reflecting the speed limit and guiding road users in choosing the right speed. So-called sustainable safety concept aims at preventing severe road crashes and were impossible – limiting their consequences (SWOV, 2013).

There is global voluntary performance Target No. 6 for Road Safety Risk Factors and Service Delivery Mechanisms there is stated: "By 2030, halve the proportion of vehicles travelling over the posted speed limit and achieve a reduction in speed-related injuries and fatalities" (World Health Organization, 2018).

The rational speed limit is a safe one, which most people consider appropriate, that protect the public, and can be enforced. Artificially low-speed limit leads to poor compliance as well as significant variations in speed within the traffic flow. Increased speed variance creates more conflicts and passing manoeuvres that can lead to more crashes. In road sections in rural areas where crash risk is typically lower, many experts recommend posting the speed limit at the 10 km/h multiple closest to the 85th percentile speed (V_{85} the speed at which no more than 85% of drivers are observed operating their vehicles during free-flow conditions). Most experts agree that in road section with a high crash rate, a detailed crash analysis needs to be conducted to identify the contributing factors for all crashes (Srinivasan, Parker, Harkey, Tharpe, & Sumner, 2006).

The fact that the speed limit is set conforming to road design guidelines based on traffic safety considerations and neglected the road users natural speed adaptation to the roadway contribute to the high rates of speed violations (Vadeby & Forsman, 2014). The debate raises whether the V_d specified in the road design guidelines (the minimum radius for a V_d) is indeed overestimated and doubtfully based on traffic safety. In a comparison done by Organization for Economic Cooperation and Development (European Conference of Ministers…, 2006), typically 40%–50% of drivers tend to exceed the posted speed limit (European Conference of Ministers…, 2006). It is shown in further research that drivers prefer to drive 4–5 km/h faster than the speed limit they consider as safe (Goldenbeld & van Schagen, 2007).

An accepted principle is that every 1% increase in mean speed produces a 4% increase in the fatal crash risk and a 3% increase in the

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fatal crash risk. Also, a 5% reduction in average speed can reduce the number of fatalities by 30% (World Health Organization, 2018).

The speed limit rarely is credible when operating speed (V_{85}) is higher than the posted speed limit. A credible speed limit is defined as the driving speed that most road users consider to be reasonable, for that particular road layout (Aarts, van Nes, Donkers, & van der Heijden, 2010). Drivers tend to better comply with the speed limit when speed limits are more credible (Goldenbeld & van Schagen, 2007).

The design speed must never be lower the permissible speed. It is unreasonable to have a speed limit that is much lower the V_d of a road. This incompatibility damages the credibility of a speed limit. Furthermore, the V_d must be consistent over a longer stretch of road. A substantial reduction of V_d at a particular Site must be supported by more than just a sign with the reduced speed limit (European Commission, 2015).

The German Guide has an officially used concept of V_{85} for the Geometric Design of Highways since 1973. The regulation used the V_{85} as an evaluation parameter for alignment consistency. Also, subsequent regulations (1984 and 1995) provided different diagrams for new and existing roads to estimate the V_{85} as a function of road characteristics. The road design guidelines of many other countries provide Operating Speed Prediction Models (OSPMs) (for example, France, Greece, and Australia) or provide a design process, which is associated to the 85th percentile speed (for example, the United Kingdom). These road design guidelines usually contain specific evaluations to check the consistency of the alignment or sight distance using V_{85}.

Moreover, in these countries, the V_{85} is also used for determining permissible speed. On the contrary, there are several countries (for example, Lithuania, Italy, Slovenia, and Spain) whose road design guidelines conceal V_{85} concept. In these cases, the design process generally uses a V_d, which is unrelated to an experimental survey but is based on theoretical considerations (Dimaiuta, Donnell, Himes, & Porter, 2011). The need for OSPMs is particularly significant for the evaluation of existing roadway conditions to aid in the selection and identification of valid and defensible roadway improvements.

Operating speed considers the expected actual speed behaviour and usually is expressed as V_{85}. The operating speed is used for safety evaluation process conforming to Safety Criteria I to III and also it is used to determine inconsistencies between V_d in design regulations and actual drivers behaviour (American Association of State…, 2018; Lamm, Beck, Ruscher, Mailänder, Cafiso, & La Cava, 2007). Among the different existing measures for design consistency evaluation, the V_{85} approach appreciable as the most efficient and quantified measure.

Operating speed backgrounds should be part of every modern road design guideline when striving for proper curvilinear alignment, and a more consistent and safer road characteristic (Lamm, Beck, Ruscher, Mailänder, Cafiso, & La Cava, 2007).

The development of OSPMs on rural roads in Lithuania is still at its early stage. The research described in this paper aims at taking the development of OSPM in Lithuania one step further. The focus is, therefore on the practice of Lithuania, where relatively small horizontal curves in rural roads are of great concern, and their use is unrelated to experimental driving speed studies. A pilot study has been carried out to make sure there is a need to refine the V_{85} background in Lithuania. How normative limitations to V_d and the minimum radius of the horizontal curve is corresponding to V_{85} on rural two-lane roads or how the speed selected by the driver differs from the V_d.

The paper aims at the revision of other countries road design guidelines and OSPMs, describing a basic framework for the development of V_{85} background in horizontal curves in practice. The following section describes the experiment background for comparable results. Subsequently, field results are analysed, V_{85} calculated and discussed.

Methodology and fundamentals used for calculating radius of the horizontal curve are widely discussed by other researches (American Association of State…, 2018; DHV Environment and Transportation, 2005; Gintalas, 2010; Lamm, Psarianos, & Mailaender, 1999). The methodology suggested by World Bank considers that the minimum radius is related to the applied superelevation of the horizontal curve. Also, specific skid resistance factors are used at various design speed. The Eq. (1) is used to calculate the radius of the horizontal curve:

$$R_h \geq \frac{V_d^2}{127\left(f_z + \frac{i}{100}\right)}, \tag{1}$$

where R_h – the radius of the horizontal curve, m; V_d – design speed, km/h; f_z – skid resistance factor; i – superelevation.

The basic formula for vehicle operation on a horizontal curve developed from the laws of mechanics is shown by Eq. (1).

The equation, as mentioned above, is used in various countries but with different values of skid resistance factors. The values used for skid resistance, mainly vary with them V_d within different countries worldwide.

Many countries use V_d, which is manually defined or tabular parameter with interrupted functionality, dependent on the road category and importance and is used for defining boundary design parameters.
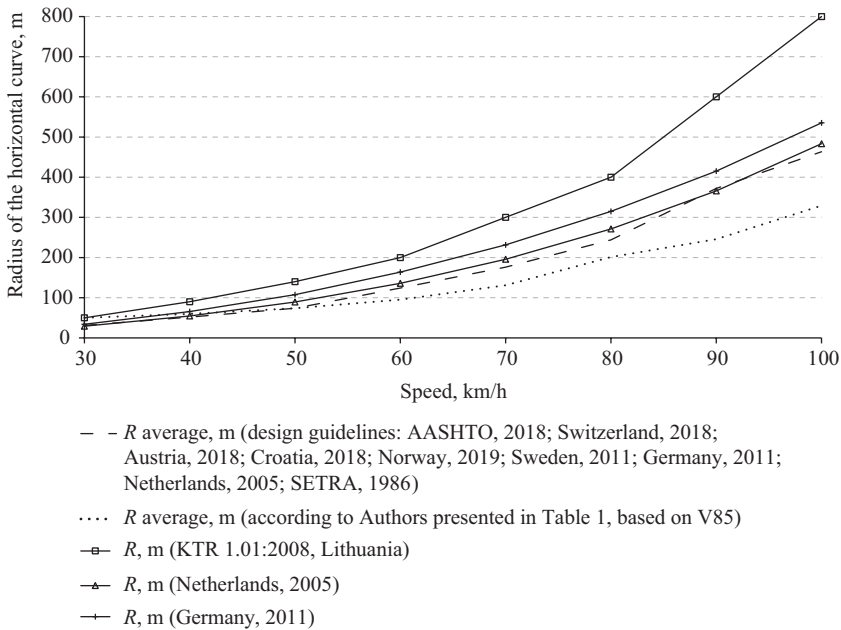
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— – *R* average, m (design guidelines: AASHTO, 2018; Switzerland, 2018;
      Austria, 2018; Croatia, 2018; Norway, 2019; Sweden, 2011; Germany, 2011;
      Netherlands, 2005; SETRA, 1986)

···· *R* average, m (according to Authors presented in Table 1, based on V85)

–□– *R*, m (KTR 1.01:2008, Lithuania)

–△– *R*, m (Netherlands, 2005)

–+– *R*, m (Germany, 2011)

Figure 1. Average of minimum radius of horizontal curve at certain design
speed in various countries and average of developed operating speed
prediction models by various authors.

Design speed in Lithuania strictly depends on the road category,
as stated in the available road design guidelines. However, there is
inconsistency with Road Traffic Rules. The design speed of the road
category V with asphalt pavement is 70 km/h. However, the permissible
speed by the Road Traffic Rules is 90 km/h. Under widely in various
countries developed speed predicting models and V_d, minimum design
radius of the horizontal curve in Lithuania is overestimated. It is unrelated
to defined driving speed measurements (Figure 1). Either there is no term
V_{85} or operating speed used in available Lithuanian road design guidelines.

Figure 1 shows a significant difference between radius of the
horizontal curve and V_d in Lithuanian regulations and leading countries
(Germany, Netherlands) with high traffic safety standards. There were
calculated average V_d and V_{85} for fixed radius of the horizontal curve
(*R*) as stated in national standards or description provided in published
articles (American Association of State…, 2018; Abbas, Adnan, & Endut,
2011; Camacho-Torregrosa, Pérez-Zuriaga, Campoy-Ungría, & García-
García, 2013; Castro, Pardillo-Mayora, & Jurado, 2013; Dilling, 1973;
Kanellaidis, Golias, & Efstathiadis, 1990).

Table 1. Operating Speed Prediction Models developed by various authors

No.	Country	Speed prediction model	Variables	Source
1	Spain	$V_{85} = 125.94 - \dfrac{5806.33}{R}$	V_{85}, horizontal curve radius (R) based on 42 horizontal curves	Castro, Pardillo-Mayora, & Jurado, 2013
2	Spain	$V_{85} = 102.048 - \dfrac{3990.26}{R}$, when 70 m < R ≤ 400 m	V_{85}, horizontal curve radius (R) based on 62 segments	Camacho-Torregrosa, Pérez-Zuriaga, Campoy-Ungría, & García-García, 2013
3	Germany	$V_{85} = 5.32 + 1.12V_{avg}$, $V_{avg} = 25.10 + 5.57b + 0.05R - 0.05CCR$	V_{85}, horizontal curve radius (R) V_{avg} – average driving speed on a horizontal curve, b – lane width, CCR – curvature change rate of the roadway section	Dilling, 1973
4	Greece	$V_{85} = 129.88 - \dfrac{623.1}{\sqrt{R}}$	V_{85}, radius (R)	Kanellaidis, Golias, & Efstathiadis, 1990
5	Malaysia	$V_{85MC} = 75.344 - \dfrac{368.14}{\sqrt{R}} + 0.307V_{85AT}$	V_{85MC} at the middle horizontal curve, horizontal curve radius (R), V_{85AT} at approach tangent	Abbas, Adnan, & Endut, 2011
6	France	$V_{85} = 93.83 - \dfrac{2955.40}{R}$	V_{85}, horizontal curve radius (R)	Castro, Pardillo-Mayora, & Jurado, 2013
7	Canada	$V_{85MC} = 94.30 + 8.6710^{-6}R^{2}$	V_{85MC} at the middle horizontal curve, horizontal curve radius (R)	Misaghi & Hassan, 2005

Usually, in the design standards, the minimum radius of the horizontal curve (R_{min}) is determined assuming skid resistance factor for a wet and clean surface. Therefore, when measuring driving speed on a dry surface, commonly registered driving speeds are much higher than those assumed for V_d. Nevertheless, the radius of the horizontal curve in Lithuanian road design guidelines has unreasonably high safety margin compared to other countries.

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Figure 1 and Table 1 present, the average operating speed models developed by many authors based on field studies show that drivers tend to drive faster than the V_d in the horizontal curve specified in the road design guidelines. This consideration agrees with the findings of OSPMs presented in Table 1.

There is a lack of in-depth investigation that has been reported on the V_{85} model for the horizontal alignment, which reflects rural roads condition in Lithuania. Nether wide range of speed measurements associated with the investigation of road geometry was implemented.

1.   Data collection

The research program focused on the driving speed in the horizontal curves, which include:
- the selection of road sections appropriates for the study;
- the collection of field data of the road sections;
- the measurement of driving speeds at each section.

Site selection was limited to sections with the following characteristics (Lamm, Beck, Ruscher, Mailänder, Cafiso, & La Cava, 2007):
- a tangent to the horizontal curve section;
- removed from the influence of intersections;
- without physical features adjacent to or in the roadway, which may create abnormal hazards;
- average annual daily traffic between 1000 vpd and 12 000 vpd.

Field data collection involves obtaining parameters of each horizontal curve. Information recorded includes a radius of the horizontal curve, length of the horizontal curve, superelevation rate, gradient, lane width and average annual daily traffic.

Speed data collection ensured that the driving speed of all passing vehicles was recorded. The speed of different type of vehicles was

Table 2. Example of data recorded on the road No. 2610, Site 1

Date	Direction	Speed, km/h	Length, dm	Class
15/01/2020 09:20	Inner radius lane	59	42	PC
<...>				
15/01/2020 09:22	Outer radius lane	51	46	PC
<...>				
15/01/2020 09:26	Outer radius lane	41	99	HV
<...>				

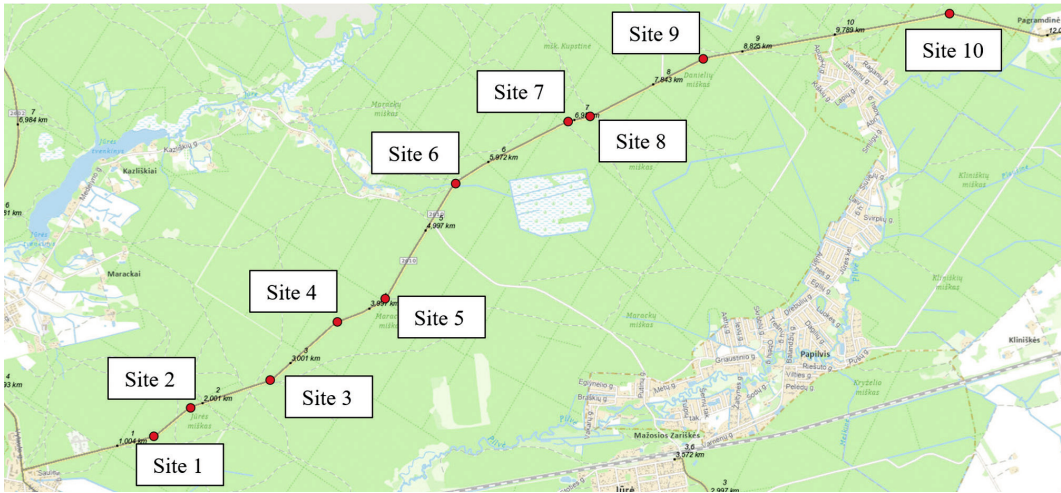Note: PC – a passenger car, HV – heavy vehicle.

Figure 2. Speed measurements sites along the road No. 2610

collected by observation value using "*SDR Traffic Detector*". This device records every single vehicle speed, date, time, direction and classifies vehicles in four categories by determining its length. Example of data recorded presented in Table 2. The data collected were recorded to the database to make it easy for further analysis. The observations of speed were recorded at the middle point of the horizontal curve placing detector at outside lane shoulder. The detector, as specified in the installation manual, was faced to upcoming traffic on mounting pole and turned at the angle of 45° to road axis.

The research was conducted on the selected road No. 2610 Kazlų Rūda–Pažėrai (Figure 2). Speed measurements sites were selected in the middle point of every horizontal curve in 10 km long road section. The test road was chosen according to the regional significance, pavement type and condition. The asphalt pavement was laid in the different test road sections in 2009–2014. Annual daily traffic is 1196 veh/year, and trucks consist below 15% of all traffic. Superelevation on the horizontal curves is fixed at 4%, and the longitudinal gradient is less than 4%. Long tangents separate horizontal curves. Spiral horizontal curves are applied at each horizontal curve in both directions. Also, the influence of intersections is insignificant, and the test road is a transit route. Speed measurement device mounted in place on short pole at the height of 1.2 m (Figure 3).

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Figure 3. The speed measurement device is mounted in place Site 6 (marked in red circle)

2.   Data analysis

Driving speed data of each Site was categorised and filtered by its time (day, twilight, and night). In further analysis, only Day time speed data were analysed. The free flow condition is satisfied when the gap between two adjacent vehicles is of 6 s (Lamm & Choueiri, 1987). Statistical analysis was carried out to verify the hypothesis of free flow. The data were grouped by the time between vehicles: below 3 s, no less than 3 s and below 6 s, no less than 6 s, also trucks data were filtered out and excluded. Limitations in the amount of data available for trucks made it more reasonable to analyse with only the passenger car data.

Two statistical tests were performed to evaluate the difference between the mean speeds and the speed variance of isolated and unisolated vehicles. The absence of the significant difference between the mean speeds and the speed variances indicates that these samples can be combined as one sample.

Random independent samples drawn from two populations are used to test the equality of two population means. It is assumed that sufficiently large samples are large enough, e.g. more than 25 observations (Washington, Karlaftis, Mannering, & Anastasopoulos, 2010). The null hypothesis H_0 in the two-tailed test states that the two population means μ_1 and μ_2 are equal. The test statistic is calculated as:

$$Z = \frac{\left(\overline{X}_1 - \overline{X}_2\right) - \left(\mu_1 - \mu_2\right)}{\sqrt{\dfrac{s_1^2}{n_1} + \dfrac{s_2^2}{n_2}}}, \tag{2}$$

where μ – population mean, $\overline{X}$ – sample average, s^2 – sample variance, n – sample size.

In Eq. (2) $(\mu_1 - \mu_2)$ is equal to zero under the null hypothesis, $(\overline{X}_1 - \overline{X}_2)$ is the actual difference in the sample means, s_1^2 and s_2^2 are the sample variances and n_1 and n_2 are the number of observations in the two samples. The denominator in the Eq. (2) is the standard error of the difference between the two sample means and requires two independent samples. The confidence interval for the difference in means is t-distributed with degrees of freedom equal to $(n_1 + n_2 - 2)$. The null hypothesis is rejected when the calculated test statistic is larger than the critical value obtained from the t distribution tables.

Random independent samples drawn from two populations are used to test the equality of two population variances. The null hypothesis H_0 in the two-tailed test states that the two variances σ_1^2 and σ_1^2 are equal. The test statistic is calculated as:

$$F_{(n_1-1, n_2-1)} = \frac{s_1^2}{s_2^2},$$

(3)

where $F_{(n_1-1, n_2-1)}$ is an F-distributed random variable with $n_1 - 1$ degree of freedom in the numerator and $n_2 - 1$ degree of freedom in the denominator.

The larger sample variance is placed in the numerator of the Eq. (3). The null hypothesis is rejected when the calculated test statistic is larger than the critical value obtained from the F distribution tables. Both hypothesis tests were performed with a 95% confidence level.

2.1. Example Site 1

Interest is focused on whether the mean speed difference between unisolated vehicles (time is below 3 s) and isolated vehicles (time is no less than 6 s) exists. All recorded data was filtered and exclusions of heavy vehicles, night and twilight were eliminated. Were used 46 observations below 3 s and 445 observations no less than 6 s to test this hypothesis. A 5% significance level was used. Descriptive statistics show that average speeds in below 3 s and no less than 6 s are $\overline{X}_{below\,3\,s} = 68.93$ and $\overline{X}_{no\,less\,than\,6\,s} = 69.41$, respectively. Further, it was found that the variances are $s_{below\,3s}^2 = 54.20$ and $s_{no\,less\,than\,6\,s}^2 = 92.44$ respectively. The competing hypothesis was (Eqs (4) and (5):

$$H_0 : \mu_{below\,3\,s} - \mu_{no\,less\,than\,6\,s} = 0,$$

(4)

$$H_a : \mu_{below\,3\,s} - \mu_{no\,less\,than\,6\,s} \neq 0.$$

(5)

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Table 3. Descriptive statistics for Site 1 recorded

t-test: two-sample assuming unequal variances	Unisolated vehicle	Isolated vehicle
	below 3 s	no less than 6 s
Mean	68.93	69.41
Variance	54.20	92.44
Observations	46	445
Hypothesized Mean Difference	0	
df	62	
t stat	−0.401	
P (T no less than t) one-tailed	0.345	
t critical one-tailed	1.670	
P (T no less than t) two-tailed	0.690	
t critical two-tailed	1.999	

Using Eq. (2), the test statistic is (Eq. (6):

$$Z = \frac{(68.93 - 69.41) - 0}{\sqrt{\frac{54.20}{46} + \frac{92.44}{445}}} = -0.401. \tag{6}$$

The test statistic (Table 3) is lower than 1.999, the critical value for a two-tailed test at the 5% significance level, and so the null hypothesis is accepted. This result indicates that at Site 1, there is no mean speed increase or decrease between unisolated vehicles (time is below 3 s) and isolated vehicles (time is no less than 6 s). Thus, with 95% confidence, speed means are equal in the interval between −0.944 km/h and 0.000 km/h.

The mean speeds between isolated and unisolated vehicles in nine sites were found to be equal (Table 4). The result at Site 10 indicates that there is a mean speed increase between unisolated vehicles (time is below 3 s) and isolated vehicles (time is no less than 6 s). Thus, with 95% confidence means are not equal between −5.937 km/h and 0.000 km/h.

The speed variance for isolated and unisolated vehicles in all sites were found to be equal. The result of the higher speed variance for isolated vehicles is reflected in the V_{85}, that are slightly higher than for unisolated vehicles (from 0.15 km/h to 6.00 km/h). A higher variance for isolated vehicles was obtained due to the presumptive absence of a slower-moving leading vehicle. Following vehicle driver likely more often choose a similar speed to the leading vehicle. The significant difference

Table 4. Descriptive results of unisolated-isolated vehicles

Description	Site									
	1	2	3	4	5	6	7	8	9	10
Length of the straight section before the horizontal curve, m	657	343	673	719	398	834	1086	21	1067	426
Horizontal curve radius, m	60	450	250	250	150	300	550	550	500	180
Horizontal curve length*, m	37	224	168	171	161	228	233	235	225	122
Length of the straight section after the horizontal curve, m	343	673	719	398	834	1086	21	1067	426	756
Number of observations, below 3 s	46	54	58	67	62	71	64	67	52	75
Number of observations, no less than 6 s	445	429	430	453	410	470	481	475	534	529
Equal variance	+	+	+	+	+	+	+	+	+	+
Equal V_{mean}	+	+	+	+	+	+	+	+	+	−
V_{mean} (below 3 s), km/h	68.93	78.65	78.09	79.66	72.81	81.23	86.38	84.37	82.52	72.19
V_{mean} (no less than 6 s), km/h	69.41	80.89	78.93	81.15	74.21	82.20	88.81	86.72	85.40	75.16
V_{85} (below 3 s), km/h	75.00	88.05	87.00	90.10	83.85	88.00	98.55	95.10	95.00	82.00
V_{85} (no less than 6 s), km/h	79.00	93.00	90.00	92.00	84.00	94.00	103.00	99.00	100.00	86.00
Difference of V_{85} (no less than 6 s) − V_{85} (below 3 s), km/h	4.00	4.95	3.00	1.90	0.15	6.00	4.45	3.90	5.00	4.00
Variance (speed, below 3 s)	54.20	124.65	80.47	95.62	96.52	110.55	189.44	113.60	155.98	88.21
Variance (speed, no less than 6 s)	92.44	144.41	138.77	127.08	116.52	148.97	186.26	171.94	201.02	121.70

Note: V_{85} calculated and grouped by the time gap between vehicles: below 3 s, no less than 6 s, that identifies isolated and unisolated vehicles; * including transitions.

can be observed in mean speeds when analysing more horizontal curves or a particular combination of road alignment elements.

In further analysis, it was used only isolated vehicles data as stated by Lamm, Beck, Ruscher, Mailänder, Cafiso, & La Cava (2007) to avoid errors in the assessment of V_{85}.

Next comparison was between the isolated vehicles V_{85} versus V_d and posted speed limit. Descriptive statistics and results presented in Table 5.

The permissible speed limit in Sites 1 through 10 is no higher than 90 km/h. The absence of a posted speed limit sign indicates the permissible speed limit is 90 km/h as stated in the national regulation. The posted speed limit in all Sites is no lower the V_d (Table 5).

Table 5. Descriptive results for unisolated vehicles in all Sites recorded

Radius, m	60	450	250	250	150	300	550	550	500	180
Site	1	2	3	4	5	6	7	8	9	10
Average	69.4	83.1	78.9	81.2	74.2	82.2	88.8	86.7	85.4	75.2
Standard deviation	9.60	9.84	11.77	11.26	10.78	12.19	13.63	13.10	14.16	11.02
Variance	92.4	97.0	138.8	127.1	116.5	149.0	186.3	171.9	201.0	121.7
Min	26	32	29	31	13	28	44	48	34	43
Max	102	113	116	127	103	116	131	125	127	105
Count	445	429	430	453	410	470	481	475	534	529
V_{85}	79.00	93.00	90.00	92.00	84.00	94.00	103.00	99.00	100.00	86.00
Posted speed limit, km/h	70	90	90	90	70	70	90	90	70	50
Overspeeding posted speed, %	50%	24%	17%	21%	71%	88%	44%	41%	37%	98%
V_d, km/h	30	80	70	70	50	70	90	90	85	60
Overspeeding V_d, %	100%	62%	81%	87%	98%	88%	63%	41%	53%	91%

It was determined that from 17% to 98% of drivers tend to exceed posted speed limit, and from 41% to 100% of drivers exceeds V_d in the horizontal curve.

The results indicate that there is a substantial inconsistency between Lithuanian road design guideline and permissible speed to how the driver recognises road geometry and what driving speed is expected from the horizontal alignment element. The radius of the horizontal curve posted speed limit, and permissible speed is few of many or indecisive factor on the driver decision of driving speed.

There is stated target in Lithuanian State Traffic Safety Improvement Program "Vision – Zero": reduce the proportion of motor vehicles exceeding the permissible speed on rural roads, from 68% in the year 2017 till 20% in the year 2030 (The Ministry of Transport…, 2019). The initial results of the Pilot Study conducted indicate that the levels of overspeeding are generally far from the 2030 targets. The statement holds even the level of V_{85} somewhat overestimated and the speed compliance underestimated considered the measurements made on a single straight flat road, absence of major intersections or driving speed limiting environment.
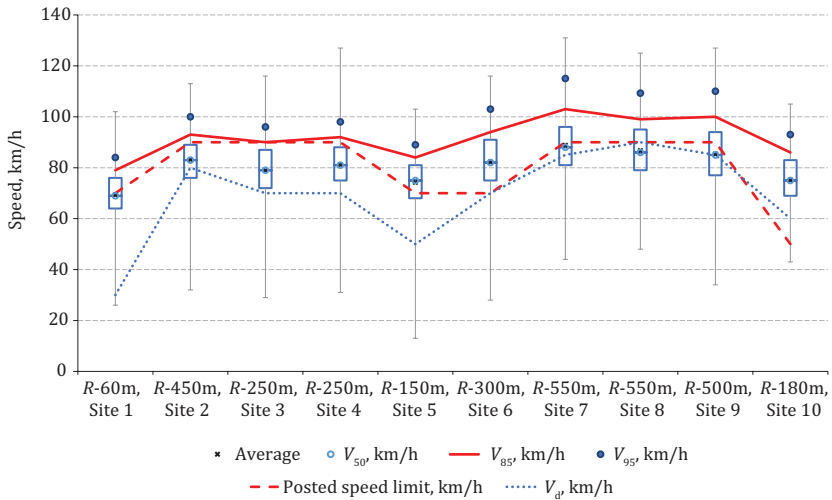
Figure 4. Road No. 2610 speed profile with measured driving speed and calculated V_{50}, V_{85}, V_{95} and V_d

In Figure 4 presented speed profile and basic statistics of road section analysed. Posted speed limit, V_d and calculated V_{85} shows overspeeding tendency along the road section. Also, for speed distribution overview percentile of V_{50} and V_{95} is marked.

In Site 2, Site 3, and Site 4 there is no posted speed limit, and V_{85} is from 0 km/h to 4 km/h higher than permissible speed and 13–24 km/h higher than V_d (Figure 4). In Site 6 radius of the horizontal curve is 300 m, but despite posted speed limit is 70 km/h, drivers tend to choose their driving speed such as in the horizontal curves with radius 250–450 m (Site 2, Site 3, and Site 4).

In all sites, V_d as stated in Lithuanian technical regulation is 13–49 km/h lower than actual measured V_{85}.

The posted speed limit, in most cases, differs from V_d. The presumed reason is the road environment parameters or local approach. In all cases, the posted speed limit is a safe driving speed, which should be lower the V_d.

In Figure 5 presented measured V_{85}, V_d and posted speed limit by radius increase order. Calculated V_{85} shows an overspeeding downward trend with an increase of radius compared to V_d. Despite permissible speed limit variates from 50 km/h to 90 km/h and V_d from 30 km/h to 90 km/h, V_{85} remains from 79 km/h to 103 km/h.

Also, the tendency found that in an increase of R, the measured V_{85} variates less between sites with a radius above 250 m (Figure 5).
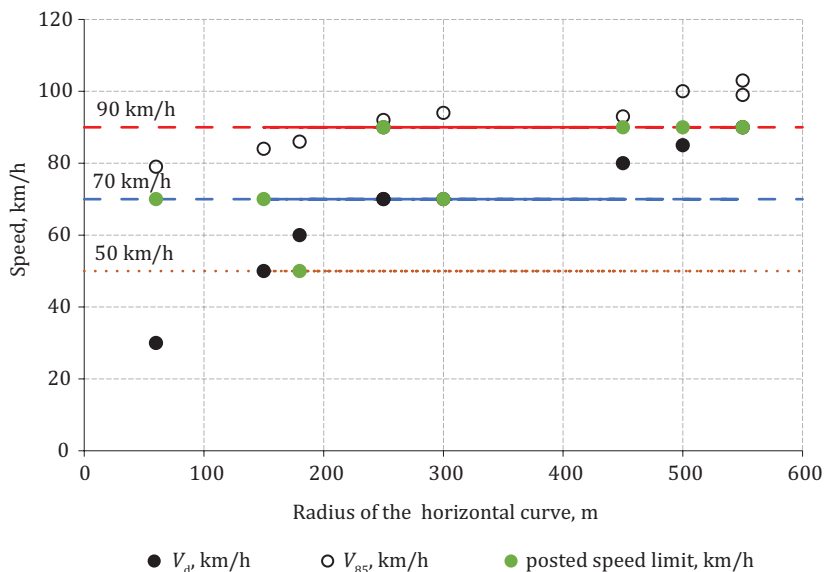
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Figure 5. Measured V_{85}, V_d and posted speed limit in comparison to various radius of horizontal curve

Measured and calculated V_{85} values are above line 90 km/h. The choice of driving speed becomes similar to the desired driving speed, that is 90–103 km/h and corresponds to OSPM developed by Camacho-Torregrosa, Pérez-Zuriaga, Campoy-Ungría, & García-García (2013) and Castro, Pardillo-Mayora, & Jurado (2013). Drivers were found to reduce speed for the horizontal curve with the posted speed limit, but the magnitude is much less than the suggested speed reduction on the road sign, which corresponds to research done by Wang, Hallmark, Savolainen, & Dong (2018).

Calculated V_{85} values (Figure 5) on individual horizontal curves correspond to the OSPM presented in Table 1 and are more like regulation of various countries road design guidelines, than to Lithuanian road design guidelines (Figure 1).

Conclusions

1. This paper shows the results of a pilot study on the relationship between design speed on an individual horizontal curve and measured operating speed towards posted speed limit and credible speed limit. Conclusions for the horizontal curves on

specific road analysed must be approved with additional research before adoption to the entire road network.

2. It was determined limitation differences in radius of the horizontal curve dependent on country and regulation. Differences exponentially depend on speed and at 30 km/h, radius of the horizontal curve difference is only 28 m, at 50 km/h – 90 m, at 70 km/h – 170 m, at 90 km/h – 300 m.

3. The operating speed data, obtained during the study on individual curves, coincide more to design speed in different countries than stated in Lithuanian regulation.

4. The literature review shows that the radius of the horizontal curve has a little effect on the speed choice of drivers. Design speed in Lithuania is one of the lowest among many countries reviewed for the respective radius of the horizontal curve. Widely used and confirmed in multiple Operating Speed Prediction Models, minimum radius of the horizontal curve for specific design speed in road analysed is much lower than accepted in Lithuanian road design guidelines. The critical finding is that despite differences that exist between operating speed and design speed there is a still seen tendency: when the radius of the horizontal curve increases, the difference between operating speed and design speed decrease.

5. It was determined that drivers choose a driving speed higher than permissible speed or as intended by the designer using the geometrical parameters specified in the road design guidelines. The research shows that from 17% to 98% of drivers tend to exceed posted speed limit, and from 41% to 100% of drivers exceeds design speed in horizontal curve. Thus, the radius of horizontal curves specified in the road design guidelines for a given speed differs from the driving speed chosen by the drivers. Design inconsistencies appear when the permitted speed of one element of the road alignment coincides with higher design speed (like operating speed, usually 90 km/h) and the other element with lower design speed (when design speed is below 90 km/h, usually operating speed is much higher). Such design inconsistencies reduce recognizability of the road environment and increase the probability of overspeeding.

6. Change in speed limit is often subject to intense social and political debates. A credible speed limit on horizontal curve, with a specific radius, is a limit that is logical by (the majority of) drivers for that specific road in the particular road environment.

7. The horizontal curves of the radius more than 250 m and the absence of additional safety measures have no driving speed

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limitation effect on a choice for driving speed when design speed is 90 km/h. Before deciding on the increase of speed limit in such horizontal curves, road environment and accident data at a specific location must be considered with great care.

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