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EXPERIMENTAL RELATIONSHIPS BETWEEN OPERATING SPEEDS OF SUCCESSIVE ROAD DESIGN ELEMENTS IN TWO-LANE RURAL HIGHWAYS

Laura Eboli, Giuseppe Guido, Gabriella Mazzulla, Giuseppe Pungillo

Dept of Civil Engineering, University of Calabria, Italy

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Abstract. Speed has been identified for a long time as a key risk factor in road traffic. Inappropriate speeds contribute to a relevant part of road crashes, and then to the mortality and disabilities resulting from them. Starting from this consideration this paper investigates road safety by analysing operating speed, which is the 85th percentile speed. Particularly, two regression models are proposed to predict operating speeds for different road elements related to specific road conditions. The case study is represented by a two-lane rural highway. Smartphone-equipped vehicles were used to evaluate the operating speed for each element of the analysed road segment. Continuous speed data were recorded by the vehicles driven by users with different driving behaviours. Since the lack of safety is often linked to an inconsistency roadway geometric design, we effected a preliminary quantitative design consistency evaluation that confirmed the need of having accurate experimental measures of operating speed or appropriate models for predicting it. We propose two types of operating speed models: one for estimating speed profiles for horizontal curves, and the other one for tangents. According to both models, operating speed is predicted by the combination of an independent variable representing a geometric characteristic (curve radius for the curves and length for the tangent elements) and an independent variable relating to the speed, and specifically the operating speed of the previous road element. The models show a good predictive capability, and can be considered as a useful tool for operators and technicians for road management.

Keywords: road safety; design consistency evaluation; safety criteria; design speed; operating speed; experimental models.

Introduction

Speed is a key factor in road safety, influencing both the risk of road accidents as well as the severity of the injuries that result from crashes. Inappropriate speeds are responsible for a high proportion of the mortality and disabilities that result from road crashes (OECD 2006). In many cases, geometric road elements (curve and tangent), defined as a function of the design speed, are not in accordance with drivers expectancy, and consequently with their driving behaviour (FHWA 1986).

Road design consistency, that studies the road geometry's conformance with driver expectancy, is gaining an important role in road design (FHWA 2000a; Ng, Sayed 2004; Garach Morcillo *et al.* 2014). Nowadays, the main criteria to evaluate the design speed are based on operating speed, often determined as the 85th percentile speed of a sample of vehicles (Sowmya *et al.* 2012). Operating speed is the speed under which 85% of vehicles operate under free-flow condition on clean and dry road pavement (only 15% of the drivers exceeds the measured speed). Many researchers agree with considering this speed as a truer measure of the behaviour actually required by drivers (Camacho-Torregrosa *et al.* 2013). Other authors retain that the lack of speed consistency in the road section is reflected also by the large amount of speed differential in the operating speed between the two successive elements along a road (Park, Saccomanno 2006). The knowledge and management of the operating speeds seem to be a crucial point to enhance road safety conditions, because it allows the alignment of the road to be tested as a function of the potential heterogeneity in drivers' behaviour, as well as to highlight safety issues in the existing roads test of safety conditions (Atashafrazeh, Yadollahi 2013).

The best estimate of the operating speed is obtained by performing speed measurements on the road. If it is not possible, then operating speed prediction models may be used to estimate the operating speed as a func-

Corresponding author: Gabriella Mazzulla
E-mail: *gabriella.mazzulla@unical.it*

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tion of road geometric characteristics (e.g. curve radius, degree of curvature, curvature change rate). An exhaustive review of the operating speed prediction models has been proposed by the FHWA (2000b) and by Ng (2002), and more recently by Atashafrazeh and Yadollahi (2013). Recent studies introduce more complex operating speed models, as reported in Praticò and Giunta (2012).

Models reported in the scientific literature are generally useful for analysing operating speed but only for specific sites. For this reason, in this paper, two regression models for predicting operating speeds for different road elements related to specific road conditions are developed. Being the lack of safety often referred to an inconsistency roadway geometric design, we made a preliminary quantitative design consistency evaluation. Speed profiles were obtained from smartphone-equipped vehicles used to evaluate the operating speed of the elements of a road segment of a two-lane rural highway.

After this brief introduction, in the following we firstly describe the case study and the data gathered to support this research; afterwards we show the design consistency evaluation of the road layout in order to verify the need to have experimental measures of the operating speeds and/or reliable models that allow their prediction. Then, experimental models are introduced, and finally we report brief conclusive observations about the work.

1. Case Study: Data Gathered

The survey interested a part of the Italian National Road No 106 'Jonica' (SS106). The SS106 is a two-lane rural highways connecting Apulia with Calabrian regions between Taranto and Reggio Calabria (Fig. 1).

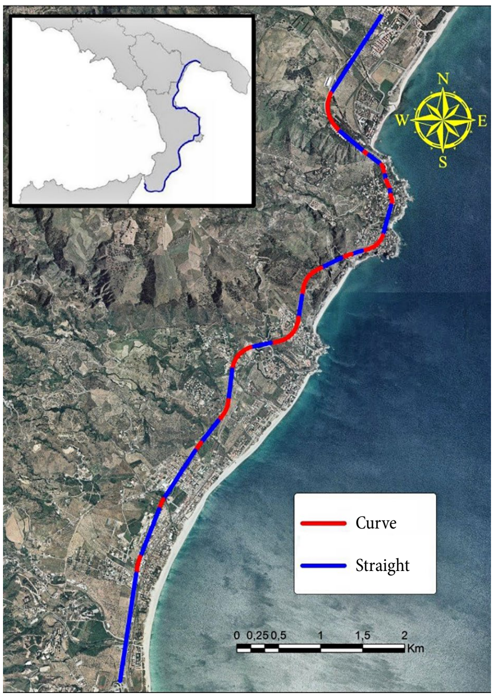

Fig. 1. The SS106 analysed segment

SS106 is an eighty-year-old road, 491 km long; it is annually interested by a large number of accident and so it was named 'death road'. As reported by the Italian Institute for the statistical analysis (ACI 2010), in 2009 SS106 was the Italian road with the highest death rate (0.46 dead persons per km).

The analysed road segment is 10 km long; it is an interurban almost flat road with a maximum longitudinal grade equal to ±4%.

The road segment is a two-way road with one lane for each travel direction; each lane is 3.5 metres wide. It is lacking in lighting and, although the road is far from significant urban areas, there are junctions and private accesses not detected or inadequately detected along the route. From a planimetric point-of-view the path presents a very discontinuous pattern, with radii of curvature between 120 and 520 metres and very tortuous path, especially in the southern part.

The analyzed road segment consists of 29 elements: 15 tangents and 14 curves. Each element was characterised by length (L), curve radius (R), degree of curvature (DC) (that is the angle at the centre point of the circular curve, expressed in degrees, corresponding to an arc length of 100 metres), curvature change rate (CCR) (that is the angular variation in the travel direction, expressed both in degrees or grades per km), longitudinal grade from South to North direction (G_{S-N}), longitudinal grade from North to South direction (G_{N-S}), design speed (V_d) (Table 1). Design speed values were calculated by using the formulation proposed by Italian National Research Council (CNR 2002) as a function of the curve radius and by considering the physical laws that govern a vehicle's motion with respect to the road geometric characteristics.

The analysed road segment was repeatedly run in order to collect the instantaneous speed values along the pattern. To this aim, vehicles equipped with a GPS-embedded smartphone were used; a specific app allowed the speed values to be recorded, by adopting a frequency of 1 Hz, together with the instantaneous vehicle position (latitude and longitude). The modern GPS receivers are able to calculate speed values by means of algorithms based on Doppler (Kaplan, Hegarty 2005), that is on the measurement of the frequency variation of the waves emitted by a source and perceived by an observer, when source and observer are in relative motion.

Instantaneous vehicle speed data were acquired by 27 drivers that covered the segment test both in northbound and southbound direction (Pungillo 2013).

Data were reported on GIS in order to locate the surveyed points included in each homogenous segment (curve or tangent). Starting from these data, we can calculate the operating speeds, which is the 85th percentile speeds of the sampled drivers for each road element. Operating speeds were calculated for each direction (North–South direction, from Squillace to Soverato, and South–North direction, from Soverato to Squillace), and also by considering the speed values surveyed in both directions. Table 1 shows the geometric characteristics of the road elements together with the values of the design speeds and the operating speeds.

Table 1. Characteristics of the road elements

ID	Road element	L [m]	R [m]	DC [deg/100 m]	CCR [deg/km]	G_{N-S} [%]	G_{S-N} [%]	V_d [km/h]	$V_{85(N-S)}$ [km/h]	$V_{85(S-N)}$ [km/h]	V_{85} [km/h]
0	Tangent	1079				1	–1	100	76.09	84.70	77.97
1	Curve	480	422	13.58	150.95	1	–1	97.14	81.32	81.22	81.22
2	Tangent	397				3	–3	100	80.49	79.52	80.34
3	Curve	69	430	13.33	148.14	4	–4	97.84	76.88	–	76.88
4	Tangent	201				4	–4	100	–	55.26	55.26
5	Curve	122	192	29.86	331.77	4	–4	71.84	64.43	54.80	59.75
6	Tangent	58				0	0	100	66.39	48.94	57.07
7	Curve	118	386	14.85	165.03	–3	3	93.88	63.24	51.03	60.65
8	Tangent	55				–3	3	100	70.91	59.69	64.60
9	Curve	118	120	47.77	580.83	4	–4	59.72	73.77	62.79	66.71
10	Tangent	344				4	–4	100	79.46	79.06	79.36
11	Curve	352	356	16.10	178.93	4	–4	91.03	75.78	83.90	77.98
12	Tangent	145				2	–2	100	75.34	87.27	77.34
13	Curve	143	320	17.91	199.06	3	–3	87.40	78.01	92.49	83.96
14	Tangent	299				2	–2	100	78.54	98.73	87.88
15	Curve	429	410	13.98	155.37	–3	3	96.07	78.49	88.84	84.01
16	Tangent	242				–4	4	100	91.21	86.31	89.83
17	Curve	513	380	15.08	167.63	–4	4	93.32	88.83	83.61	85.66
18	Tangent	288				–3	3	100	89.55	87.78	89.55
19	Curve	370	270	21.23	235.93	–3	3	81.91	90.11	104.86	95.05
20	Tangent	331				–1	1	100	94.16	110.08	96.59
21	Curve	270	435	13.17	146.44	–1	1	98.27	98.79	116.64	103.31
22	Tangent	333				–2	2	100	100.55	121.34	107.79
23	Curve	118	520	11.02	122.50	–3	3	100	106.23	121.56	108.90
24	Tangent	687				–2	2	100	113.82	120.92	114.49
25	Curve	120	480	11.94	132.71	–2	2	100	118.62	109.00	109.52
26	Tangent	573				1	1	100	119.08	109.27	110.58
27	Curve	190	510	11.24	124.90	1	1	100	118.81	106.73	109.22
28	Tangent	1177				0	0	100	102.15	99.45	99.76

Notes: L – length; R – radius; DC – degree of curvature; CCR – curvature change rate; G_{N-S} – longitudinal grade for southbound direction; G_{S-N} – longitudinal grade for northbound direction; V_d – design speed; $V_{85\,(N-S)}$ – operating speed for southbound direction; $V_{85\,(S-N)}$ – operating speed for northbound direction; V_{85} – operating speed for both directions.

The analysis of the characteristics of the road elements highlights that all the tangent elements have a design speed of 100 km/h, while for the curves it varies from 60 to 100 km/h; finally, operating speeds varies from about 50 to 120 km/h.

2. Design Consistency Evaluation

In order to verify the design consistency of the analysed road segment and the resulting driver behaviour in free-flow condition, we analysed speed values of the road design elements. The analyses were restricted to a road segment of about 6 km (6096 metres) because in some parts of the investigated road segment, interested by tunnels, GPS signal was lost and the smartphone did not acquire the data.

In Fig. 2 the instantaneous values of registered speeds (V_t) are reported, together with operating speed (V_{85}) and mandatory speed limit (V_L) profiles for each road element. The diagram can help in a qualitative design consistency evaluation, because it immediately shows that speed values maintained by the drivers are well over the design speeds (V_d) in many points of the path, and in some cases the mandatory speeds limits are higher than the design speeds.

A quantitative design consistency evaluation was made by considering the main methodologies reported in the scientific literature, and specifically those based on speed analysis; from these we chose the methodology proposed by Lamm *et al.* (1999), who introduced three 'consistency' criteria in order to have a safety-related evaluation of the interactions between road geometric design, driving behaviour, driving dynamics, and accident situation:

– *safety criterion I* aims to achieve the 'design consistency', and requires a control between 85th percentile speed (V_{85}) and design speed (V_d);

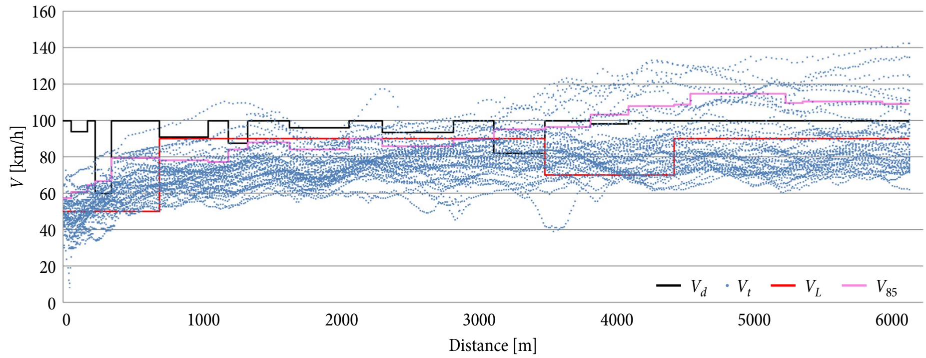

Fig. 2. Speeds profiles

- *safety criterion II* aims to achieve the 'operating speed consistency', that is achieving consistent road characteristics, by means of a control of the operating speeds V_{85} between successive design elements;
- *safety criterion III* aims to achieve the 'driving dynamic consistency' by assuming that the difference between side friction assumed for curve design (as a function of V_d) and side friction required at curved sites (as a function of V_{85}) represents a quantitative measure of driving dynamic safety or unsafety.

In our analysis we chose to verify the design consistency by using the *safety criterion I* proposed by Lamm *et al.* (1999). According to this criterion, the quality level of the road design can be defined as 'good', 'fair' or 'poor' depending on the difference between operating and design speed values (Table 2). When the level is 'good' a balanced speed behaviour can be expected, especially at curved site, and no corrections in the road design are necessary. If the level is 'fair' the speed behaviour should be brought down through speed limits and appropriate traffic control devices, although the quality level of the road design can be defined as 'tolerable'. A level 'poor' indicates that critical discrepancies between design speed and actual driving behaviour are present as a consequence of the inadequate road design; therefore, redesigns are normally recommended.

Table 2. *Safety criterion I* proposed by Lamm *et al.* (1999)

Design quality level	Recommended interval
Good	$\|V_{85} - V_d\| \leq 10$ km/h
Fair	10 km/h $< \|V_{85} - V_d\| \leq 20$ km/h
Poor	$\|V_{85} - V_d\| > 20$ km/h

The results of the design consistency evaluation made according to Lamm's *safety criterion I* are reported in Fig. 3. From the results, we can observe pattern inconsistency mainly in the first part of the road stretch (from North to South). In these elements, we registered a remarkable difference between operating and design speeds; this fact indicates a situation of potential risk, with consequent decay of the minimum requirements for the safety of the infrastructure. The central part of the pattern does not have particular problem, because the operating speeds are very similar to the theoretical

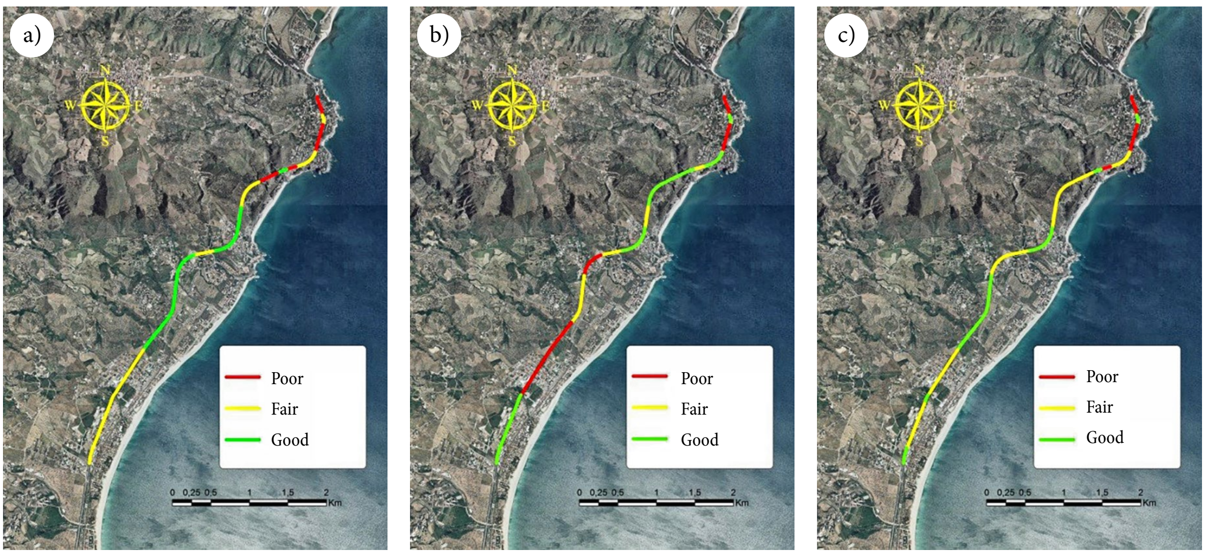

Fig. 3. Design consistency evaluation according to Lamm's *safety criterion I*:
a – North–South direction; b – South–North direction; c – both directions

speeds assumed for sizing the roadway. In the last part of the pattern, the design consistency evaluation shows a 'tolerable' situation, where the quality of the design can be considered 'acceptable' but some operating speed control systems have to be provided.

The design consistency evaluation suggests the need of accurate experimental measures of operating speed or, in alternative, suitable prediction methods. Therefore, calibrating reliable models capable of predicting as close as possible the real speeds values is surely convenient. The main purpose of this research is to propose models for estimating the operating speeds in road sections having similar characteristics to the analysed one.

3. Experimental Models

Two types of operating speed models were defined in order to estimate real speed profiles for two-way undivided rural highways: one for horizontal curves and the other for tangent elements. The operating speed models were calibrated based on continuous operating speed profiles obtained on the SS106 segment by means of smartphone-equipped vehicles, as described in the previous sections. These models can accurately reflect drivers' behaviour overcoming the limitations of other operating speed models based on speed-spot data collection.

3.1. Operating Speed Model for Curves

Preliminarily, it was necessary to analyze the correlation matrix for geometric characteristics, design speed and operating speed to understand how the operating speed depends on geometric features for curves, and to determine the final variables to be considered in the model. The correlation matrix shown in Table 3 was obtained for 8 variables including curvature features.

Speeds recorded on the SS106 segment are partially affected by some specific local factors (low-volume conditions, good weather conditions, dry road surface), that were not considered by the proposed regression model. For these reasons, some data were excluded from the analysis; twenty curvilinear elements were finally examined, with radii varying between 120 and 520 meters and operating speeds ranging from 62 to 122 km/h.

From this analysis it appears that the parameters mostly affecting the operating speed are the operating speed of the previous segment ($V_{85,i-1}$) and the radius of the curve (R). Despite some models account for other variables, such as grade and sight distance (Ng 2002), this research is directed toward finding formulations characterized by few variables (easily determinable), and then by a simple analytical form that can be easily used by operators and technicians for the road infrastructure management. Therefore, the proposed operating speed model for curves uses radius and operating speed of the previous element as explanatory variables according to the following equation:

$$V_{85,c,i} = a \cdot V_{85,i-1} + b \cdot R_i + c, \quad (1)$$

where: $V_{85,c,i}$ is the operating speed for curve i [km/h]; $V_{85,i-1}$ is the operating speed of the previous element [km/h]; R_i is the radius of the curve i [m]; a, b and c are the model parameters to be calibrated.

Table 4 shows the estimated parameters of the model. Both independent variables were found to have a significantly positive effect on operating speed on curve. More importantly, the fit measures indicate that the proposed model fits the data well ($\rho^2 = 0.944$, $\rho^2_{adj} = 0.937$, $MSE = 18.743$, $RMEQ = 4.329$).

Based on these results, the operating speed model for curves can be described through the following expression:

$$V_{85,c,i} = 0.858 \cdot V_{85,i-1} + 0.037 \cdot R - 1.288. \quad (2)$$

Table 3. Correlation matrix for geometric characteristics, design speed and operating speed for curvilinear elements (n = 20)

Variable	R	L	DC	CCR	G	V_d	$V_{85,i-1}$	$V_{85,c,i}$
L	–	–						
R	–	–0.05						
DC	–0.90	–0.18	–					
CCR	–0.90	–0.18	1.00	–				
G	0.00	0.00	0.00	0.00	–			
V_d	0.96	0.11	–0.98	–0.98	0.00	–		
$V_{85,i-1}$	0.53	–0.05	–0.40	–0.40	0.02	0.44	–	
$V_{85,c,i}$	0.62	–0.06	–0.47	–0.47	0.03	0.52	0.97	–

Notes: L – length; R – radius; DC – degree of curvature; CCR – curvature change rate; G – longitudinal grade; V_d – design speed; $V_{85,i-1}$ – operating speed for previous segment; $V_{85,c,i}$ – operating speed for curve i.

Table 4. Model parameter estimates ($V_{85,c}$)

Source	Value	Standard deviation	t	p	Lower bound (95%)	Upper bound (95%)
Constant	–1.288	6.148	–0.209	0.837	–14.260	11.684
$V_{85,i-1}$	0.858	0.082	10.481	<0.0001	0.686	1.031
R	0.037	0.011	3.401	0.003	0.014	0.060

3.2. Operating Speed Model for Tangents ($V_{85,t}$)

As previously performed for the curves, a preliminary correlation analysis was carried-out to identify the explanatory variables to be used in the operating speed model for tangents (Table 5).

Table 5. Correlation matrix for geometric characteristics, design speed and operating speed for tangent elements (n = 20)

Variable	L	G	$V_{85,i-1}$	V_{85}
L	–			
G	0.00	–		
$V_{85,i-1}$	0.75	0.06	–	
V_{85}	0.83	–0.04	0.94	–

Notes: L – length; G – longitudinal grade; $V_{85,i-1}$ – operating speed for previous segment; V_{85} – operating speed.

We found that drivers' behaviour over tangent segments, expressed in terms of speed, can be considered dependent on the bounding curves; this implies that an in-depth analysis has to be done to better explain the relationship between the operating speed on tangents and the operating speed on curves preceding tangent elements.

Specifically, it should be noted that operating speed of a tangent segment depends only partially on the length of the segment itself; on the other hand, the operating speed on tangent cannot be fully explained by the operating speed on the previous curve, although the two variables are strongly correlated. Furthermore, while length is the main geometric feature of the tangent element affecting the drivers' performance with the same weather, visibility and traffic conditions, operating speed on the previous curve is linked to the behaviour experienced by users approaching the tangent segment.

These findings suggest that a combination of the two variables (length of the tangent element and operating speed of the previous curve) may increase the predictive capabilities of the simple regression models, as demonstrated by other authors (Ng 2002). Based on the above-mentioned experimental studies the analytic form of the proposed operating speed model for tangents is:

$$V_{85,t,i} = a \cdot V_{85,i-1} + b \cdot \log_{10}\left(L_i\right) + c, \quad (3)$$

where: $V_{85,t,i}$ is the operating speed for tangent i [km/h]; $V_{85,i-1}$ is the operating speed for the previous segment [km/h]; L_i is the length of the tangent i [m]; a, b and c are the model parameters to be calibrated.

Table 6 shows the estimated parameters for the model. It can be seen that both independent variables were found to have a significantly positive effect on operating speed on curve. The goodness of fit indices show that the proposed model closely replicates the observed operating speed values on tangents ($\rho^2 = 0.912$, $\rho^2_{adj} = 0.902$, MSE = 39.335, $RMEQ$ = 6.272).

Based on these results, the operating speed model for tangents can be described by the following equation:

$$V_{85,t} = 0.762 \cdot V_{85,i-1} + 13.994 \cdot \log_{10}\left(L\right) - 10.721. \quad (4)$$

3.3. Results

In order to have a comparison between the proposed model and others reported in the literature (Ng 2002), we select the models considering the same independent parameters, and by assuming a base value of 70 km/h for the speed on the previous road element (Fig. 4a) and 300 metres for the length of the tangent (Fig. 4b), respectively.

From Fig. 4 we can observe that our model has estimated coefficients in the range of the same parameters considered by other authors, in different experimental contexts.

Finally, in order to have an immediate measure of the model goodness of fit, we propose a scatter diagram of the 'reliability', where observed and estimated speed values are compared, for curves and tangents operating speed models, respectively (Fig. 5).

We can observe that operating speed model for curves is more reliable than the other model.

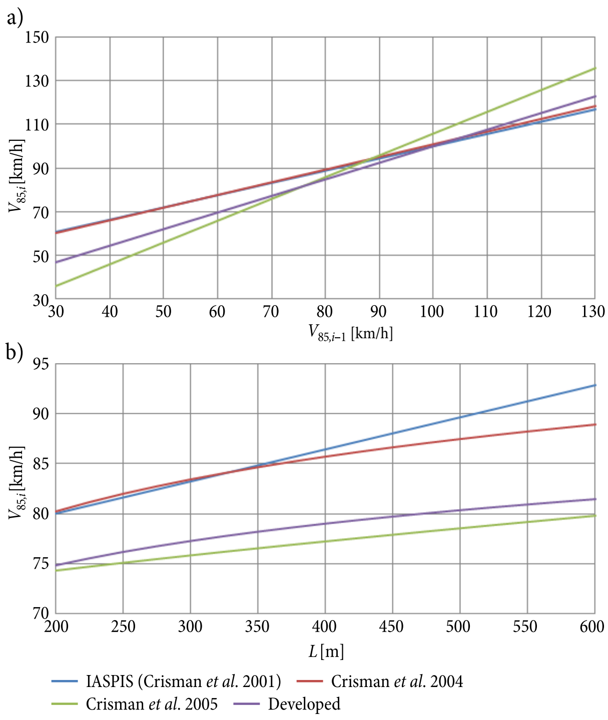

Fig. 4. Comparisons between the proposed model and some models reported in the literature

Table 6. Model parameter estimates ($V_{85,t}$)

Source	Value	Standard deviation	t	p	Lower bound (95%)	Upper bound (95%)
Constant	–10.721	9.703	–1.14	0.267	–27.95	5.69
$V_{85,i-1}$	0.762	0.117	6.46	0.000	0.55	0.96
L	13.994	6.634	2.17	0.043	2.93	25.87

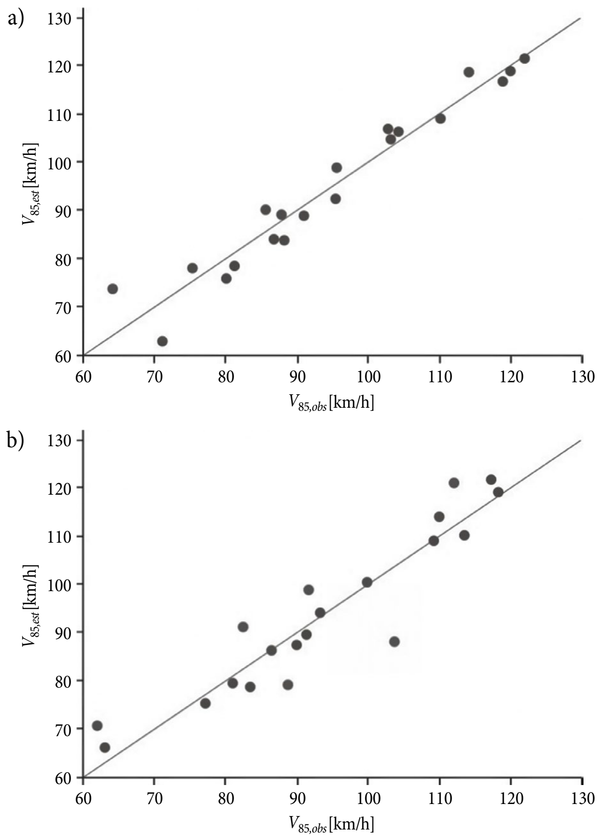

Fig. 5. $V_{85,est}/V_{85,obs}$ for curves (a) and tangents (b)

Conclusions

This paper has presented a road safety study in which safety is investigated by analysing operating speeds on two-lane rural highways. Lack of safety is often referred to an inconsistency roadway geometric design, which implies geometric features that may cause incorrect drivers behaviour, and hence produce potential for risk collision.

Preliminarily, a quantitative design consistency evaluation was performed on a two-way undivided rural highway case study by adopting the methodology proposed by Lamm *et al.* (1999). Speed profiles obtained from a sample of smartphone-equipped vehicles were used to evaluate the operating speed for each element of the road.

The case study was used to calibrate two types of operating speed models in order to estimate speed profiles for horizontal curves and tangents. Both operating speed models were calibrated based on continuous speed data recorded by smartphone-equipped vehicles. The models show a good predictive capability, despite their formulation is characterized by few variables (secondary factors are not considered, such as grade and sight distance) to be easily used by operators and technicians for road management. Specifically, the main findings suggest that a combination of two variables, one relating to the geometric characteristics (curve radius for the curves and length for the tangent elements) and the other relating to the operating speed of the previous road element may increase the predictive capabilities of the simple regression models.

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References

ACI. 2010. *Incidenti stradali: Anno 2009*. Automobile Club d'Italia (ACI). 24 p. Available from Internet: http://www.aci.it/fileadmin/documenti/studi_e_ricerche/dati_statistiche/incidenti/Sintesi_dello_studio_2009.pdf (in Italian).

Atashafrazeh, M.; Yadollahi, M. M. 2013. Geometric design consistency model based on speed and safety in rural highways in some European countries: a review, *International Journal of Structural and Civil Engineering Research* 2(2): 129–136.

Camacho-Torregrosa, F. J.; Pérez-Zuriaga, A. M.; Campoy-Ungría, J. M.; García-García, A. 2013. New geometric design consistency model based on operating speed profiles for road safety evaluation, *Accident Analysis* & *Prevention* 61: 33–42. http://dx.doi.org/10.1016/j.aap.2012.10.001

CNR. 2002. *Norme funzionali e geometriche per la costruzione delle strade* (D.M. 5.11.2001, G.U. 4.1.2002). Italian National Research Council (CNR). (in Italian).

Crisman, B.; Marchionna, A.; Perco, P.; Roberti, R. 2005. Operating speed prediction model for two-lane rural roads, in *3rd International Symposium on Highway Geometric Design: Compendium of Papers CD-ROM*, 29 June – 2 July 2005, Chicago, US, 1–22.

Crisman, B.; Marchionna, A.; Perco, P.; Roberti, R. 2004. Operating speed prediction model for two-lane rural roads, in *Proceedings of the 2nd SIIV International Congress: New technologies and Modelling Tools for Roads Applications to Design and Management*, 27–29 October 2004, Firenze, Italy, 1–9.

Crisman, B.; Marchionna, A.; Perco, P.; Roberti, R. 2001. *Modelli di previsione delle velocità operative. Rapporto conclusivo del Progetto di Ricerca IASPIS* (Interazione Ambiente Sicurezza nel Progetto delle Infrastrutture Stradali). Firenze. (in Italian).

FHWA. 2000a. *Evaluation of Design Consistency Methods for Two-Lane Rural Highways: Executive Summary*. Publication No. FHWA-RD-99-173. Federal Highway Administration (FHWA). 29 p. Available from Internet: https://www.fhwa.dot.gov/publications/research/safety/ihsdm/99173/99173.pdf

FHWA. 2000b. *Speed Prediction for Two-Lane Rural Highways* No. 99-171. Federal Highway Administration (FHWA). 213 p. Available from Internet: https://www.fhwa.dot.gov/publications/research/safety/ihsdm/99171/99171.pdf

FHWA. 1986. *Driver Expectancy in Highway Design and Traffic Operations*. Report No. FHWA-TO-86-1. Federal Highway Administration (FHWA). 48 p.

Garach Morcillo, L.; Calvo Poyo, F. J.; Pasadas Fernández, M.; De Oña, J. 2014. Measurement of road consistency on two-lane rural highways in Granada (Spain), *Procedia – Social and Behavioral Sciences* 162: 237–242. http://dx.doi.org/10.1016/j.sbspro.2014.12.204

Kaplan, E. D.; Hegarty, C. J. 2005. *Understanding GPS: Principles and Applications*. 2nd edition. Artech House. 726 p.

Lamm, R.; Psarianos, B.; Mailaender, T. 1999. *Highway Design and Traffic Safety Engineering Handbook*. McGraw-Hill Professional Publishing. 1088 p.

Ng, J. C. W. 2002. *Quantifying the Relationship Between Geometric Design Consistency and Road Safety*: MSc Thesis. The University of British Columbia, Canada. 103 p. Available from Internet: https://circle.ubc.ca/handle/2429/13445

Ng, J. C. W.; Sayed, T. 2004. Effect of geometric design consistency on road safety, *Canadian Journal of Civil Engineering* 31(2): 218–227. http://dx.doi.org/10.1139/l03-090

OECD. 2006. *Speed Management*. Organisation for Economic Co-operation and Development (OECD), European Conference of Ministers of Transport (ECMT). 285 p. Available from Internet: http://www.internationaltransportforum.org/Pub/pdf/06Speed.pdf

Park Y.-J.; Saccomanno, F. F. 2006. Evaluating speed consistency between successive elements of a two-lane rural highway, *Transportation Research Part A: Policy and Practice* 40(5): 375–385. http://dx.doi.org/10.1016/j.tra.2005.08.003

Praticò, F. G.; Giunta, M. 2012. Modeling operating speed of two lane rural roads, *Procedia – Social and Behavioral Sciences* 53: 664–671.
http://dx.doi.org/10.1016/j.sbspro.2012.09.916

Pungillo, G. 2013. *La progettazione e l'adeguamento delle infrastrutture stradali in base alla classificazione di tratti stradali a differente livello di rischio*: Dissertation. University of Calabria, Italy. 255 p. (in Italian).

Sowmya, N. J.; Ravi Shankar, A. U.; Anjaneyulu, M. V. L. R. 2012. Modelling operating speed and speed differential on intermediate lane rural roads, *International Journal of Earth Sciences and Engineering* 5(5): 1408–1414.