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QUANTIFYING THE EFFECT OF PRESENT, PAST AND ONCOMING ALIGNMENT ON THE OPERATING SPEEDS OF A TWO-LANE RURAL ROAD

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Abstract. In the last decades several studies were conducted in order to develop operating speed prediction models for two-lane rural roads. Many factors were found to affect the operating speed, such as radius of horizontal curve or curvature changes rate, grade, length of horizontal curve, deflection angle, sight distance, superelevation rate, side friction factor, and pavement conditions. Though this, many issues arise when there is an appreciable and continuous variance of geometric features along the road and, for example, short and long tangents coexist in the same road. In such conditions, assessing homogeneous sections, calibrating robust algorithms aimed at V_{85} prediction is a severe task and safety goals are not easily achieved. In the light of the abovementioned facts, objective and scopes of this work were confined into the quantifications of the effect of past, present, and future geometric elements on operating speeds. In particular, attention was focused on the consistency of the assumption of an environmental speed as a reference value for both short (dependent) and long (independent) tangents. Authors proposed a new operating speed model in which the geometric features of the previous and oncoming alignment were explicitly considered. The proposed speed prediction algorithm was validated on the basis of a wide experimental survey carried out in a rural road of the Province of Reggio Calabria – southern Italy. Problem modelling, experimental plan and results discussion are reported. Results proved the validity of the proposed model even if further experiments are needed to make the model able to predict the operating speed in different type of roads.

Keywords: operating speed, rural road, radius, length, present past and oncoming alignment.

1. Background

It is well known that vehicle speeds depend on many factors relating to drivers, vehicles, roadway environment, etc. (Kanellaidis 1995). In the last decades several studies were conducted in order to develop operating speed prediction models for two-lane rural roads (Castro *et al.* 2011; Fitzpatrick *et al.* 2000; Gintalas *et al.* 2008; Krammes *et al.* 1995; Lamm *et al.* 1988; McLean 1981; Misaghi, Hassan 2005, Zuriaga *et al.* 2010). Many factors were found to affect the operating speed, such as, radius of horizontal curve or curvature change rate, grade, length of horizontal curve, deflection angle, sight distance, superelevation rate, side friction factor, and pavement conditions (Boscaino, Praticò 2001; Praticò *et al.* 2010; Ong, Fwa 2010).

Among these parameters the curve radius or the curvature change rate are considered to be the most important elements in determining operating speed in curve sections. In fact, the most common operating speed models for two-lane rural highways express V_{85} as a function of horizontal curvature even if other curve elements were found to be significant. Generally, when the horizontal radius of curvature decreases, the operating speed decreases.

Models were usually set out on the basis of given boundary conditions: such as lane and shoulder width, longitudinal grade, range of horizontal curve radius, dry or wet pavement.

Furthermore, many models predict the operating speed on a tangent or on a curve only in function of the horizontal characteristics of the individual element, while others (Abdul-Mawjoud, Sofia 2008; Fitzpatrick *et al.* 2000) consider the combination of horizontal and vertical alignment and different equations are introduced in order to predict the operating speed in function of different vertical alignment conditions. Polus *et al.* (2000), Yagar (1984), Schurr *et al.* (2002) identified a number of roadway characteristics as speed factors on two-lane rural highways. These authors found that operating speeds were related to speed limits, highway grade, traffic volume, and specific elements of the horizontal and vertical curvature, such as the radius, the super-elevation rate, and the sight distance.

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In particular Polus *et al.* (2000), based on the operating speeds, collected 162 tangent sections of two-lane rural highways, developed a regression model for predicting operating speed on tangents in which the effects of preceding and following horizontal curves are considered. They concluded that on tangent sections the speed of vehicles is dependent on a wide array of roadway characteristics, such as length of the tangent section, radius of the curve before and after the section, cross-section elements, vertical alignment, general terrain, and available sight distance. They also found that the tangent length and the radii of preceding and following curves were the most important variables in the regression equations. Finally they concluded that a single model for tangent speed was inadequate because of the low R^2 value, and they subsequently developed four models using descriptors of the highway environment based on curve radii and tangent lengths.

Yagar, Van Aerde (1983) studied the effects of the geometric and environmental conditions on mean speeds. Mean speeds were found to be strongly related to land use and legal speed limit. Grade, access from other roads, and lane width, followed in that order. The above significant factors explained 85% of the across-sites variation in speed, leaving relatively small residual errors. Road curvature, presence of an extralane, sight distance, center line markings and lateral obstructions were not found to have statistically significant effects on speed.

Regarding the curve sections, it was observed that curves having similar radius and deflection angle are often travelled at a different speed due to the fact that the drivers choose the speed in function of the general character of the previous alignment. Some models (Cardoso *et al.* 1998; Kerman *et al.* 1982; Krammes *et al.* 1995) consider the features of the alignment before the element by introducing the speed of the approaching tangent in the speed prediction model of the curves.

McLean (1979) supposed that the operating speed in a curve depends not only on the curve radius but also on the desired speed. This latter is defined as "the speed at which drivers choose to travel under free-flow conditions, when they are not constrained by alignment features". The desired speed is affected by road function, overall standard alignment and typical trip purpose.

Crisman *et al.* (2003) developed a speed model in which the operating speed was calculated in function of the curvature degree and the environmental speed V_{env}, defined as the max value of the operating speed related to the longest tangent or to the curve having the widest radius in a homogeneous stretch of road. The introduction of the environmental speed in the model improved the coefficient of determination of the regression.

Kerman *et al.* (1982) proposed a model in which the bend speed depends on the approach speed and on the curve radius. The approach speed refers to the average curvature, the visibility, the cross section and the intersections and accesses frequency in the stretch of road 2 km long before the curve.

Kanellaidis *et al.* (1990), based on a wide experimental survey in Greece, modelled the operating speed in curve as a function of the curve radius and the desired speed. Also Bennett (1994) investigated the effect of curvature on speed in New Zealand. He found that the operating speed on horizontal curves depends on the curvature and on the 85th percentile approach speed.

Krammes *et al.* (1995) assessed the approach speed by means of experimental observations and defined a correlation between the operating speed and several parameters related to the curve, such as the degree of curve, the length, the deflection angle, and the 85th percentile approach speed.

All these studies demonstrated the importance of considering the conditions of the alignment before or, well again, the overall alignment of the road to better estimate the operating speed in a current horizontal element. In particular, regarding the influence of the past geometric features, the length of actual and past elements (or in alternative the duration of travel of past and current elements) interacts in determining V_{85}.

Furthermore, also the information related to what the driver sees after the current element demonstrated to be relevant for the operating speed. Such information cannot be easily missed because it usually plays an outstanding role in suggesting the drivers the right speed to adopt.

Authors proposed a new operating speed model in which the geometric features of the previous and oncoming alignment were explicitly considered. The proposed speed prediction algorithm was validated on the basis of a wide experimental survey carried out in a rural road of the Province of Reggio Calabria – southern Italy. Problem modelling, experimental plan and results discussion are below reported. Results proved the validity of the proposed model even if further experiments are needed to make the model able to predict the operating speed in different type of roads.

2. Theoretical model and estimation methodology

As is well known, the vehicle dynamics in a given curve is governed by the following relationship:

$$V = a_g R(f_t + tg\beta), \tag{1}$$

where V – the speed related to the given value of $f_t \le f_{tmax}$, km/h; a_g – the gravitational acceleration, m/s^2; R – the curve radius, m; f_t – the transverse friction coefficient; $tg\beta$ – the transverse slope.

On the other hand, when the operating speed, V_{85}, is concerned, many other factors related to the driver's behaviour have to be considered. In particular:

- there is a clear influence of the geometry of the previous elements (particularly, L_{i-1} and R_{i-1}, where L_{i-1} is the length of the previous tangent/curve, included the progressive curve, if any) (Lamm *et al.* 2001);

- the length of the curve/tangent and the lane width (W) greatly affect the operating speed, due to both the actual risk perception and the real curvature followed by the vehicle;
- the well known tendency to accelerate (after the curve) and to decelerate (before the following curve), included the relative characteristic times over the tangent (time of acceleration and time of deceleration), represents a synergetic expression of most of the above-mentioned single factors (Ottesen, Krammes 2000);
- the longitudinal grade, g, not involved in the abovementioned equation, modifies the actual speeds (Abdul-Mawjoud, Sofia 2008);
- the actual transverse slope is another important parameter, which affects V_{85} and safety (Lamm *et al.* 2001);
- the CCR of the section to which the element belongs is another relevant parameter. It is related to the desired speed and to the general character of the road alignment (Perco 2008);
- driver perception of past geometric features and incoming predictable accident risks also affect the actual speeds.

Indeed, there is a synergetic contribution of vehicle dynamics and road perception. In particular, note that for a given radius, different operating speeds are expected based on different sight distances (Praticò, Giunta 2010; 2011).

As a consequence, the following algorithm for the operating speed in curve is proposed:

$$V_{85i} = a_g R(f_t + tg\beta) + F(L_{i-1}) + F(W, g), \tag{2}$$

where F – stands for function.

When tangents are concerned, the conceptual framework is summarised as follows:

$$V_{85i} = V_{i-1} + \delta(a_l, S_L, R_{1+1}) + F(W, g), \tag{3}$$

where F – stands for function, while $\delta(a_l, S_L, R_{i+1})$ is a function which operates on a_l (longitudinal acceleration) and splits its value from positive to negative as a function of the curvature of the following curve. It follows that the length of the part of the tangent on which there is acceleration from V_{i-1} up to the max value (which depends also on speed limits S_L) is in practice determined in terms of form (i.e. coefficients) of the function δ, each time numerically controlled by R_{i+1}.

Based on the abovementioned factors, V_{85} is supposed to depend on three main classes of parameters related to:

- past geometric features and/or their consequences (V_{i-1}, $F(L_{i-1})$, etc.);
- present geometric features ($F(W,i)$, $[a_g R(f_t + tg\beta)]$, L_i);
- oncoming geometric features ($\delta(a_l, S_L, R_{i+1})$, L_{i+1}).

From a numerical point of view, in the light of the abovementioned facts the following simple model, valid for curves and tangents, is proposed:

$$V_{85} = \frac{a}{R^d} + b + cg, \tag{4}$$

where g – stands for longitudinal grade (decimals). By referring to this equation, the following critical points need for further clarification and studies. The coefficient a tunes the weight of the main variable, i.e. R, and it is relevant on both a statistical and a phenomenological viewpoint.

The parameter b is the value to which V_{85} approaches when $\frac{1}{R}$ tends to zero and i is null. As a consequence, it is supposed that it relates to the so-called desired speed. But other solutions are the environmental speed, the design speed and also the posted speed. Further, other convenient statistics of the speed along the road stretch could influence such parameter. Note that the lower d the higher the effect on V_{85} in the transition lower to middle radii, while a does not seem to have a similar remarkable effect on V_{85} variations.

As abovementioned, Eq (4) states that there is a noteworthy influence of current and "environmental" geometric features on operating speeds. On the other hand this equation presents from a conceptual standpoint the following drawbacks:

- the effect of past geometric features is not well grounded in logic: a curve or a tangent placed just before the current geometric element are not considered in a different way. In other words, all the information from the past or "from" the future seems condensed into the factor b. On the contrary, it appears relevant that a curve with small radius will have a very different effect on the following element if compared with a long tangent;
- another critical point relies on the extension (length or/and travel time) of the element under examination; many studies confirm that the longer it is, the higher its influence on operating speeds. One can speculate that the same radius, the same longitudinal grade will affect differently operating speeds if travelled for one second or five seconds. This fact doesn't result considered in Eq (4) and calls for further research;
- furthermore, another relevant problem originates from the absence of information related to what the driver sees after the current element. Such information cannot be easily missed because it usually rules an outstanding role in suggesting the driver the right speed to adopt. In the case, for example, of a small radius following a tangent, the driver will be forced to adapt the speed to the oncoming curve and this fact will affect operating speed.

In order to propose a conceptual framework able to take into account the abovementioned issues (particularly, in terms of the effect of past and approaching elements), the concept of element relevance is here introduced through the following element parameter α_i:

$$\alpha_i = 1 - \frac{1}{1 + \left(\frac{L_i}{f}\right)^n}, \qquad (5)$$

where L_i – stands for length of the i^{th} element, m, while f (positive) and n (positive, dimensionless) are model parameters to estimate

It results

$$0 \le \alpha_i \le 1. \qquad (6)$$

Note that the higher the length L_i, the higher is the element parameter. In particular, if L_i tends to infinite, then the element factor tends to 1 (Fig. 1). On the contrary, the lower L_i, the closer to zero is the element factor

$$\lim_{Li \to \infty} \alpha_i = 1, \qquad (7)$$

$$\lim_{Li \to 0} \alpha_i = 0, \qquad (8)$$

In the model here set out, the element parameter is used in order to quantify the influence of the geometric features of the i^{th} element on V_{85}.

The effect of the geometric features of the i^{th} element on the relative operating speed can be evaluated by the following equation:

$$\frac{a}{R_i^d} + \alpha_i (b + cg_i), \qquad (9)$$

where a, c – model parameters which don't depend on the i^{th} element (such as the abovementioned b). In contrast, R_i (horizontal radius of the i^{th} element), g_i (longitudinal grade of the i^{th} element) and α_i (element parameter) are element-specific.

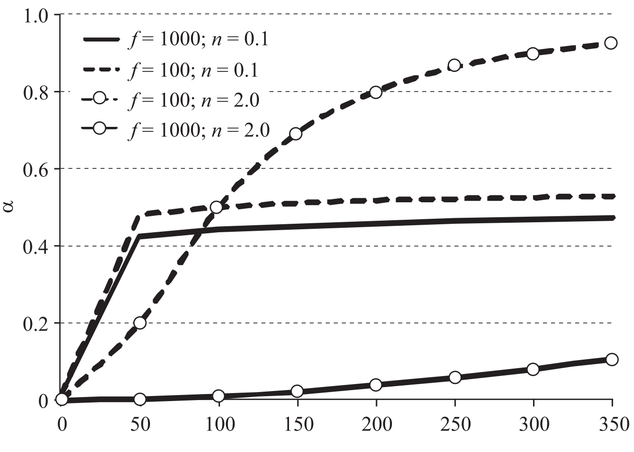

Fig. 1. α vs L_i

Similarly, the effect of the $(i - 1)^{th}$ element on the operating speed of the i^{th} element is evaluated by

$$\frac{e}{R_{i-1}^d} + \alpha_{i-1}\alpha_i (b + cg_{i-1}), \qquad (10)$$

The parameter e is expected to be

$$|e| < |a|, \qquad (11)$$

while the product $\alpha_{i-1}\alpha_i$ takes into account for the synergetic effect of the lengths of the i^{th} and $(i - 1)^{th}$ elements.

Note that being $\alpha_j < 1$, usually it will be

$$\alpha_{i-1}\alpha_i << 1, \qquad (12)$$

On a general standpoint the influence of all the previous (P) or current (C) elements on the operating speed of the i^{th} element will be:

$$P + C = \frac{a}{R_i^d} + \alpha_i (b + cg_i) + \frac{e}{R_{i-1}^d} + \alpha_{i-1}\alpha_i (b + cg_{i-1}). \qquad (13)$$

As for the effect of "future", F_u, elements (and in particular the $(i + 1)^{th}$ element) on V_{85i}, the following hypotheses are set out:

- if the $(i + 1)^{th}$ element is very similar (in curvature) to the i^{th} element, its influence will be negligible;
- if the $(i + 1)^{th}$ curvature radius is higher than the previous i^{th} element, its influence will be still negligible;
- if the $(i + 1)^{th}$ curvature radius is strongly lower than the previous i^{th} element, its influence will be very valuable and it will affect V_{85i}.

The factor F_u, which takes into account the influence of the following elements, is given by:

$$F_u = \left[\frac{1}{R_{i+1}} - \frac{1}{R_i}\right] h \left[\frac{1}{1 + \left(\frac{R_{i+1}}{R_i}\right)^{n_1}}\right], \qquad (14)$$

where n_1 (dimensionless) and h – coefficients to be estimated (Fig. 2).

The following consequence is outlined when very small radii are involved:

$$\lim_{R_i \to \infty} F_u = \left[\frac{1}{R_{i+1}}\right] h. \qquad (15)$$

Note, that by elaborating more on the concept of influence of "future" or "past" elements, a sum is derived. As

1st step the series is truncated after one term (1st successive/previous element).

Fig. 2 shows how the parameter F_u approaches zero when $\frac{R_{i+1}}{R_i}$ ranges from 0 to 1.

Finally, from Eqs (13) and (14), the following equation is derived ($P + C + F_u$):

$$V_{85} = \frac{a}{R_i^d} + \alpha_i(b + cg_i) + \frac{e}{R_{i-1}^d} +$$

$$\alpha_{i-1}\alpha_i(b + cg_{i-1}) + \left[\frac{1}{R_{i+1}} - \frac{1}{R_i}\right] h \left[\frac{1}{1 + \left(\frac{R_{i+1}}{R_i}\right)^{n_1}}\right]. \quad (16)$$

If $R_{i+1} \cong R_i$, $\alpha_{i-1} \cong 0$, $\alpha_i \cong 1$ and $e \cong 0$, Eq (4) is obtained as a particular case:

$$V_{85} \cong \left[\frac{a}{R_i^d} + b + cg_i\right]. \quad (17)$$

3. Experiments and results

To the purpose of validating the abovementioned model, an experimental survey was planned and carried out. The road SS 18 was considered. The SS 18 is a two-lane rural road in the Province of Reggio Calabria – southern Italy.

As the majority of rural single carriageways roads, the SS 18 follows historic alignments. The consistency with design standards is often unsatisfactory. The SS18 is characterized by low traffic volumes. This fact reduces the potential for restricted vehicle flows. The longitudinal slope covers a range of ±5.0%.

As a preliminary step, the investigation focused on the accuracy and precision (ISO 5725) of the laser speed gun, used to collect the speeds. Figs 3 and 4 illustrate how the error depends on the angle. Angles (degrees) are reported on x-axis. The ratio $\frac{V_{meas}}{V_{act}}$ (in percentage, left y-axis, where V_{meas} is the measured speed and V_{act} is the actual speed) is plotted against angles. Right y-axle refers to repeatability, r.

The 1st phases of the experimental plan were the collection of the geometric data of the road and the identification of the horizontal and vertical elements. Speed data was collected at 273 sites.

The actual speeds of vehicles at the midpoint of curves and at independent tangents were collected by means of a speed laser gun. The operator of laser gun was always hidden from oncoming vehicles, and only angles close to 0° or 180° (0 ± 10°; 180° ± 10°) were used.

For each curve and tangent monitored at least 125 measures of speed were performed (Pignataro 1973).

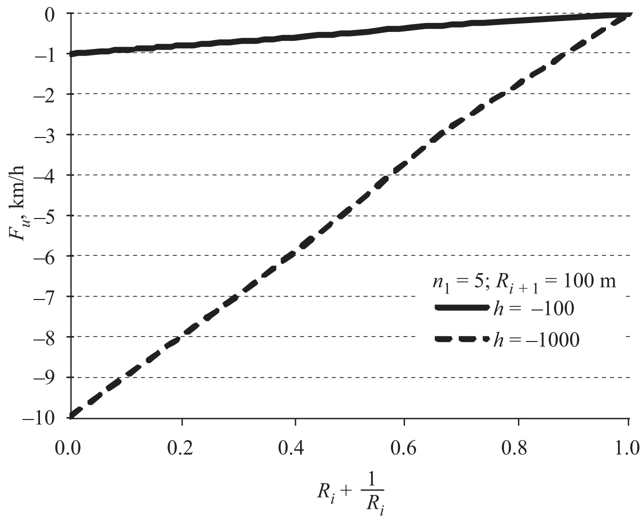

Fig. 2. Variation of F_u as a function of radii ratio

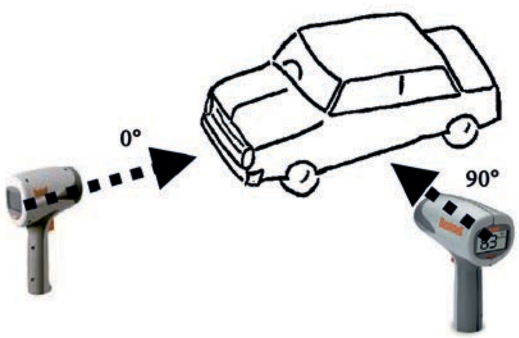

Fig. 3. Example of measurements at 0 or 90 degrees angles

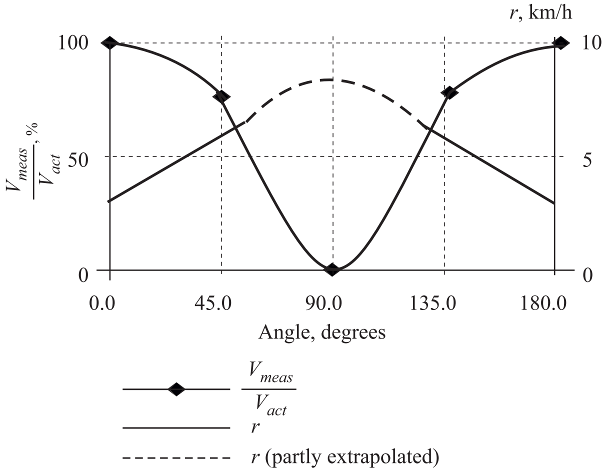

Fig. 4. Accuracy (% of true speed) and precision (r)

All the measurements were conducted under free flow conditions, in a day time and in dry pavement condition.

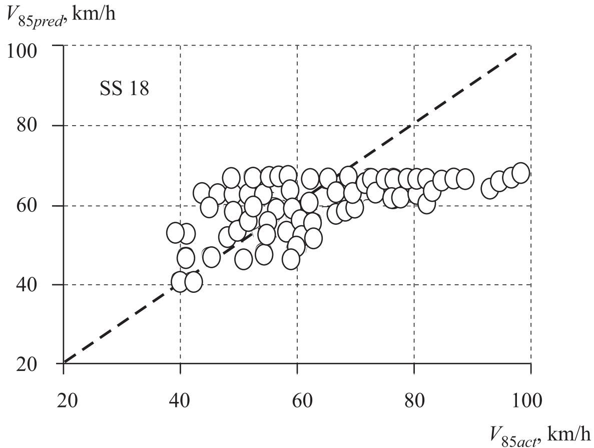

Fig. 5. Case *i*

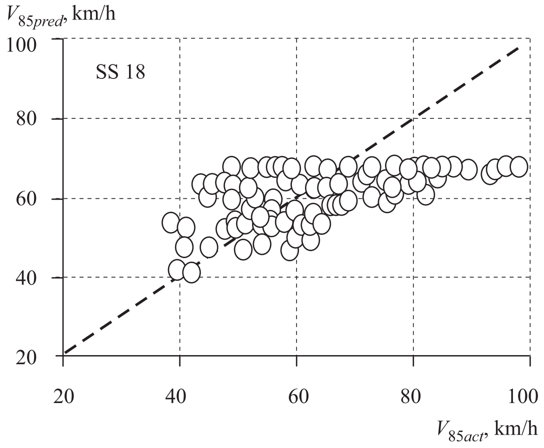

Fig. 6. Case *ii*

Tables 1–3 summarize the main statistics of geometric features and operating speeds of the road under investigation (SS 18).

Figs 5 to 10 and Tables 4 and 5 summarize the results. In order to validate the model, seven progressive models (*i* to *vii* cases) were taken into account. In each case, data were examined through an algorithm differing from the previous only for a component. As a consequence, it was possible to analyse the actual need for optimized models, taking into account also present, past and oncoming geometric features. More precisely, the validation model was performed for successive steps in order to carefully evaluate the influence of the features of the previous and future elements on the operating speed in a current element (curve or tangent). This allowed to demonstrate, step by step, the performance of the proposed algorithm and the improvement achievable in speed prediction.

Figs 5 to 10 display the collection of points each having the value of actual V_{85} (V_{85act}, km/h), determining the position on the horizontal axis and the value of the predicted V_{85} (V_{85pred}, km/h) determining the position on the vertical axis. The equality line is also reported (dotted line).

Cases *i* to *iii*

When the simple model (Eq (4)) was considered, without the influence of the grade ($c = 0$) and by fixing the value of d equal to 1, the results shown in Fig. 5 were obtained.

The agreement of the model with the experimental data was quite unsatisfactory ($R^2 = 0.29$).

It was easily recognized that the predicted speeds (y axis) both downhill and uphill varied in a small range limited by the term b which in this case seems to represent a

Table 1. General data of SS 18 under investigation

Length, m	Grade, %	Number of element surveyed, n°		Speed data, n°		V_{85}, km/h		
		Dir. RC-SA	Dir. SA-RC	per element	total	min	max	avg
12644.38	–5 ~ +5	143	144	125	35875	40	97	63

Table 2. Statistics for curves

Direction	Number	Radius, m			Length, m			V_{85}, km/h		
		min	max	avg	min	max	avg	min	max	avg
Dir. RC-SA	88	13	1638.3	121.54	10.10	377.00	33.90	41.00	93.15	61.08
Dir. SA-RC	89	13	1638.3	121.54	10.10	377.00	33.90	39.65	84.00	60.62

Table 3. Statistics for tangents

Direction	Number	Length, m			V_{85}, km/h		
		min	max	avg	min	max	avg
Dir. RC-SA	55	6.40	357.00	52.12	49.00	98.00	68.44
Dir. SA-RC	55	6.40	357.00	52.12	48.65	96.15	66.90

reference speed of the entire alignment (desired speed, environmental speed, etc.). Note, that the operating speeds in the downhill case were often underestimated (Fig. 5). It is deduced that the curvature $\left(\frac{1}{R}\right)$ of the single element in this case is not sufficiently exhaustive in describing the influence on operating speed.

An improvement of the correlation between model and experimental data was obtained in the previous model when the influence of the grade was taken into account (Fig. 6). Even if the estimated speeds are still lower than the max value *b*, in this case the R^2 value had a small increase.

When all the parameters of the simple model (*a*, *b*, *c* and *d*) were considered, the performance of the model remained substantially unchanged, even if the value of the model parameters *a* and *d* varied appreciably. The results in terms of error and coefficient of determination were similar to the ones obtained in the previous case (Fig. 7).

Cases *iv* to *vii*

Table 5 and Fig. 8 illustrate the effect of the introduction of the abovementioned element coefficient as a correction factor able to "tune" the effect of longitudinal grade and lengths on operating speeds. In particular, Figs 9–10 show that thanks to the introduction of the element coefficient the cloud of points was progressively rotated (about 45 degrees). As a consequence, estimated and actual speeds in the range 50–80 km/h resulted quite close to the equality line. R^2 value increased from 0.41 to 0.51 and the average error decreased from 7.0 to 6.6 km/h c.a.

Cases *vi* and *vii* did not result in a satisfactory performance of the model, due to the interaction between *b* and the element factor, which resulted in very low element factors and very high coefficients *b*. When the curvature of the previous element was considered, the coefficient of determination increased from 0.51 to 0.61 (Fig. 9). It is relevant to point out that the coefficients *a* and *e* resulted quite similar (~–100). Furthermore, through the synergistic effect of *b* and of the radius of the previous element, the model better estimated several very high operating speeds (Fig. 9).

An improvement in speed prediction was obtained when the following further aspects were considered (Fig. 10):

- the curvature and the length of the previous element;
- the grade of the previous element. Note that also the simple model demonstrated the influence of the longitudinal grade on the operating speed especially for values higher than 4%.

This resulted in a slight increase of R^2 value while the average error decreased.

When the curvature of the $(i + 1)^{th}$ element was considered (case *vii*) the correlation between experimental data and model remained unchanged with respect to the case in which only the previous element was considered.

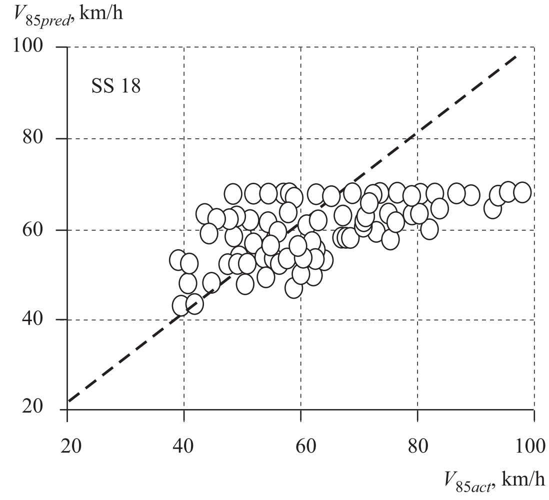

Fig. 7. Case *iii*

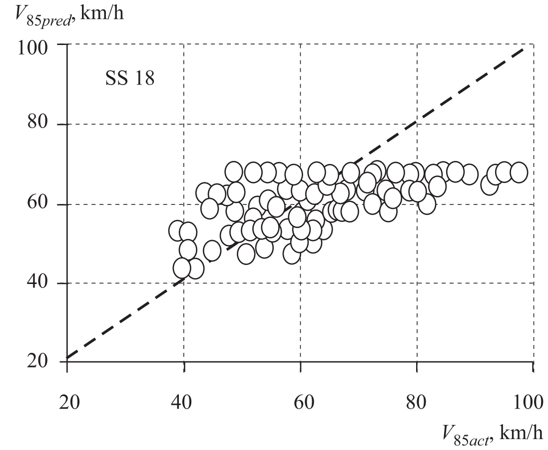

Fig. 8. Case *iv*

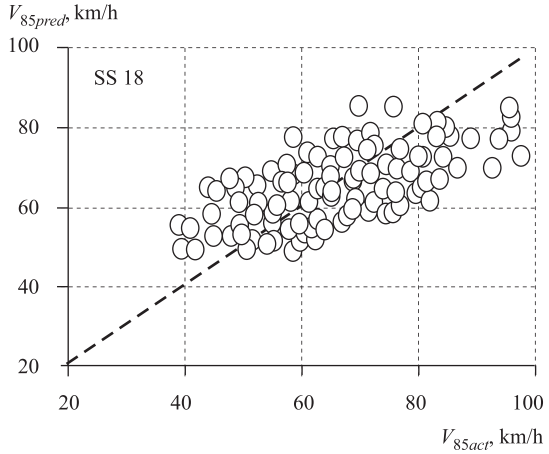

Fig. 9. Case *v*

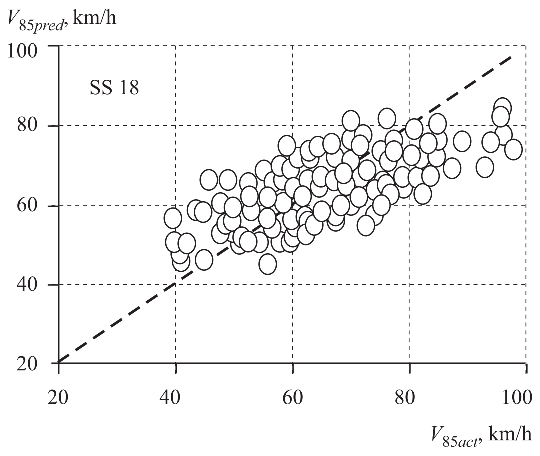

Fig. 10. Case *vi*

Although only several points resulted closer to equality line, this further term resulted quite effective in taking into account for speed calming due to the oncoming elements.

Table 5 offers a *resumé* in the light of the conceptual framework above proposed.

By referring to Tables 4 and 5 it is important to point out that:

- – the value of *a* ranged from –500 to –100 *circa*; the most important cause of variation was the consideration of a power law for the radius. As for the scaling exponent, it ranged from 0.1 to 1.0;
- – the coefficient *b* ranged from 70 to 270. The most relevant cause for this variation was the consideration of the element coefficient, related to tangent length; when the influence of the tangent length was not taken into account, the value of *b* represented

Table 4. Summary of models taken into account

Case	Correlation	
i	$V_{85} = \frac{-515}{R} + 68; \quad R^2 = 0.29$	(18)
ii	$V_{85} = \frac{-515}{R} + 68 - 0.03g; R^2 = 0.35$	(19)
iii	$V_{85} = \frac{-316}{R^{0.86}} + 68 - 0.03g; R^2 = 0.41$	(20)
iv	$V_{85} = \left[\frac{-108}{R^{0.1}} + \alpha_i 268 - \alpha_i 0.08 g_i\right]; R^2 = 0.51$	(21)
	$\alpha_i = 1 - \frac{1}{1 + \left(\frac{L_i}{100}\right)^{0.046}}$	(22)
v	$V_{85} = \left[\frac{-108}{R^{0.1}} + \alpha_i 268 - \alpha_i 0.12 g_i\right] + \frac{-103}{R^{0.1}_{i-1}}; R^2 = 0.61$	(23)
	$\alpha_i = 1 - \frac{1}{1 + \left(\frac{L_i}{100}\right)^{0.095}}$	(24)
vi	$V_{85} = \left[\frac{-108}{R^{0.1}} + \alpha_i 268 - \alpha_i 0.12 g_i\right] + \frac{-103}{R^{0.1}_{i-1}} + \alpha_{i-1}\alpha_i\left[268 - 0.12 g_{i-1}\right]; R^2 = 0.62$	(25)
	$\alpha_i = 1 - \frac{1}{1 + \left(\frac{L_i}{100}\right)^{0.095}}$	(26)

the (constant) operating speed on tangents; on the contrary, when the element coefficient was considered, $b\alpha_i$ represented the max achievable operating speed on tangents. In this second case, b was higher than the previous value, because of the fact that the actual operating speed was affected by tangent length. Furthermore, these findings suggested the presence of an appreciable number of drivers who did not obey to speed limits ("violators", as in Kanellaidis 1995);

- as for the longitudinal slope, probably due to the considered range of the investigated slopes (from –5% to 5%), its influence ranged up to 6%;
- as for the influence of the curvature of the previous element, based on the elaborations which were run, such influence was always lower than that of the curvature of the current element ($|e| < |a|$);
- the coefficients f and n which adjust the importance of the i^{th} tangent as a function of the availability of length in which the operating speed can increase, resulted quite constant;
- on average, the current element explained the 51% of variance while the previous one only the 11% and the future elements only 1%;
- the considered geometric features did not explain the remaining 37% of variance.

4. Conclusions

1. The assumption of an environmental speed not dependent on the tangent length resulted quite unsatisfactory for the road under investigation. The length of the element under investigation resulted very relevant especially when comparing short and long tangents. As a consequence, due to the introduction of the element factor, it was possible to adjust the term b. This fact originated a rotation of the cloud of points in the scatter plots. Furthermore, the introduction of the element factor permitted to solve the issues related to (very) short tangents. Indeed, very often, short tangents are located between two curves and the operating speeds on such very short elements are strongly dependent on the previous and successive element. Through the introduction of this multiplicative factor, these short elements were associated to a very low element factor, thus resulting in a prevalence of the remaining factors.

2. From a statistical standpoint, the influence of the geometric features of the current element resulted prevailing both on past and oncoming elements. More precisely, the current element explained five times the variance explained by the previous element and around 50 times the variance explained by the future element.

3. Authors are aware that although about 36 000 speeds were considered the analyses carried out do not justify the derivation of general conclusions. In particular the following main issues call for further research: relationship speed limits *vs.* element factor, country-specificity and/or transportability of the concept of the element factor.

Table 5. Contribution of present, past and future element on V_{85}

	(Additional) Factor	Contribution to V_{85} variance	Total contribution, %
Present	Radius	0.29	51
	Slope	0.06	
	Scale factor	0.06	
	Element coefficient	0.10	
Past	Previous radius	0.10	11
	Previous tangent	0.01	
Future	Oncoming tangent	0.01	1
	Unexplained variance	0.37	37

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