4th International Symposium on Highway Geometric Design

June 2-5 2010 Valencia, Spain

Operational and safety effects of two-lane roads alignment

Filippo Giammaria Praticò
Associate Professor
DIMET Department
University "Mediterranea" at Reggio Calabria
Via Graziella, Feo di Vito
89100 Reggio Calabria
Tel/fax +39 0965 875230
e-mail: filippo.pratico@unirc.it

Marinella Giunta*
Researcher
DIMET Department
University "Mediterranea" at Reggio Calabria
Via Graziella, Feo di Vito
89100 Reggio Calabria
Tel. +39 0965 875471
e-mail: marinella.giunta@unirc.it

word count:

abstract	266
text	3606
references	545
tables (3)	750
figures (6)	1500
TOTAL	**6667**

* corresponding author

Operational and safety effects of two-lane roads alignment

ABSTRACT

It is well known that traffic safety is one of the main objective in road design and management.

Further, it is widely recognised the importance of operating speeds for design consistency and in order to establish a comprehensive safety strategy for rural roads.

Operating speeds depend on geometric features such as lanes and shoulders width, radius of curve (or curvature change rate), longitudinal grade and transverse slope.

Although several models are available in literature for the prediction of operating speeds, they are usually road-specific and transportability is an unsolved issue.

As a consequence, when the performance level of a two-lane rural road in a given context has to be assessed, researchers and practitioners need to treat the problem of operating speed dependence on section alignment by using proper methodologies and models.

In the light of the above-mentioned facts the objectives and the scopes of the paper were the analysis and modelling of the operational and safety performance of a two-lane rural road by means of the comparative study of operating speeds and road alignment.

The model was applied to several case-histories, related to typical Italian rural roads.

Alignment and actual speeds were analysed and monitored and the entire road was discretized into single stretches.

Experiments proved that the formalized model for predicting operating speeds can be useful in analysing, predicting and assessing the safety performance of a rural road, even if some issues still call for further research.

Future research will aim to gain a better understanding of the effect of some of the remaining boundary conditions on the relationship operating speeds *vs.* road alignment.

INTRODUCTION

Road design consistency refers to road geometry's conformance with driver expectancy. The main measures of design consistency are calculated using the operating speed.

In what follows, operating speeds are intended to be the 85-th percentile of actual speeds (free flow conditions), while design speed is intended as the reference speed used to determine geometric features.

Vehicle speed is an important engineering, traffic safety and public policy issue. An excessive vehicle speed reduces the driver ability to face up to curves or to manoeuvre around obstacles in the roadway, extends the stop distance, increases the distance travelled by driver during the reaction to an hazard.

Speed is used both as a design criterion to promote consistency and as a performance measure to evaluate road design. In any case the knowledge and the management of the operating speeds seem to be a crucial point to enhance road safety conditions.

In the light of this fact, accurate speed prediction models are needed to evaluate design consistency and therefore the actual safety performance of the roads. Operating speed models are usually country specific and road type specific.

In the last decades many studies were conducted in order to develop operating speed prediction models for two-lane rural roads [1], [2], [3], [4], [5]. Many factors were found to affect the operating speed, such as, radius of horizontal curve or curvature change rate (CCR), grade, length of horizontal curve, deflection angle, sight distance, superelevation rate, side friction factor, and pavement conditions. Among these parameters the curve radius or the curvature change rate are considered to be the most important elements in determining operating speed. Generally, when the radius of curve decreases or the curvature change rate increases, the operating speed decreases. Note that the curvature change rate referred to single curve is often termed CCRs or simply CCR. In contrast, when a road stretch is considered, it is possible to take into account an average curvature change rate referred to a road stretch and in the following indicated as CCR_L* (if both tangents and curves are included) or the CCR_s* (if only the curves are considered). Both CCR_L* e CCR_s* are obtained through the consideration of the sum of absolute angular changes ($\Sigma|\varphi_i|/L$), being L the lengt of the stretch.

Further many models can predict the operating speed in a tangent or in a curve only as a function of the characteristics of the individual element. Only few models [4], [6] consider the combination of horizontal and vertical alignment introducing different equations to predict the operating speed in function of the vertical alignment conditions. In this manner also the grade was included in the models.

However, it has been observed that curves having similar radius are often travelled with different speed due to the fact that the drivers choice the speed in function of the general character of the previous alignment. To this purpose, some models [7], [8], [9] consider the features of the alignment preceding the element, introducing, for example, the speed of the approaching tangent.

Mc Lean [10] 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 choice 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. Also Crisman et al. [11] 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 "maximum 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.

It is important to observe that the curvature change rate is usually used as main parameter to select the homogeneous sections. A plot relating the distance along the road (x-axis) to the sum of the

absolute values of angular changes (y-axis) is derived. This allows to identify road sections with relatively uniform horizontal alignment, called homogeneous sections, because they are characterized by an almost constant slope.
In the light of the above considerations the aim of the present study is the development of a speed model for two-lane rural roads in order to correlate the operating speed in the individual alignment element with the curvature of the element, the grade and the general character of the road alignment expressed by means of a reference (or environmental) speed.
To this purpose, a speed prediction algorithm for two-lane roads was modelled and speed surveys were carried out for several rural roads of the Province of Reggio Calabria - southern Italy, in order to validate and calibrate the proposed algorithm. 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.

PROBLEM MODELLING

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

$$V^2=gR\cdot(f_t+tg\beta) \qquad (1)$$

where f_t is the transverse friction coefficient, $tg\beta$ is the transverse slope, R is the curve radius and V is the speed related to the given value of $f_t \le f_{tmax}$, g is the gravitational acceleration.
On the other hand, when the operating speed is concerned, many other factors related to the driver's behaviour have to be considered. In particular:

1. there is a clear influence of the geometry of the previous elements (in particular, we refer to the length L_{i-1} of the previous tangent, included the progressive curve, if any) [12];
2. the length of the curve and the lane width (W) can greatly affect the operating speed, due to both the actual risk perception and the real curvature followed by the vehicle;
3. the actual transverse slope is another important parameter;
4. the CCR_L* of the section to which the element belongs is another relevant parameter. It is related to the desired speed ad to the general character of the road alignment [13];
5. the longitudinal grade, *i,* not involved in the above-mentioned equation, in some cases can modify the actual speeds [6]; to this purpose terrain type and vehicle mass can be determinant (Dixon et al., 1999 [14], Gintalas et al. 2009 [15], Ottesen and Krammer, 2000 [16]);
6. driver perception of past geometric features and incoming predictable accident risks can 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 can be expected based on different sight distances, especially when short distances are involved. On the other hand the available sight distance depends on the following relationships:

$$\Delta^*=R\cdot(1-cos(0.5\cdot D\cdot R^{-1})) \qquad (2)$$

$$\Delta=D^2/(8R) \qquad (3)$$

where R stands for horizontal radius, D for sight distance and Δ^* and Δ are side distances from obstacles and $0.5\cdot D\cdot R^{-1}$ is a construction angle (rad).

Based on the abovementioned facts, the following algorithm for operating speed is here proposed:

$$V_{85}= (gR\cdot(ft+tg\beta))^{0.5}+F_1(L_{i-1})+F_2(W, i) \qquad (4)$$

where F_i stand for functions.
Note that if CCR is considered, the following alternative expression can be considered:

$$V_{85}= F_3(CCR)+ F_1(L_{i-1})+ F_2(W, i) \quad (5)$$

When tangents are concerned, it is well known that vehicle dynamics depends on the relationship among its length (L) and the following curve radius (R_{i+1}). Further, the following supplementary factors must be taken into account:

7. there is an auxiliary effect of the geometry of the previous elements (in particular, we refer to the radius R_{i-1} and to the length L_{i-1} of the previous curve) that can be easily interpreted also in terms of speed over the prior curve, V_{i-1};
8. also in this element the lane width can greatly affect the operating speed, due to risk perception;
9. as abovementioned, the longitudinal grade, *i*, can influence the actual speeds;
10. driver perception of past geometric features and incoming predictable accident risks can affect the actual speeds. As a consequence, the CCR_L* (see above) of the homogeneous road stretch to which the tangent belongs can be relevant;
11. access density can be also relevant;
12. the well known tendency to accelerate (after the curve) and to decelerate (before the following curve), included the relative timetable over the tangent (time of acceleration and time of deceleration), represents a synergetic expression of most of the above-mentioned single factors.

Given this, the following conceptual framework can be proposed for tangents:

$$V_{85}= V_{i-1}+ \delta(a_l, S_L, R_{i+1})+ F_2(W, i) \quad (6)$$

where F_2 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 maximum 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}.
On a numerical point of view, in the light of the abovementioned facts, the following model, valid for curves and tangents, can be proposed:

$$V_{85}=a/R^d+b+c\cdot i \quad (7)$$

where *a, b, c, d* are calibration factors, better explained below, and *i* stands for longitudinal grade (decimals).
Note that *a* and *d* are coefficients which take into account for the tuning of horizontal radius effect.
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 (see Figure 1).
It is possible to observe that the lower is *d* the higher is the effect on V_{85} in the transition lower to middle radii, while *a* doesn't seem to have a similar remarkable effect on V_{85} variations.

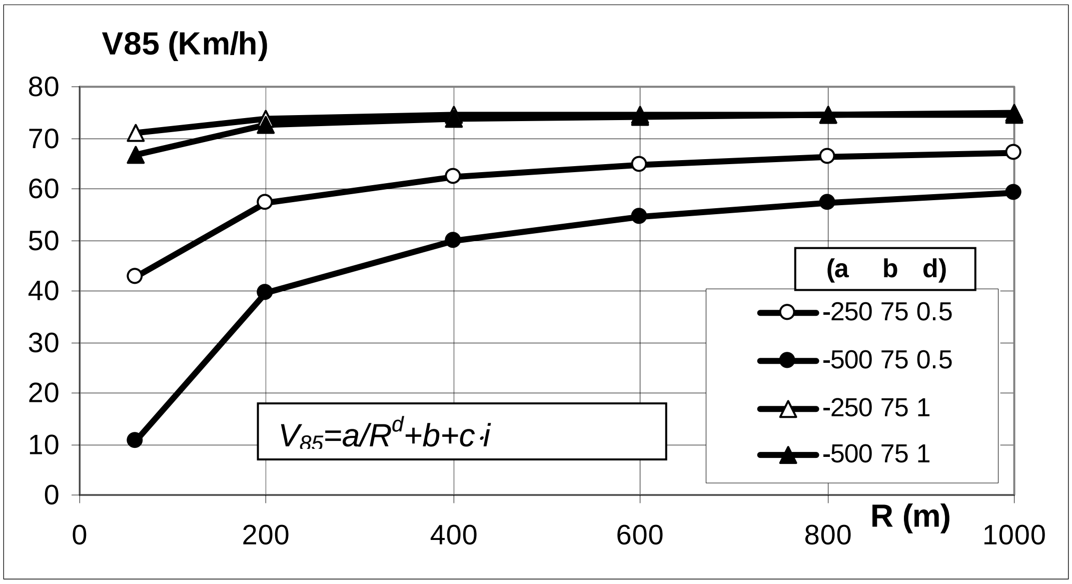

FIGURE 1 Effect of *a* and *d* on *V85*

It can be supposed that *b* itself depends on geometric features [11], [13].
Further, the parameter *b* is the value to which V_{85} approaches when *1/R* tends zero and *i* is null. As a consequence it can be supposed that it relates to the so-called desired speed, McLean, 1981 [1], namely the speed at which drivers choose to travel under free-flow conditions when they are not constrained by alignment features.
Other ways to interpret *b* could be the environmental speed, the design speed and also the posted speed. Further, other convenient statistics of the *speed* along the road stretch could relate to such parameter.
An important issue, which calls for further research, is if *a*, *b*, *c* and *d* can be considered constant as far as road type changes or, and this could be a very interesting point, it can be assumed that *b* is able to take into account for all the remaining geometric features of the road not included into the algorithm.

EXPERIMENTAL PLAN

To the purpose of investigating the quoted points an experimental survey was planned and carried out. This section deals with the experimental plan and its development.
The preliminary phases of the experimental plan were:
- selection of roads;
- execution of Road Safety Audit Review (RSAR);
- data collection (accident ratio survey and analyses, AR, average annual daily traffic, AADT, curvature change ratio, CCR, width of the paved road, Wp, roadside hazard issues, RSH, transverse slope, tgβ, operating speeds (OS), V_{85});
- deriving additional parameters for homogeneous sections. In what follows as homogeneous section is intended a road stretch in which the main geometric (curvature change rate, lanes and shoulders width, roadside hazard, access frequency, etc.) and traffic features can be considered constant or are affected by low variability.

The actual speeds of vehicles at the midpoint of curves and independent tangents were collected by means of speed laser gun. Only light vehicles were considered. The operator of laser gun was

always hidden from oncoming vehicles. For each curve and tangent monitored at least forty measures of speed have been performed until now. All the measurement were conducted in free flow conditions, in day time and in dry pavement conditions.
The experimental plan is not completed and data collection is still in progress to the purpose of creating an extensive database able to improve the performed modelling.
The roads under inspections are below reported (see figure 2):

- SP1 (from SS 18 -Gioia Tauro- to SS 106 –Locri), length, L, 52925m, on which the RSAR & AR were performed and the survey of operating speeds, OS, was planned;
- SP4 (from SS 111 - Taurianova to the border of the province – Dinami), L=39820m, RSAR & AR performed, OS planned;
- SP5, on which the RSAR & AR were performed;
- SS106 (or better SS106 and SS106ter) (from Km 9+000 to Km 20+000+106ter), L = 12.000 m c.a, RSAR & AR performed, OS and related analyses, executed;
- SP 21 (from S.S.106 to Motta S. Giovanni), L = 6265m, RSAR & AR performed, OS and geometry discussed, and other analyses planned;
- SP 22 (from S.S.106 to Saline - Montebello – Fossato), L=14680m, RSAR & AR performed, OS planned;
- SP 52 (from Rosarno to Laureana di Borrello – Mantegna), L=27265m, RSAR & accident ratio analysis, AR, performed and OS planned;
- SP 72 (from intersection S.S. 106 to S. Luca), L=9645m, RSAR & AR performed, and OS analyses planned;
- SS18, RSAR performed and OS planned.

All the selected roads are rural infrastructures in the Province of Reggio Calabria (southern Italy) as it is shown in Figure 1. As for the development of models for predicting speeds on two-lane rural roads, at the beginning attention was focused on SP21 and SS106.

FIGURE 2 Roads under investigation

RESULTS AND DISCUSSION

The speed surveys, carried out for the abovementioned roads, allowed to derive some important speed statistics. In the following (see Table 1) we refer about the speed distribution related to SS 106 ter, SS 106, SS 18 and S.P. 21.

TABLE 1 Main statistics of speed distribution and their relationship

SS 106 ter	
Uphill	V_{85}=0.87V_{max}=1.24V_{avg}=1.29V_{med}=1.35V_{mod}=1.91V_{min}
Downhill	V_{85}=0.68V_{max}=1.20V_{avg}=1.22V_{med}=1.08V_{mod}=1.97V_{min}
Overall	V_{85}=0.76V_{max}=1.22V_{avg}=1.25V_{med}=1.19V_{mod}=1.95V_{min}
SS 106	
Uphill	V_{85}=0.75V_{max}=1.17V_{avg}=1.19V_{med}=1.17V_{mod}=6,26V_{min}
Downhill	V_{85}=0.76V_{max}=1.16V_{avg}=1.20V_{med}=1.19V_{mod}=3.88V_{min}
Overall	V_{85}=0.75V_{max}=1.16V_{avg}=1.19V_{med}=1.18V_{mod}=4.75V_{min}
SP 21	
Uphill	V_{85}=0.79V_{max}=1.16V_{avg}=1.18V_{med}=1.21V_{mod}=1.67V_{min}
Downhill	V_{85}=0.82V_{max}=1.16V_{avg}=1.16V_{med}=1.15V_{mod}=1.59V_{min}
Overall	V_{85}=0.81V_{max}=1.16V_{avg}=1.17V_{med}=1.18V_{mod}=1.63V_{min}
V_{85} is the operating speed, V_{max} is the maximum speed, V_{avg} is the average speed, V_{med} is the median value, V_{mod} is the mode of the distribution, while V_{min} is the minimum value (all the values were expressed in km/h).	

As abovementioned, to evaluate the influence of horizontal alignment on the operating speeds two sets of data related to the roads SS106 and SP 21 were surveyed. In fact, in these roads the number of speed measurements resulted statistically significant. Table 2 summarizes the main characteristics of the two data sets that were used in order to validate the model.

TABLE 2 Main characteristics of speed set for SS 106 and SP 21

	SS106			**SP21**		
	V_{85} [Km/h]	*R [m]*	*i [%]*	*V_{85} [Km/h]*	*R [m]*	*i [%]*
min	66.4	730.0	-1.7	30.8	33.59	-8.8
max	90.8	955.0	1.7	71.2	152.4	8.8
average	77.2	842.5	0.0	49.0	65.19	0.0
median	77.7	842.5	0.0	48.0	55.17	0.0

Based on the abovementioned model, equation (7) was used.
Many simulations were carried out in order to satisfy the boundary conditions above set out in the model. Table 3 and figures 3 to 6 show the results. R-square values ranged from to 0.46 to 0.74.
When all the data were considered (cases 1 to 4) correlations resulted significant at a 1% level of significance (see table 3).

Figure 3 refers to the case 1, figure 4 refers to the case 2, figure 5 to the case 3, while figure 6 to the case 4.

TABLE 3 Parameters *a, b, c, d*

Case	Data set	*a SS106*	*a SP21*	*b SS106*	*b SP21*	*c*	*d*	R-square	p-value
1	All	-1085.28	-1085.28	69.17	69.17	-0.84	1.00	0.59	0.0000
2	All	-411.03	-411.03	70.67	70.67	-0.84	0.72	0.60	0.0000
3	All	-171.53	-171.53	79.30	61.95	-0.84	0.59	0.73	0.0000
4	all	-1888.28	-341.12	83.30	60.95	-0.84	0.79	0.74	0.0000
5	SP21		-402.12		60.78	-0.74	0.84	0.46	0.0017
Model: $V_{85}=a/R^d+b+c\cdot i$; All: SP21+SS106									

In case 1 all the data where fitted by the same equation with the same coefficients *a*, *b*, *c*, *d*=1 (see table 3 and figure 3).
Case 2 was conceived in order to test only for *d* variability. Small variations were observed, if compared to case 1 (see figures 3 and 4).
On the contrary, in the case 3 (see figure 5), because of the different range of operating speeds involved (as above showed in terms of main statistics), two different values of the coefficient *b* were derived (one *per* road) in the minimization process (Non-linear least squares method). It is very important to point out that in this case only the parameter *b* accounted for road specificity. This originated an appreciable R-square and the correlation resulted significant at a 1% level of significance (see table 3).
As expected, in this case, it resulted *bSS106* > *bSP21*, according to the conceptual model above set out in which *b* has a specific meaning and is not a simple parameter to estimate without any boundary condition. In the following, this topic is analysed in detail.
In the case 4 (see figure 6) regression analyses were carried out without imposing any constrains.
In case 5 only data from SP21 were analysed.
Note that when all the parameters were considered unconstrained (case 4, figure 6), the parameter *a* (in absolute value) for the road SS106 resulted appreciably higher than the one obtained for the road SP21.
d, which amplifies or diminishes the influence of the radius on operating speeds, resulted to range from 0.59 (close to other researches in literature) to 1.
Finally, *c*, which takes into account for longitudinal grade influence, ranged from -0.84 to -0.74. Note that when downhill and uphill conditions (-8% and +8%) were considered (see figures 5 and 6) the lowest (SS106) and the highest (SP21) curve of each of the two data set (i.e. SS106 _downhill and SP21_uphill) resulted approximately comparable but this comparability refers to domains in which it is quite improbable to find data which belongs to both SS106 and SP21. Figure 6 illustrates the point.

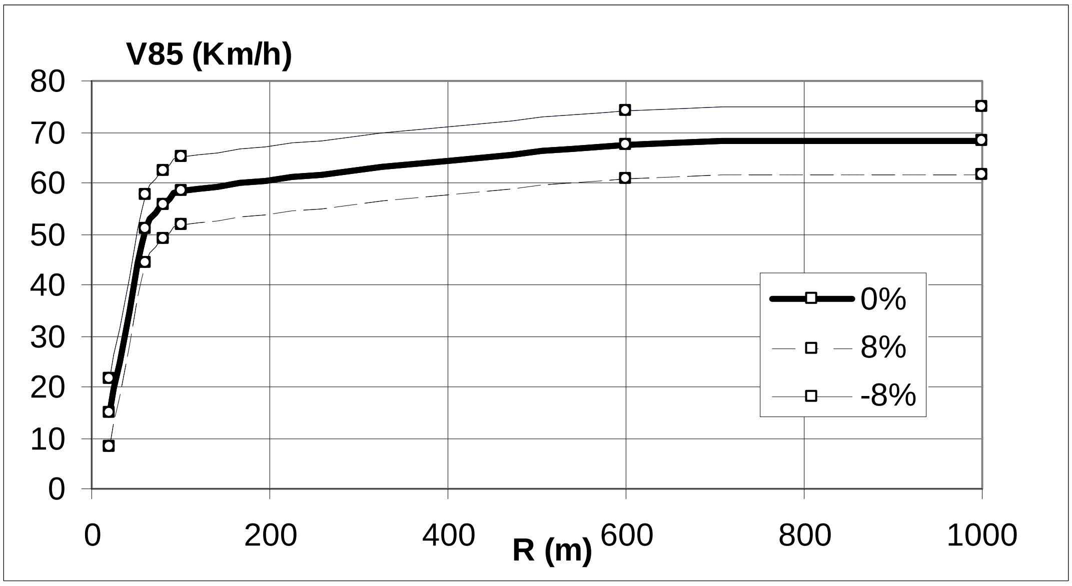

FIGURE 3 Operating speeds on curve versus radius of curve (case 1: *aSS106=aSP21*; *bSS106=bSP21*; *d*=1).

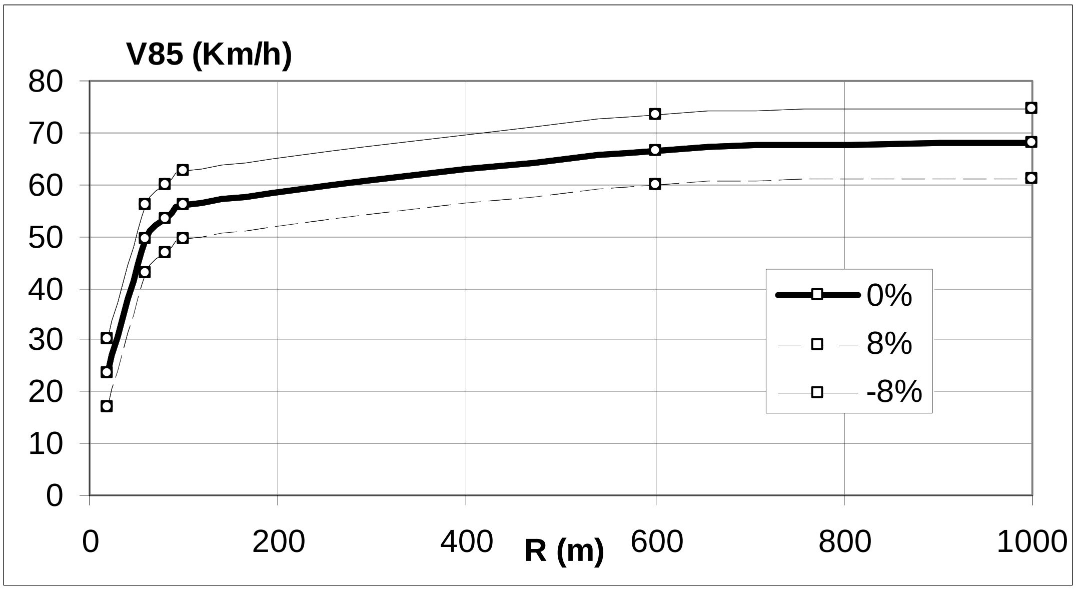

FIGURE 4 Operating speeds on curve versus radius of curve for different longitudinal grades (case 2: *aSS106=aSP21*; *bSS106=bSP21*; *d*≠1).

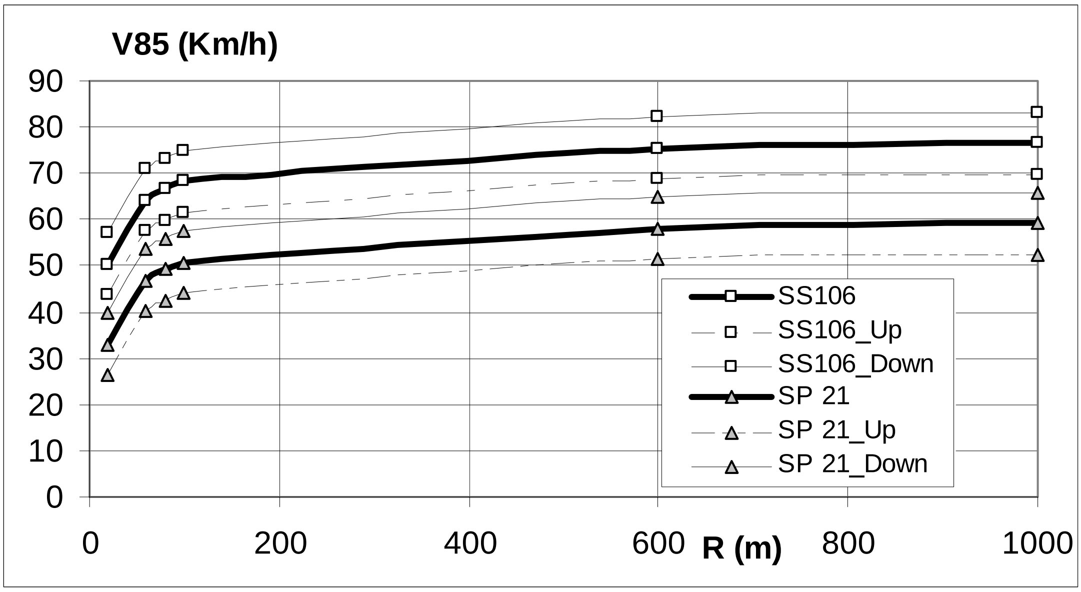

FIGURE 5 Operating speeds on curve versus radius of curve for different longitudinal grades (case 3: *aSS106=aSP21; bSS106≠bSP21*; *d*≠1).

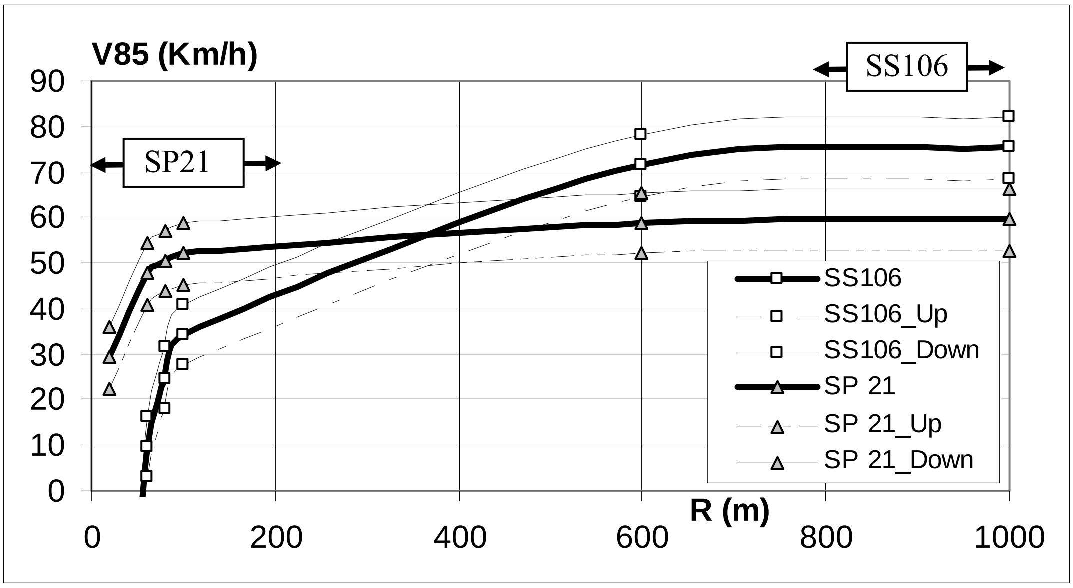

FIGURE 6 Operating speeds on curve versus radius of curve for different longitudinal grades (case 4: *aSS106≠aSP21; bSS106≠bSP21*; *d*≠1).

The following further points can be relevant in the analysis of the parameter *b*. The parameters *bSS106* and *bSP21* ranged from 61km/h (obtained for the road SP21) to 83 km/h (SS106). Note that such values are between the maximum and the average value of V_{85}s above detailed for each of the involved roads (see table 2). Further it is very interesting to observe that the abovementioned parameter *b* seems to be approximately predictable through many algorithms well known in literature (see for example equations 8 to 10 below described).
Indeed, the so-called environmental speed (Crisman et al [11]) V_{env}, can be predicted through the following algorithm:

$$V_{env} = 239.49 \cdot CCR_L^{*\,-0.1875} \tag{8}$$

CCR_L* refers to curvature change rate of the entire road stretch, including the intervening tangents, in order to take into account for the overall tendency to a desired or environmental speed. Now, if the abovementioned algorithm is applied to the SP21, it results V_{amb} = 64.61 Km/h which is relatively close to the value of *b* for the same road.
Another important estimate of the design speed (as a reference value, see Lamm et alia, 2001 [12]), to be used as far as Lamm criteria are used, can be obtained through the following formula (for longitudinal grades < 6%):

$$V_{85} = 105.31 + 2 \cdot 10^{-5} \cdot CCR_S{}^2 - 0.071 \cdot CCR_S \qquad (9)$$

where CCR_S is the (average) curvature change rate of the single curve across the section under consideration (gon/km). In the case of SP21 it results V_{85} = 55.03 Km/h.
Due to the fact that the longitudinal grades of the SP21 range from -8% up to 8%, another formula, always derived by the same authors (see Lamm et alia, 2001[12]), can be used in order to predict the above cited estimate of the design speed:

$$V_{85} = 86 - 3.24 \cdot 10^{-9} \cdot CCR_S{}^3 + 1.61 \cdot 10^{-5} \cdot CCR_S^2 - 4.26 \cdot 10^{-2} \cdot CCR_S \qquad (10)$$

In this case, for the same SP21, the formula gives V_{85} = 56.72 Km/h, which is fairly close from the value of *b* obtained for the data set under investigation. All these facts suggest that the parameter *b* could be itself related to the geometric features of the considered road.

SUMMARY AND CONCLUSIONS

Operating speed prediction models are a useful tool for evaluating the consistency of existing roads and consequently planning the strategy in order to improve the operational conditions with particular focus on safety.
Several critical points affect the definition and calibration of speed prediction models.
First of all, the models are generally road specific and country specific due to the large influence of environmental context and many other factors.
Further it must be considered that the actual speed detected on an element of road alignment is affected by several parameters related to the horizontal and vertical geometric feature of the element and also depends on the general condition of the previous alignment.
Given this, in this work an algorithm to predict operating speed was formalized. In the model the independent variables are the curvature of the element (*1/R*) and the longitudinal slope (*i*). A parameter, *b*, related to the environmental speed, and strictly connected to the type of road, its function and its environmental context, was also introduced. The weight of the curvature was adjusted through the parameters *a* and *d*. The algorithm was validated using the experimental data collected in several rural roads in Provincia of Reggio Calabria - southern Italy.
Although more experiments are needed, the model calibration pointed out that the formalized model is able to work for different roads, due to the fact that environmental speeds are adequately considered. Further, an appreciable variance of the coefficient *a* (which relates to the effect of geometric features on operating speed), was noted when different roads were examined. This condition, which could be related to the fact that the higher the environmental speed the higher the effect of horizontal curves, calls for further research.
These first results are encouraging. Further experimental analyses are in progress in order to improve the model parameter and to understand the model reliability in a road network. Attention

will be focused on the influence of the independent variables on the operating speed and on the topic of the dependence of calibration factors (namely *a* and *b*) on road type.

REFERENCES

[1] J. McLean. Driver speed behaviour and rural road alignment design. *Traffic Engineering and Contro*l Vol. 22, No. 4, United Kingdom, April 1981, pp. 208-211.

[2] Lamm, R., E.M. Choueiri, J.C. Hayward, and A. Paluri. Possible Design Procedure to Promote Design Consistency in Highway Geometric Design on Two-Lane Rural Roads. *Transportation Research Record*, No. 1195. Transportation Research Board, National Research Council, Washington, D.C., 1988, pp. 111-122.

[3] Krammes R.A., Brakett R. Q., Shaffer M. A., Ottesen J. L., Anderson I. B., Fink K. L., Collins K. M., Pendleton O. J., and C. J. Messer. *Horizontal Alignment Design Consistency for Two-Lane Highways Report.* FHWARD-94-034, FHWA, U.S. Department of Transportation, 1995.

[4] Fitzpatrick K., Elefteriadou L., Harwood D.W., Collins J.M., McFadden J.,. Anderson I.B, Krammes R.A., Irizarry N., Parma K.D., Bauer K.M., and K. Passetti. *Speed Prediction for Two-Lane Rural Highways.* Report No. FHWA – RD -99-171, Federal Highways Administration, 2000.

[5] Misaghi P. and Y. Hassan. Modeling Operating Speed and Speed Differential on Two-Lane Rural Roads. *Journal of Transportation Engineering*. Journal of ASCE, Vol. 131, No. 6, June 2005. pp. 408-416.

[6] Abdul-Mawjoud, A.A. and G.G. Sofia. Development of models for predicting speed on horizontal curves for two-lane rural highways. *The Arabian Journal for Science and Engineering*, Vol. 33, Number 2B pp. 365-377.

[7] Krammes R.A., R.Q. Brakett, M.A. Shaffer, J.L. Ottesen, I.B. Anderson, K.L. Fink, K.M. Collins, O.J. Pendleton and C.J. Messer. *Horizontal Alignment Design Consistency for Two-Lane Highways*. Report FHWA-RD-94-034, FHWA, U.S. Department of Transportation, 1995.

[8] Kerman J.A., M. McDonald, G.A. Mintsis. Do Vehicles slow down on Bends? A Study into Road Curvature, Driver Behaviour and Design. *Proceedings 10th Summer Annual Meeting, PTRC*, United Kingdom, 1982, pp. 57-67.

[9] Cardoso J., De Macedo, A.L., Kanellaidis G., Flouda A., Dimitropoulos I., Peltola H., Ranta S. and G. Drupe. Improvement of Models on the Relations Between Speed and Road Characteristics. *Task 5.3 SAFESTAR (Safety Standards for Road Design and Redesign)*, Laboratorio National De Engenharia Civil, Portugal, February 1998.

[10] J. McLean. An Alternative to the Design Speed Concept for low Speed Alignment Design. *Transportation Research Record*, No.702, TRB, National Research Council, Washington, D.C., 1979, pp. 55-63.

[11] Crisman, B., Fugaro, L. and A. Marchionna. Modello di previsione delle velocità praticate dagli utenti attraverso la definizione di una velocità ambientale. *XIII Convegno Nazionale S.I.I.V.* – Padova – 30/31 Ottobre 2003.

[12] Lamm R., Wolhuter K., Beck A. and T.Ruscher. Introduction of a new approach to geometric design and road safety. *20th South African Transport Conference*, South Africa, 16 – 20 July 2001.

[13] P.Perco. Influence of the general character of the horizontal alignment on the operating speed of two-lane rural roads. *Transportation Research Record* 2008.

[14] Dixon, K. K., Wu, C. H., Sarasua, W. and J. Daniels. Posted and Free-Flow Speeds for Rural Multilane Highways in Georgia. *Journal of Transportation Engineering* (November/December 1999) pp. 487–494.

[15] Gintalas V., Žilionienė D., Dimaitis M., Lukošaitis D, Lipnevičiūtė K. and J. Vitkienė. Analysis of design solutions in the objects of gravel roads paving programme in terms of traffic safety. *The Baltic Journal Of Road And Bridge Engineering*, 2008, 3(2): 93–100.

[16] Ottesen, J.L. and R.A. Krammes. Speed-Profile Model for a Design-Consistency Evaluation Procedure in the United States. *Transportation Research Record* 1701 2000, TRB, National Research Council, Washington, D. C.