Evaluation Of Design Consistency: A New Operating Speed Model For Rural Roads On Grades

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SYNOPSIS

Achieving an effective evaluation procedure of geometric design consistency is among the most promising strategies to increase the road safety level. Actually, it is estimated that accident probability is higher where alignment homogeneity lacks. In the last years many research works were developed with the aim of addressing the different effects of geometric parameters on the prediction of the operating speed. Based on this parameter, the design consistency on road elements can be evaluated, and different approaches have just been worked out to estimate the operating speed on two-lane rural highways.
However, the current operating speed predicting models are reliable if applied at horizontal curves, but when they have to evaluate the operating speed in high-graded and high-curved sections, the obtained results are significant different from the observed values.
Consequently, these models can be employed successfully for estimating the operating speed in horizontal highways, but they are still lacking when applied on roads characterized by sharp curves, hairpin bends, high longitudinal grades and long successions of curves with short tangents.
The purpose of the present research work was to develop a new operating speed predicting model for this kind of alignment, using data detected on two-lane rural roads, involving totally nine curved sections.
The study was carried out during daytime in good weather conditions and the operating speed was measured for the vehicles in the traffic stream under free-flow conditions to avoid the effect of traffic flow on vehicle speed. The speed data were collected for each curve at three point along each travel direction, while the geometric design data of the selected curves were obtained by a topographic relief. Furthermore, it was measured the desired speed in the tangents near the curved sections.
The performed model predicts the operating speed values on curved sections of radius ranging from 25 m to 170 m as functions of the degree of curve.
The collected speed data were then employed to compare the operating speed values to the design speed values and to estimate the design consistency of the single curved sections according to the first Lamm criterion.
Based on the performed research work, the following concluding remarks can be stated:
- the design speed, calculated according to Italian design guides, is smaller than the operating speed in the majority of the detected curved sections;
- the developed model can be successfully used to define the operating speed profile on a route and become necessary for evaluating design consistency on existing roads and for identifying any inconsistencies during the design stage of new roads;
- the degree of curve is confirmed as the most significant parameter affecting the operating speed, not only on horizontal curves, but also on graded curved sections;
- the length of curve, the deflection angle and the longitudinal grade do not seem to be significant in affecting the operating speed;
- the performed model can be successfully adopted to evaluate the design consistency on a single element and on adjacent curved sections of the alignment according to Lamm criteria;
- the developed model constitutes the integration of MOST and Kanellaidis model in predicting operating speed on curves of radius ranging from 25 to 170 m;
- for the future, the revision of the current Italian design guides to account for operating speed should be necessary to achieve safer highway designs and to improve the global safety of the highway network.

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INTRODUCTION

Achieving an effective evaluation procedure of geometric design consistency is among the most promising strategies to increase the road safety level. Actually, it is estimated that accident probability is higher where alignment homogeneity lacks. In the last years many research works were developed with the aim of addressing the different effects of geometric parameters on the prediction of the operating speed (Gibreel et al. 1999). Based on this parameter, the design consistency on road elements can be evaluated, and different approaches have just been worked out to estimate the operating speed on two-lane rural highways (Crisman et al. 2003, Kanellaidis et al. 1990, Krammes et al. 1994 & 1995, Islam and Seneviratne, 1994, Lamm et al. 1990, 1994, McFadden and Elefteriadou. 1997 and others).
However, the current operating speed predicting models are reliable if applied at horizontal curves, but when they have to evaluate operating speed in high-graded and high-curved sections, the returned results are significant different from the observed values.
Consequently, these models can be employed successfully for estimating the operating speed in horizontal highways, but they are still lacking when applied on roads characterized by sharp curves, hairpin bends, high longitudinal grades and long successions of curves with short tangents.
The purpose of the present research work was to develop a new operating speed predicting model for this kind of alignment, using data detected on two-lane rural roads.
The performed model predicts the operating speed values on curved sections of radius ranging from 25 m to 170 m as functions of the degree of curve. In order to complete the analysis, the results obtained by the model were compared to the ones returned by the operating speed predicting model MOST (Crisman et al. 2003) and by Kanellaidis model (Kanellaidis et al. 1990).
The collected speed data were then employed to compare the operating speed values to the design speed values and to estimate the design consistency of the single curved sections according to the first Lamm criterion (Lamm et al. 2003).

EXPERIMENTAL INVESTIGATION

The study involved two ancient ways of communication between Emilia and Toscana across the Appenninc chain: the Provincial Road “della Futa” (S.P. 65) and the Provincial Road “Casolana-Riolese” (S.P. 306). They both are two-lane rural roads, of type C according to the Italian Road Code (D.L. 30/04/92), with variable cross section. The lane width varies from 3.75 m to 3.00 m, while the shoulders, in the great part of alignment, are wide enough to include tapers. The investigation kept into consideration a segment of 20 km on each roadway.
The analyzed routes cross hilly and mountain terrains and are characterized by successive curves with short tangents, sharp curves, hairpin bends and longitudinal grades ranging from 2% to 5%. Some singular points in S.P. 65 have longitudinal grades of 13%, while in S.P. 306 the maximum value is 8%.
The S.P. 65 segment is composed by 167 tangents, with a minimum length of 9 m and a maximum of 316 m, and by 256 curves of radius ranging from 10 m to 1534 m.
The selected segment of S.P. 306 is less tortuous and it is composed by 87 tangents (minimum length 8 m, maximum 1236 m) and 119 curves (radius ranging from 10 m to 2861 m).
The road designs lack because of the ancient origin of the roads, so that the horizontal alignment has been defined on CTR 1:5000 cartography.
After that, the horizontal consistency was evaluated drawing up the design speed profile according to Italian design guide (D.M. 5/11/01). The analysis revealed that both the alignments do not respect the new Italian consistency standards in the majority of the route. However, the considered design guide mentions explicitly that the specifications inside concern the design of all typologies of highways defined in the Code but the mountain rural roads which cross difficult terrains from the morphological point of view, for that it is generally impossible to respect the included design criteria.

In fact, the analysis showed that the design speed profile can only be a qualitative indicator of global consistency of alignment, but it is inadequate to estimate the real vehicle speeds and to evaluate the horizontal consistency of this typology of road.
For these reasons a set of operating speed predicting models was developed. The models provide more reliability values of vehicle speeds on curvilinear elements and they can be applied for evaluating the design consistency of these kinds of roads.
For this purpose a series of speed data were collected in nine selected curved sections. The relief was carried out during daytime in good weather conditions, and the operating speed was measured for the vehicles in the traffic stream under free-flow conditions to avoid the effect of traffic flow on vehicle speed. The speed data were detected for each curve at three point along each travel direction, while the geometric design data of the curves were obtained by a topographic relief. Furthermore, it was measured the desired speed in the tangents near the curves.
Many model trials were performed and only the most significant and logical ones were presented. In order to develop the final analysis the following conditions were adopted (Gibreel et al. 2001):
- the coefficient of determination R^2 must be significant at least at the 0.05 level on two tails test;
- the regression coefficients of each independent variable must be significantly different from zero at least at the 0.05 level on two tails test;
- the algebraic signs of the regression coefficients must have a logical explanation.

OPERATING SPEED MODELS ON S.P. 65 "DELLA FUTA"

The aim of the analysis was to investigate the relationship between the operating speed and the geometric parameters of the curves. For this purpose, four curved sections on S.P. 65 were selected based upon the following general conditions:
- no influence of intersections and of other adjacent sections;
- no physical features or activities adjacent to or in the course of the roadway that may influence vehicle speed, such as schools, factories or recreational parks.

The trajectories of vehicles was observed in order to position the speed detectors in the points where the vehicles begin to decelerate to run the curves and where they start the acceleration after the curve. Pneumatic tubes devices were employed. Figures 1 to 4 represent the selected curves and the disposition of detectors.

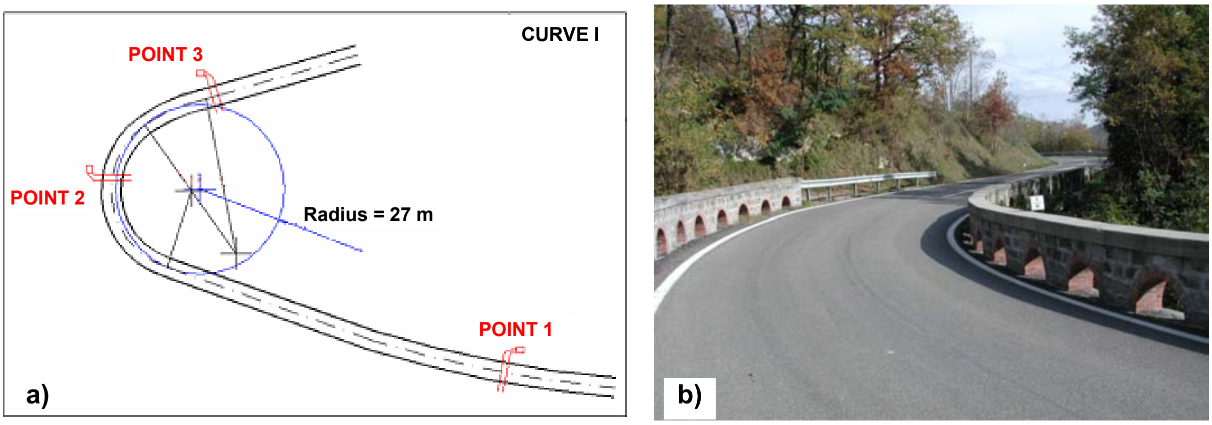

Figure 1: Curve I, S.P. 65, detectors position (a) and picture between point 2 and 3 (b)

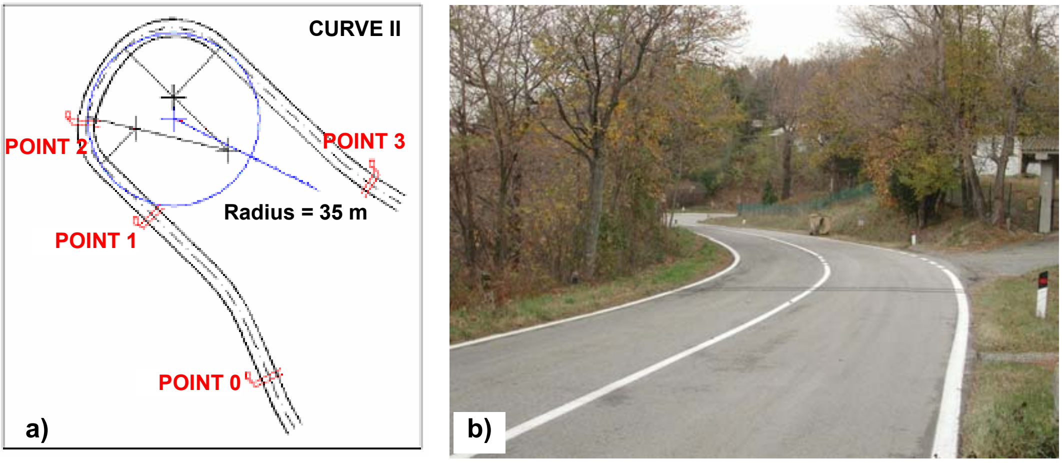

Figure 2: Curve II, S.P. 65, detectors position (a) and picture at point 0 (b)

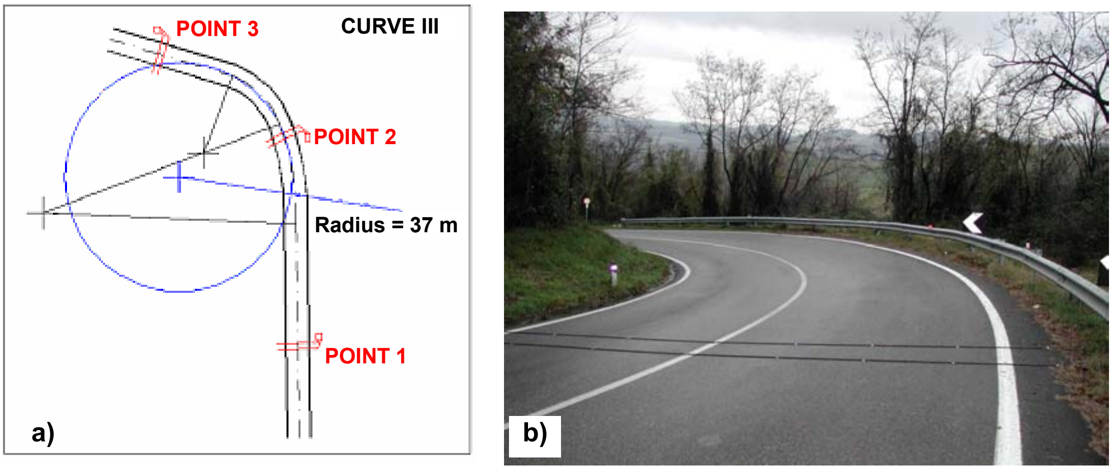

Figure 3: Curve III, S.P. 65, detectors position (a) and picture at point 2 (b)

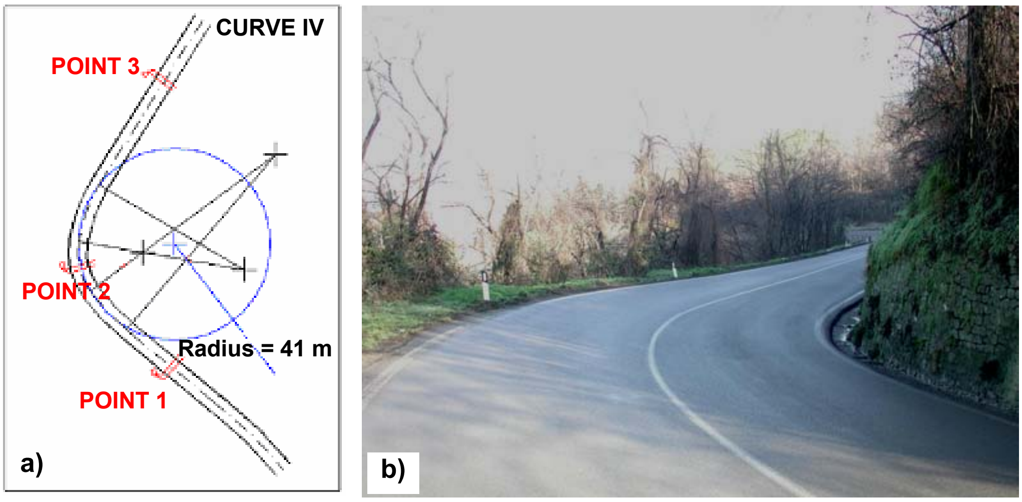

Figure 4: Curve IV, S.P. 65, detectors position (a) and picture at point 2 (b)

A topographic relief provided accurate measures of spirals, curves, cross sections and vertical profile of the sites. Equivalent values of radius were then adopted in order to represent the global geometric characteristics of each selected curved section: after various trials, the value best approaching the totally of curvilinear element was employed, even if it does not respect the tangent condition (figures 1 to 4).
Table 1 summarizes the main geometric characteristics of the curved sections.
The operating speed values were calculated considering only the data detected between 6.00 a.m. and 8.00 a.m. on accumulation intervals including less than 10% of heavy vehicles.
The results are reported in table 2. It should be noted that on each curve the design speed *Vp* is about 10 km/h lower than the operating speed.

Table 1: S.P. 65, geometrical parameters of curves

Curve	Equivalent radius *r* (m)	Degree of curve *DC* (°/100 m)	Equivalent deflection angle (°)	Length (m)	Average longitudinal grade (%/100)
I	27	212.21	111	52.31	2.30
II	35	163.70	180	109.96	3.92
III	37	154.85	68	43.91	11.63
IV	41	139.75	79	56.53	8.90

Table 2: S.P. 65, operating speed on curves

Curve	Point	Downgrade		Upgrade		Average	Design speed *Vp* (km/h)
		V_{85} (km/h)	processed values	V_{85} (km/h)	processed values	$V_{85average}$ (km/h)	
I	1	62.5	31	68.6	30	65.6	-
	2	39.7	42	40.0	39	39.9	31.0
	3	54.1	33	55.0	33	54.6	-
II	0	61.1	33	56.1	32	58.6	-
	1	55.0	32	50.1	33	52.6	-
	2	45.2	51	46.9	40	46.1	35.3
	3	58.3	31	64.2	39	61.3	-
III	1	66.4	61	51.2	51	58.8	-
	2	46.0	52	47.5	52	46.8	36.3
	3	51.7	60	54.1	47	52.9	-
IV	1	67.4	67	57.1	55	62.3	-
	2	47.8	66	50.0	55	48.9	38.2
	3	57.7	65	49.5	56	53.6	-

The detection was completed by skid tests, performed on both the lanes 0.50 m from the edge of carriageway, with the aim to evaluate skid resistance and macro-texture where the right wheel of vehicles pass through. The BPN coefficient always resulted greater than 60 and the HS test always recorded values higher than 0.40 mm, with the exception of a site where a value, however acceptable, of 0.35 mm was registered.

Data analysis

Figure 5 and figure 6 show the operating speed variation measured in the centre (point 2, figures 1 to 4) and in the preceding tangents (point 1 and 3, figures 1 to 4) of each curve. It should be observed that either the vehicles that run the curves downward or the ones which run upward trend to keep the same speed in the centre of the curve, even when the tangent speed is sensibly different.

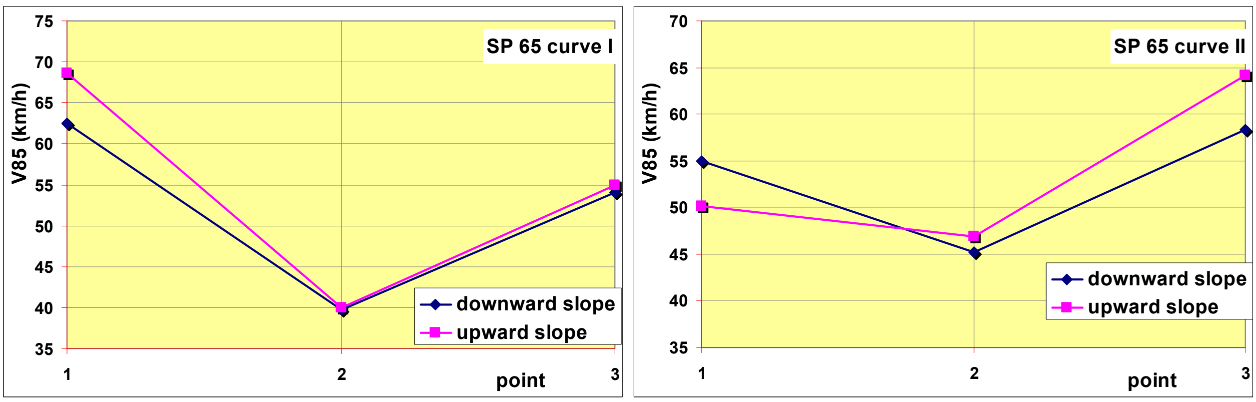

Figure 5: S.P. 65, curve I and curve II, variation in operating speed along the curve

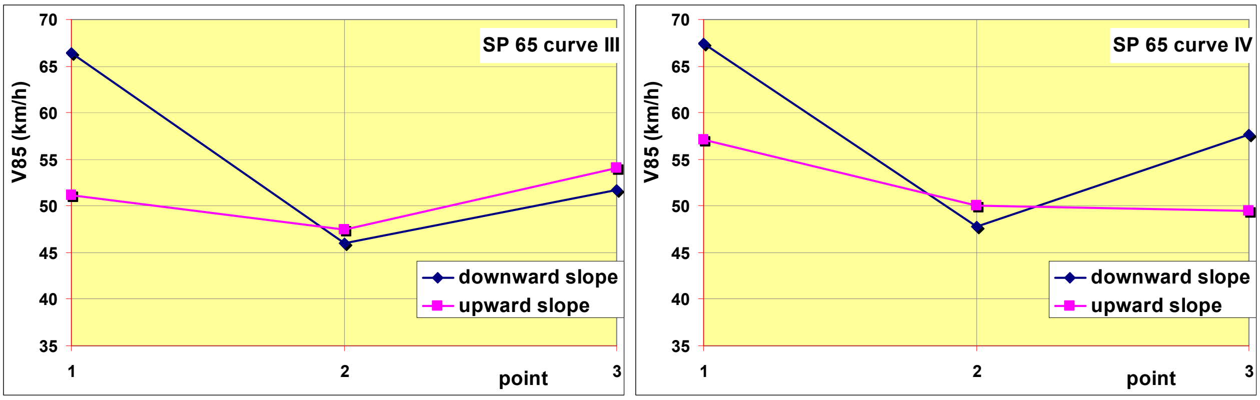

Figure 6: S.P. 65, curve III e curve IV, variation in operating speed along the curve

Furthermore, the presence of significant correlations between operating speed and geometric characteristic of curves was investigated. The dispersion diagrams in figure 7 and 8 show a high positive correlation between operating speed in the centre of the curves and radius, while deflection angle, length and grade do not seem to be correlated with V_{85}.

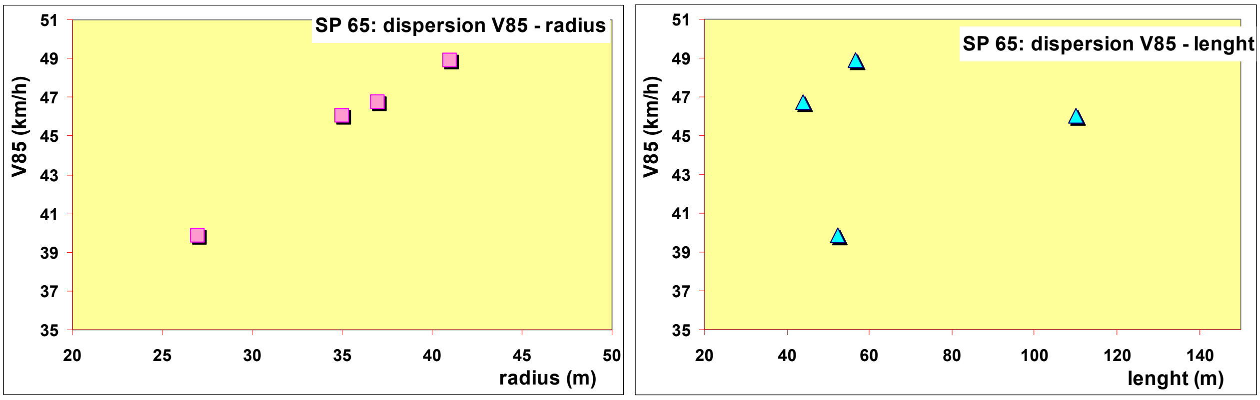

Figure 7: S.P. 65, dispersion between operating speed, radius and length

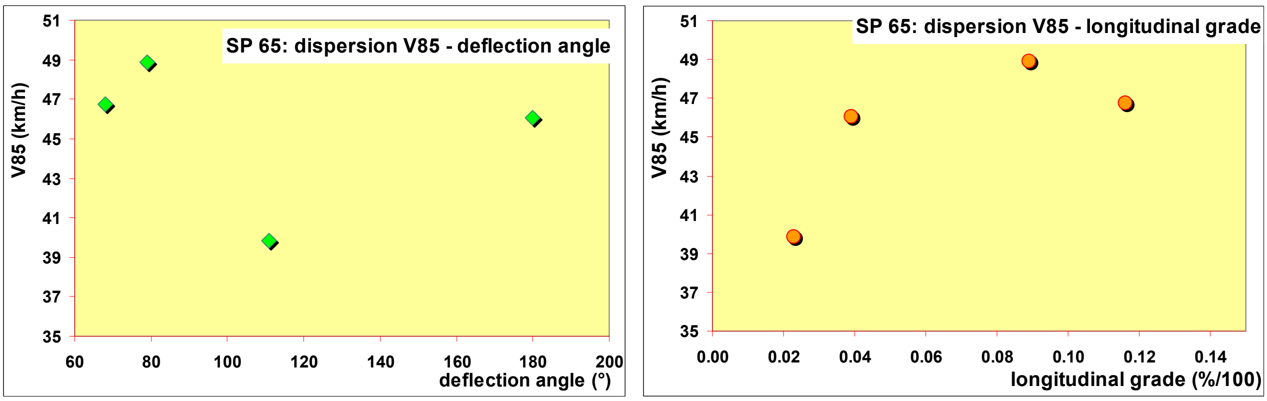

Figure 8: S.P. 65, dispersion between operating speed, deflection angle and grade

Pearson correlation analysis confirmed the considerations deduced by the dispersions diagrams. Table 3 shows that the correlation between V_{85} and radius is significant at the level 0.01 on two ties test (R = 0.992). Moreover, the Pearson's matrix reveals a higher negative correlation between operating speed and degree of curve DC (R = -0.999), with equally significance.

The degree of curve DC is expressed as follows:

$$DC = 100 \times \frac{360}{2\pi r}$$

where r (m) is the equivalent radius of the curve.

All the others parameters don't result correlated with V_{85}. The average operating speed measured on point 3 present a high positive correlation either with deflection angle or curve length; however, these relationships are considered as accidental.

Table 3: S.P. 65, correlation matrix

Pearson Correlation Matrix S.P. 65 “della Futa”		V_{85} (km/h)	$V_{85}(1)$* (km/h)	$V_{85}(3)$** (km/h)	*DC* (°/100m)	Radius (m)	Av. long. grade (%/100)	Deflection angle A (°)	Lenght s (m)
V_{85} (km/h)	Pearson’s correlation significance (2-tails) N***	1 . 4	-0.454 0.546 4	-0.026 0.974 4	**-0.999** **0.001** 4	**0.992** **0.008** 4	0.733 0.267 4	-0.213 0.787 4	0.119 0.881 4
V_{85} (1)* (km/h)	Pearson’s correlation significance (2-tails) N***	-0.454 0.546 4	1 . 4	-0.768 0.232 4	0.439 0.561 4	-0.339 0.661 4	-0.065 0.935 4	-0.637 0.363 4	-0.797 0.203 4
V_{85} (3)** (km/h)	Pearson’s correlation significance (2-tails) N***	-0.026 0.974 4	-0.768 0.232 4	1 . 4	0.059 0.941 4	-0.133 0.867 4	-0.577 0.423 4	**0.980** **0.020** 4	**0.987** **0.013** 4
DC (°/100m)	Pearson’s correlation significance (2-tails) N***	**-0.999** **0.001** 4	0.439 0.561 4	0.059 0.941 4	1 . 4	-0.993** 0.007 4	-0.761 0.239 4	0.247 0.753 4	-0.084 0.916 4
Radius (m)	Pearson’s correlation significance (2-tails) N***	**0.992** **0.008** 4	-0.339 0.661 4	-0.133 0.867 4	-0.993** 0.007 4	1 . 4	0.762 0.238 4	-0.312 0.688 4	0.016 0.984 4
Average longitudinal grade (%/100)	Pearson’s correlation significance (2-tails) N***	0.733 0.267 4	-0.065 0.935 4	-0.577 0.423 4	-0.761 0.239 4	0.762 0.238 4	1 . 4	-0.724 0.276 4	-0.492 0.508 4
Deflection angle A (°)	Pearson’s correlation significance (2-tails) N***	-0.213 0.787 4	-0.637 0.363 4	**0.980** **0.020** 4	0.247 0.753 4	-0.312 0.688 4	-0.724 0.276 4	1 . 4	0.945 0.055 4
Lenght s (m)	Pearson’s correlation significance (2-tails) N***	0.119 0.881 4	-0.797 0.203 4	**0.987** **0.013** 4	-0.084 0.916 4	0.016 0.984 4	-0.492 0.508 4	0.945 0.055 4	1 . 4

*average V_{85} at point 1
**average V_{85} at point 3
***number of processed values

The models

According to Pearson correlation analysis a set of three regression models were performed. All the models predict the operating speed as function of the degree of curve *DC* (table 4). The value of *DC* must be inserted in °/100 m, while V_{85} is expressed in km/h. It should be noted that such high values of R^2 may have resulted from the small number of data used in developing these models.

Table 4: S.P. 65, summary of models

Model	Expression	R^2	Correct R^2	Standard error
1	$V_{85} = 66.164 – 0.124DC$	0.998	0.997	0.20381
2	$V_{85} = 55.366 – 3.46E\text{-}04DC^2$	0.996	0.994	0.31032
3	$V_{85} = 65.745 – 0.119DC – 1.35E\text{-}0.5DC^2$	0.998	0.995	0.28792

In tables 5 and 6 are shown the results of ANOVA and the significance tests on the regression coefficients. ANOVA provides a 0.01 significance level in models 1 and 2, and a 0.05 significance level in model 3.

Table 5: S.P. 65, ANOVA

Model		Sum of squares	df	Average of squares	F	Significance
1	Regression	45.214	1	45.214	1088.498	.001[a]
	Residual	.083	2	.042		
	Total	45.297	3			
2	Regression	45.104	1	45.104	468.376	.002[c]
	Residual	.193	2	.096		
	Total	45.297	3			
3	Regression	45.214	2	22.607	272.717	.043[b]
	Residual	.083	1	.083		
	Total	45.297	3			

a Estimator: (Constant), DC
b Estimator: (Constant), DC, DC^2
c Estimator: (Constant), DC^2

Table 6: S.P. 65, coefficients of regression

Model		Not standardized coefficients		Standardized coefficients	t	Significance
		B	Standard error	Beta		
1	(Constant)	66.164	.638		103.718	.000
	DC	-.124	.004	-.999	-32.992	.001
2	(Constant)	65.745	9.033		7.278	.087
	DC	-.119	.104	-.960	-1.150	.456
	DC^2	-1.349E-05	.000	-.039	-.047	.970
3	(Constant)	55.366	.486		113.813	.000
	DC^2	-3.460E-04	.000	-.998	-21.642	.002

On the other hand, the t Student test on the regression coefficients does not show any significance concerning the coefficients of model 3, while in models 1 and 2 they are significant at the 0.01 level, so that, considering the values of coefficients of determination R^2 reported in table 4, model 1 results the most representative predicting model of operating speed (figure 9).

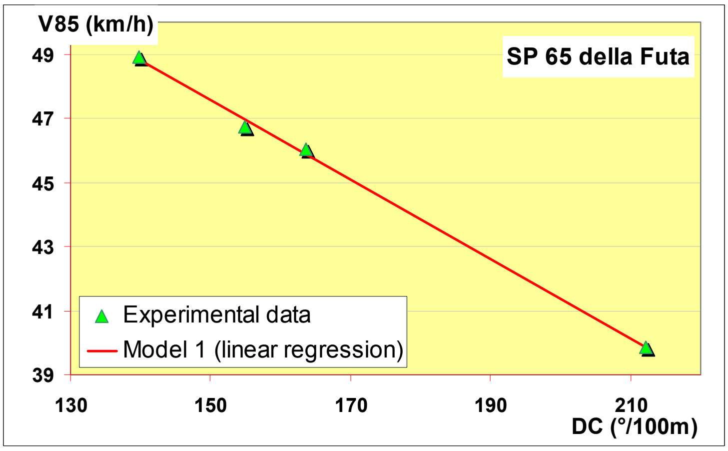

Figure 9: S.P. 65, linear V_{85} predicting model versus *DC*

OPERATING SPEED MODELS ON S.P. 306 "CASOLANA RIOLESE"

The same procedure of operating speed detection, applied on S.P. 65, was adopted on S.P. 306. Five curved sections were selected. The geometric characteristics were provided by a topographic relief and are reported in table 7. The speed data were collected using a laser device, opportunely hidden to the motorists.

Table 7: S.P. 306, geometrical parameters of curves

Curve	Equivalent radius *r* (m)	Degree of curve *DC* (°/100 m)	Equivalent deflection angle (°)	Length (m)	Average longitudinal grade (%)
A	36	159.15	39	24.19	2.95
B	48	119.37	95	79.48	1.44
C	82	69.83	25	35.55	0.37
D	160	35.81	47	129.93	1.19
E	168	34.10	26	75.41	1.58

Table 8: S.P. 306, operating speed on curves

Curve	Point	Downgrade		Upgrade		Average	Design speed V_p (km/h)
		V_{85} (km/h)	processed values	V_{85} (km/h)	processed values	$V_{85average}$ (km/h)	
A	1	46.4	31	49.8	41	48.1	-
	2	42.8	43	43.7	42	43.2	35.8
	3	57.0	27	56.0	37	56.5	-
B	1	45.0	25	48.1	35	46.6	-
	2	50.0	39	50.4	38	50.2	41.2
	3	65.0	31	53.0	32	59.0	-
C	1	57.8	32	60.7	29	59.2	-
	2	62.2	41	60.0	36	61.1	51.7
	3	65.9	37	70.0	34	68.0	-
D	1	84.3	34	72.2	35	78.2	-
	2	69.4	45	66.0	40	67.7	68.8
	3	68.0	30	65.7	34	66.9	-
E	1	78.0	28	72.8	31	75.4	-
	2	69.0	36	69.1	36	69.0	70.1
	3	76.2	34	71.2	30	73.7	-

Data analisys

The data confirmed that, as well as S.P. 65, both the vehicles which run upward the curves and the ones that cross downward trend to keep the same operating speed value in the middle of the curve (figure 10), even when the tangent speed is sensibly different.

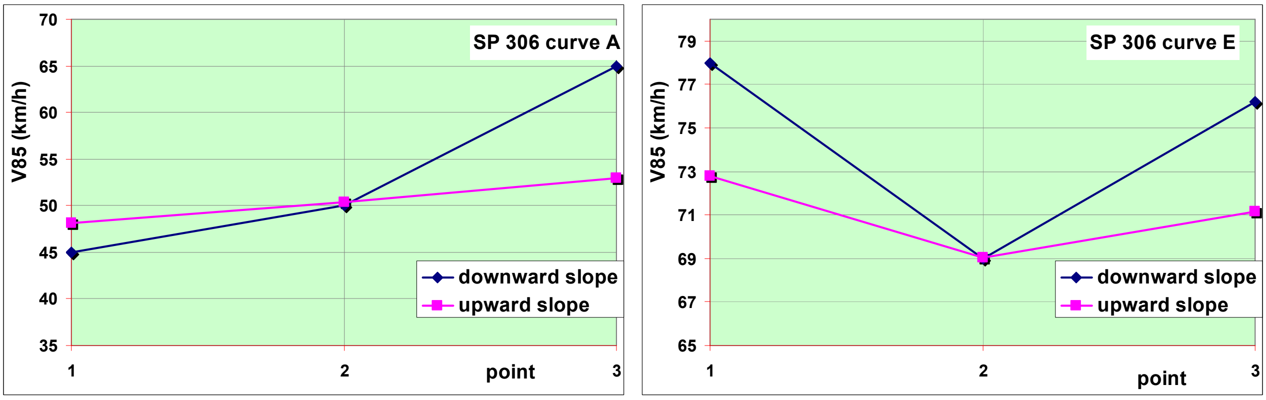

Figure 10: S.P. 306, curve A e curve E, variation in operating speed along the curves

The dispersion diagrams (figure 11 and 12) display a relationship between operating speed and radius, while length, deflection angle and grade seem to be not correlated to V_{85}.

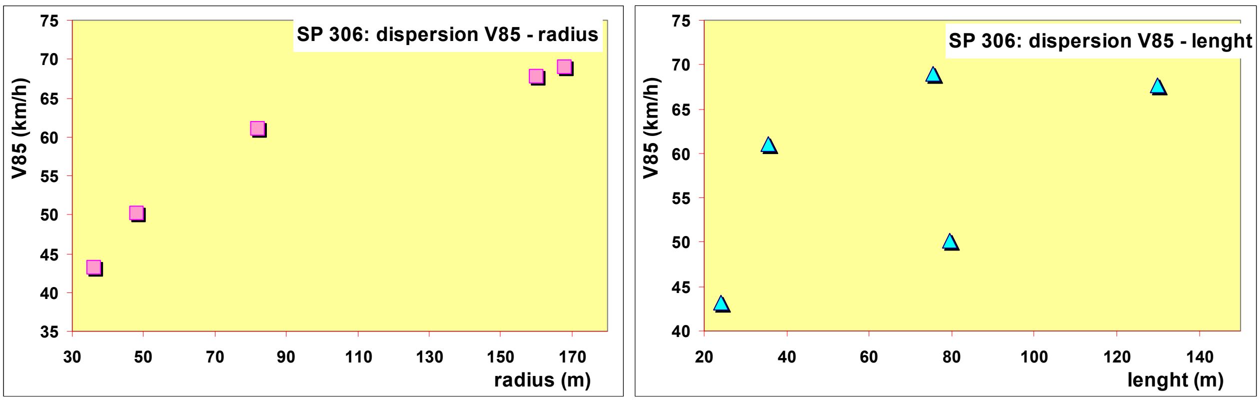

Figure 11: S.P. 306, dispersion between operating speed, radius and length

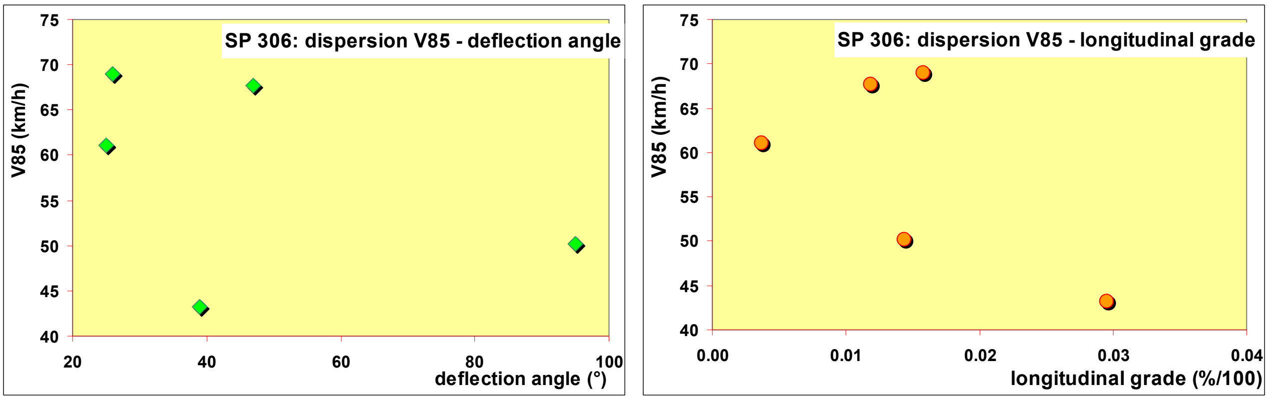

Figure 12: S.P. 306, dispersion between operating speed, deflection angle and grade

Pearson analysis provided a positive 0.05 significant correlation between V_{85} and radius of curve (R = 0.945) and a higher negative 0.01 significant correlation between V_{85} and degree of curve DC (R = -0.999); thus, the degree of curve represents the most significant parameter affecting the operating speed.
Table 9 and figure 13 show the developed predicting models. Model 3 has the higher value of R^2 but the coefficient of regressions are not significant according to t Student test. Consequently, model 1 results the most suitable to relate the operating speed to the degree of curve in the examined road.

Table 9: S.P. 306, summary of models

Model	Expression	R^2	Correct R^2	Standard error	Significance (ANOVA test F)
1	$V_{85} = 75.450 - 0.206DC$	0.998	0.997	0.64640	0.000
2	$V_{85} = 68.183 - 1.06\text{E-}03DC^2$	0.959	0.945	2.62380	0.004
3	$V_{85} = 76.732 - 0.244DC + 2.030\text{E-}0.4DC^2$	0.999	0.997	0.61387	0.001

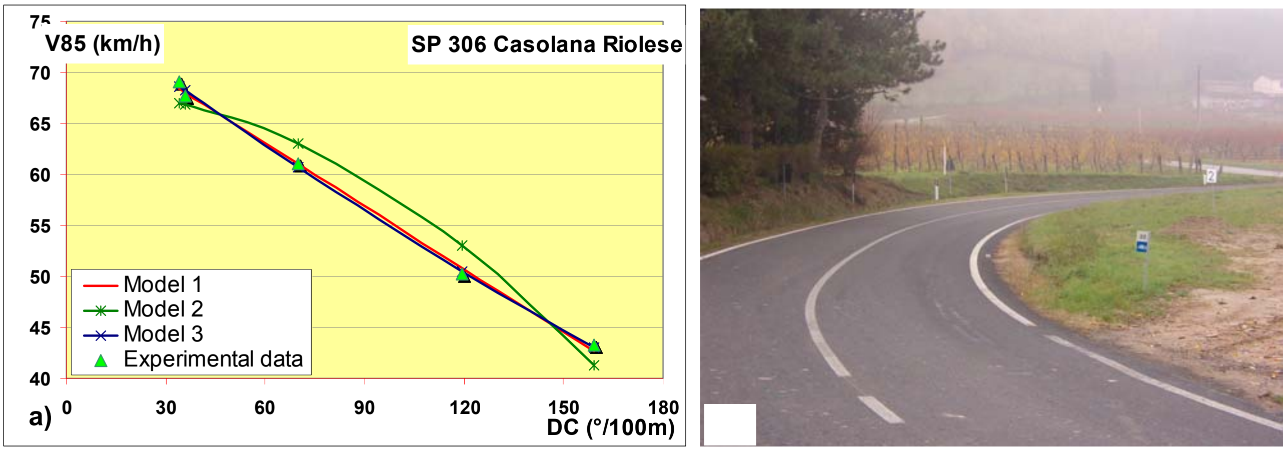

Figure 13: S.P. 306, V_{85} predicting models versus DC (a) and picture at curve B (b)

THE GENERAL MODEL

The collected data were applied to perform a set of general operating speed predicting models which can be employed to estimate V_{85} on the curvilinear elements of similar rural roads.
The performed models are summarized in table 10 and are represented in figure 14. All the models are significant according to ANOVA and all the coefficients of regression are significantly different from zero at the 0.95 confidence level.
It should be observed that the trend of model 2 is not compatible with the trend of experimental data, so that it must be discarded (figure 14). Model 3 is then the one which provides the most reliable results and can be adopted in predicting the operating speed on curves of radius ranging from 25 m to 170 m.

Table 10: Summary of models

Model	Expression	R^2	Correct R^2	Standard error	Significance (ANOVA test F)
1	V_{85} = 73.189 – 0.171DC	0.970	0.966	1.97273	0.000
2	V_{85} = 65.024 – 6.93E-04DC^2	0.864	0.844	4.22757	0.000
3	V_{85} = 77.556 – 0.276DC + 4.652E-0.4DC^2	0.990	0.986	1.26002	0.000

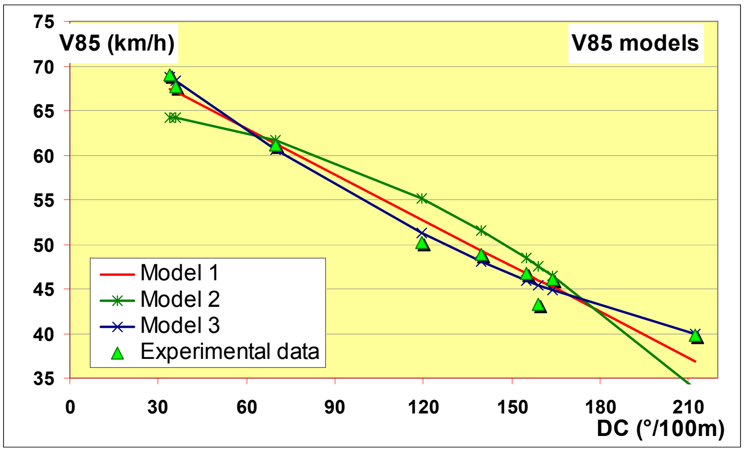

Figure 14: V_{85} predicting models versus DC

In order to complete the analysis, the operating speed on the curved sections of the considered routes was estimated by applying model MOST (Crisman et al. 2003), which was calibrated on curves having radius greater than 400 m, and Kanellaidis model (Kanellaidis et al. 1990), based on data from 48 curved sections of the Greek highway network.
These predicting models have been developed for horizontal curves in horizontal two-lane rural highways, having similar cross section to the roads considered in this research work.
The independent variables affecting the operating speed are the degree of curve and the desired speed, the last one defined as the speed kept by the vehicles in the less constraining elements of alignment. The desired speed Vd is then given by the maximum value of the operating speed measured on the longest tangents or on the widest radius curves in a unique homogeneous segment (Crisman et al. 2003). Thus, the desired speed represents an indicator of influence of road environment on vehicle speed.
Model MOST is expressed as follows:

$$V_{85} = 47.715 - 0.7121DC + 0.00389DC^2 + 0.57423Vd \qquad R^2 = 0.83$$

where Vd is the desired speed (km/h) and DC is the degree of curve (°/100 m).
Kanellaidis proposed the equation:

$$V_{85} = 17.4 - \frac{3244.8}{r} + \frac{114078}{r^2} + 0.85Vd \qquad R^2 = 0.919$$

where r (m) is the radius of curve.
The desired speed was calculated for each route by speed detections on two tangents located near the selected curves. On S.P. 65 the desired speed resulted equal at 69.1 km/h, while on S.P. 306 the obtained value was 90.4 km/h.
The application evidenced that both MOST and Kanellaidis models predicted statistically reliability values of operating speed on curves having radius ranging from 80 m to 170 m, even if these regressions were defined by considering higher values of radius (figure 15).
The model developed in this study, consequently, becomes an integration of MOST and Kanellaidis model in predicting operating speed on curves having radius ranging from 25 to 170 m.

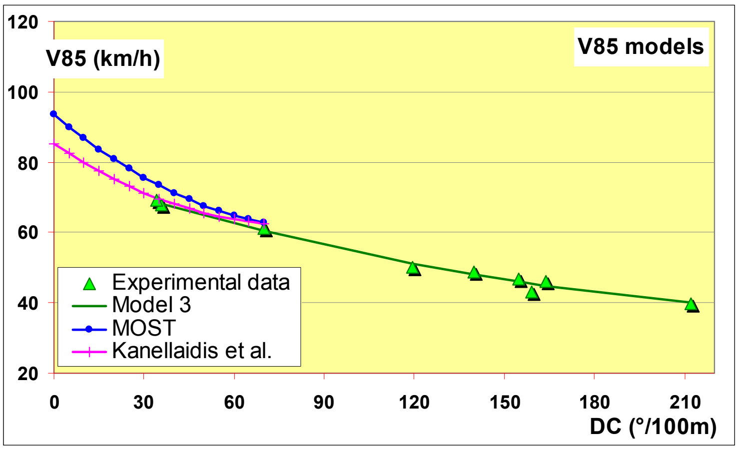

Figure 15: Application of MOST and Kanellaidis models

In conclusion, the I° consistency criterion of Lamm (Lamm et al. 1999) was applied to the nine selected curved sections, in order to evaluate the design consistency by comparing the design speed *Vd* and the operating speed V_{85}. The results are summarized in table 11. All the curves are characterized by good or fair design.

Table 11: Evaluation of consistency, Lamm first criterion (operating speed on single element)

Curve	Road	Radius (m)	I V_{85} - Vp I (km/h)	Evaluation
I	SP 65	27	8.86	Good design
II	SP 65	35	10.77	Fair design
A	SP 306	36	7.42	Good design
III	SP 65	37	10.48	Fair design
IV	SP 65	41	10.72	Fair design
B	SP 306	48	9.03	Good design
C	SP 306	82	9.39	Good design
D	SP 306	160	1.05	Good design
E	SP 306	168	1.10	Good design

It should be observed that (figure 16):
- the operating speed is greater than the design speed of about 28% on curved sections of radius ranging from 27 m to 150 m;
- the design speed resulted greater than the operating speed (about 1.5%) on curved of radius included between 150 m and 178 m.

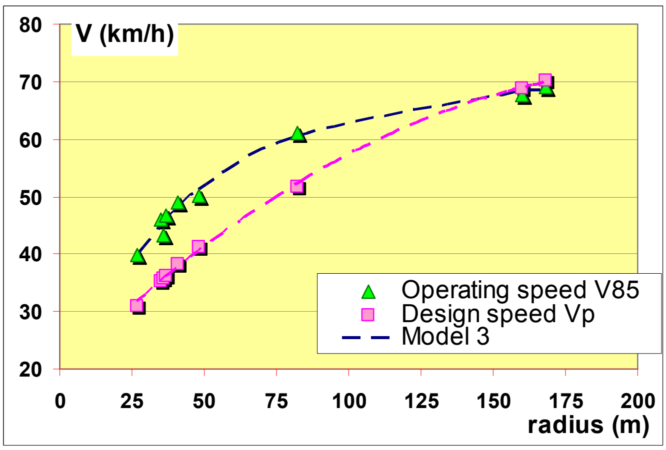

Figure 16: Difference between operating speed and design speed versus *DC*

CONCLUSIONS

Based on the performed research work, the following concluding remarks can be stated:
- the design speed, calculated according to Italian design guides, is smaller than the operating speed in the majority of the detected curved sections;
- the design speed profile, according to Italian design guides, is inadequate to evaluate the design consistency on existing rural roads on grades, consequently a cheap but efficient methodology to draw up the operating speed profile is necessary to estimate alignment homogeneity on this kind of roads;
- the performed operating speed predicting models can be successfully adopted to define the operating speed profile on a route and become necessary for evaluating design consistency on existing roads and for identifying any inconsistencies during the design stage of new roads;
- the degree of curve is confirmed as the most significant parameter affecting the operating speed, not only on horizontal curves, but also on graded curved sections;
- the length of curve, the deflection angle and the longitudinal grade do not seem to be significant in affecting the operating speed;
- the performed model can be successfully adopted to evaluate the geometric design consistency on a single section and on adjacent elements of the alignment according to Lamm criteria (Lamm et al. 1999);
- the developed model constitutes the integration of MOST and Kanellaidis model in predicting operating speed on curves of radius ranging from 25 to 170 m;
- for the future, the revision of the current Italian design guides to account for operating speed should be necessary to achieve safer highway designs and to improve the global safety of the highway network.

REFERENCES

Crisman B., Fugaro L., Marchionna A. and Roberti R. (2003), *Modello di previsione delle velocità praticate dagli utenti attraverso la definizione di una velocità ambientale*, XIII Convegno Nazionale S.I.I.V., Padova, Italy, pp.13.

D.L. 30/04/92 (1992) *Nuovo codice della strada*, Italy.

Easa M. Said (2003), *Distributing superelevation to maximize highway design consistency, Journal of Transportation Engineering*, Vol. 129, No. 2, March, Ed. by ASCE, pp.127-133.

Fitzpatrick Kay, Carlson Paul, Brewer A. Marcus, Woolridge D. Mark, and Miaou Shaw-Pin (2003), *Design speed, operating speed and posted speed practices, NCHRP Report 504, Transportation Research Board*, Washington D.C., pp.103.

Fitzpatrick Kay, Elefteriadou Lily, Harwood W. Douglas, Collins M. Jon, McFadden Jon, Anderson B. Ingrid, Krammes A. Raymond, Irizarry Nelson, Parma D. Kelly, Bauer M. Karin and Passetti Karl (1999), *Speed prediction for two-lane rural highways, FHWA Report RD-99-171*, McLean, VA, pp.217.

Fitzpatrick Kay, Woolridge D. Mark, Tsimhoni Omer, Collins M. Jon, Green Paul, Bauer M. Karin, Parma D. Kelly, Koppa Rodger, Harwood W. Douglas, Anderson Ingrid, Krammes A. Raymond and Brian Poggioli (1999), *Alternative design consistency rating methods for two-lane rural highways, FHWA Report RD-99-172*, McLean, VA, pp.162.

Gibreel G. M., Easa S. M. and El-Dimeery I. A. (2001), *Prediction of operating speed on three-dimensional highway alignments, Journal of Transportation Engineering*, Vol. 127, No. 1, January/February, Ed. by ASCE, pp.21-30.

Gibreel G. M., Easa S. M., Hassan Y. and El-Dimeery I. A. (1999), *State of the art of highway geometry desing consistency, Journal of Transportation Engineering*, Vol. 125, No. 4, July/August, Ed. by ASCE, pp.305-313.

Hassan Y., Easa S. M. (2003), *Effect of vertical alignment on driver perception of horizontal curves, Journal of Transportation Engineering*, Vol. 129, No. 4, July, Ed. by ASCE, pp.399-407.

Hassan Y., Gibreel G. M. and Easa S. M. (2000), *Evaluation of highway consistency and safety: practical application, Journal of Transportation Engineering*, Vol. 126, No. 3, May/June, Ed. by ASCE, pp.193-201.

Hassan Y., Sayed T. and Tabernero V. (2001), *Establishing practical approach for design consistency evaluation, Journal of Transportation Engineering*, Vol. 127, No. 4, July/August, Ed. by ASCE, pp.295-302.

Kanellaidis, G., Golias, J. and Efstathiadis S. (1990), *Driver's speed behaviour on rural roads curves, Traffic Engineering and Control*, London, 31(7/8), pp.414-415.

Lamm R., Beck A., Cafiso S., La Cava G. (2003), *A new procedure for evaluating traffic safety on two-lane rural roads*, XXII World Road Congress, Durban, South Africa, pp.10.

Marchionna A., Crisman B., Roberti R. and Perco P. (2002) *Il comportamento degli utenti attraverso la valutazione delle velocità operative, Strade & Autostrade*, Anno VI - n°2, March/April, pp.145-152.

Ministero delle Infrastrutture e dei Trasporti (2002), *D. M. 5/11/ 2001, Norme funzionali e geometriche per la costruzione delle strade*, G.U. N.5, January, 4th 2002, Italy.

Woolridge D. Mark, Fitzpatrick Kay, Harwood W. Douglas, Potts B. Ingrid, Elefteriadou Lily and Torbic J. Darren (2003), *Geometric design consistency on high speed rural two-lane roadways, NCHRP Report 502, Transportation Research Board*, Washington D.C., pp.92.