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Validation Procedure for Predictive Functions of Driver Behaviour on Two-Lane Rural Roads

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Abstract

The study presented here aims to validate some operating speed prediction models calibrated on two-lane rural roads by using speed data collected in Northern and Southern Italy. Operating speed is defined as the speed at which drivers of passenger cars travel on a dry road in free flow conditions during daylight hours and it is calculated using a specific percentile of speed distribution, typically the 85th. Speed measurements were carried out by using laser detectors in connection with previous environmental and traffic conditions. The study is addressed to emphasize the reliability and easy application of one predictive speed model working both on tangent segments and on circular curves. The calibration phase involved roads in the Northern Italy, while the validation phase involved roads in the Southern Italy. Three models were validated applying them on eight two-lane rural roads falling within the road network of the Province of Salerno with features that reflect those adopted in the calibration phase; the selected models to be validated present the simplest analytical structure for type and number of explanatory variables and for the performance diagram shape of the operating speed values. The validation procedure was to estimate some synthetic statistical parameters as mean absolute deviation, mean squared error and coefficient of variation. The results allow in a simple way to trace continuous operating speed profiles on two-lane rural roads and to carry out safety analyses on the horizontal alignment.

Keywords: driver speed behavior, different land contexts, results validation.

1. Introduction and Literature Review

Many researchers have dealt with driver speed behavior and traffic safety conditions on two-lane rural roads for identifying factors that can affect the driver performance and the hazard relationships between vehicles, users and environment (Ratkevičiūtė *et al.*, 2007).

Porter *et al.* (2012) investigated the interaction of geometric design, speed and safety. Five related questions were addressed: (a) What is known about the relationships between road geometry and operating speeds? (b) To what degree does road geometry influence operating speeds? (c) How are safety and security influenced by road geometry? (d) What are the potential impacts on large vehicles? and (e) What is the nature of the speed–safety trade-off? The authors underlined that the operating speeds are shown to be higher than design speeds for design speeds of approximately 55 mph or less. This outcome may be considered undesirable, but that categorization seems to be based more on subjective judgments of what is desirable than on actual safety findings.

Highway Safety Manual *HSM* (2010) published by AASHTO gives Safety Performance Functions (SPFs) to estimate the number of crashes over a specific roadway over a specific time period, and safety countermeasures for the highways. HSM provides predictive models for rural two-lane highways, giving estimates for total crashes. Because SPF equations in the HSM were developed on the basis of data from a subset of states, HSM recommends that local agencies either (a) develop SPFs for their local conditions or (b) use a calibration procedure to adjust the HSM SPFs to reflect local conditions.

Dell'Acqua and Russo (2011 a) presented two injurious crash prediction models for two-lane rural roads in low-volume conditions located in the Southern Italy: one for roadways located on flat/rolling area with a vertical grade of less than 6% and the other for roadways in the mountainous area with a vertical grade of more than 6%. This study was a "network" approach for identifying the "black" roadway segments before road adjustments are planned and economic resources are allocated.

Rifaat and Chin (2007) analyzed some factors that can affect crash severity by using an ordered probit model as driver and crash characteristics, roadway features, vehicle types. Three types of crashes were investigated: two-vehicle crashes, single vehicle crashes and pedestrian accidents. Crash data in Singapore from 1992 to 2001 were used to illustrate the process of parameter estimation. It was found that injury severity decreases over time for the three types of accident investigated.

Noland and Karlaftis (2005) focused on the interpretation of key policy variables, especially the association between safety-belt laws and administrative license revocation laws on fatalities. From a policy perspective, the authors found no evidence that passage of administrative license revocation laws that automatically suspend the license of a drunk driver have been effective while laws requiring safety-belt usage have been effective.

However, the speed is considered in the literature the parameter most representative of the driver performance.

Designing highways to influence driver operating speed effectively through environmental feedback is a key research field requiring special attention. Virtual reality video simulations were used to record the influence of environmental elements on driver judgments about the appropriate driving speed. Stamatiadis *et al.* (2010) analyzed through the fuzzy set nonlinear modeling system of Casewise Visual Evaluation methodology design factors that most strongly influenced perceived operator discomfort. The findings indicated that vegetation type and density and barrier type have a significant effect on driver discomfort and thus have the potential to influence operating speeds. Roadway width has a similar effect where narrower roadways increase driver discomfort.

Usually, 85th percentile of the speed distribution when the drivers travel on a dry road in free flow conditions during daylight hours is used to study the driver speed behavior on two-lane rural roads.

Singh *et al.* (2012) developed neural network models to predict 85th percentile speed for two-lane rural highways in Oklahoma. Several input parameters, namely, physical characteristics of road, traffic parameters (average daily traffic *ADT* and posted speed), pavement condition indices (skid number and international roughness index *IRI*), and accident data, were considered in developing the neural network models. The physical characteristics of road included surface width, shoulder type and width. The study of the model showed that 85th percentile speed decreased with an increase in the accident rate, ADT, skid number, and IRI. Similarly, widening of the surface and shoulder resulted in a higher 85th percentile speed.

Dell'Acqua (2012) proposed a model to predict the *speed environment* that is defined as the speed at which users travel in free-flow conditions when they are not constrained by the alignment of the highway and it's represented by the maximum 85th percentile value of the speeds on long tangent segments or on large curve radius belonging to a homogeneous road section. The model only includes the curvature change rate, in gon/km, as independent variable.

Agusdinata *et al.* (2009) analyzed the impact of the speed limiters or Intelligent Speed Adaptation (ISA) in-vehicle on the road safety. The authors underlined that ISA implementation was hindered by large uncertainties, for example about the impacts of ISA, the way users might respond to ISA, and the relationship between speed and accidents. They presented a Multi-Criteria Analysis approach based on exploratory modeling, which used computational experiments to explore the multiple outcomes of ISA policies (safety, emissions, throughput, and cost) across a range of future demand scenarios, functional relationships for performance criteria, and user responses to ISA.

Later, Albalate and Bel (2012) conducted the first econometric analysis of the determinants of speed limit laws by using mobility, geographic and political variables. The results suggested that geography – which reflects private mobility needs and social preferences – was one of the main factors influencing speed limit laws together with political ideology. Furthermore, they have also identified the presence of regional and time diffusion effects.

The paper presented here shows a validation procedure of three operating speed prediction models on two-lane rural roads acquired in a previous research-work (Esposito *et al.,* 2011). Eight two-lane rural roads in Southern Italy were selected to validate previous equations easier to use than remaining laborious models.

2. Data Collection

The analysis presented here was dived into two steps for studying driver speed behavior on two-lane rural roads: the calibration procedure by using ten roads located in Northern Italy phase and the validation procedure involving only three calibrated models easy to be applied and reliable for statistical coefficients of the explanatory variables that were applied on eight two-lane rural roads located in Southern Italy (cfr. Fig.1) which features reflect those adopted in the calibration phase.

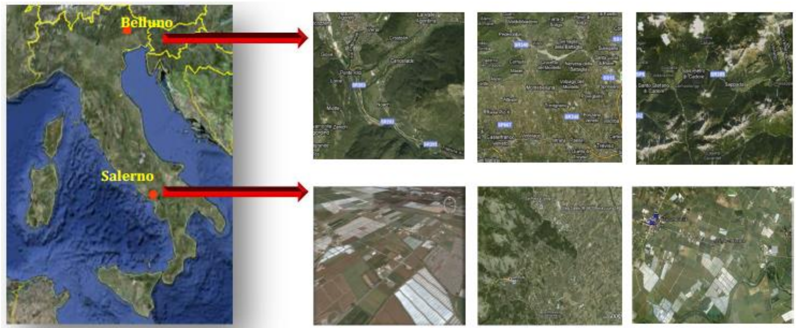

Fig. 1: Roads location

All analyzed roads are without spiral transition curves between geometric tangents and circular elements on the horizontal alignment and no sections falling in the identified transition segments at each circular curve were used for the calibration procedure (Dell'Acqua and Russo, 2011 b).

In Southern Italy, 80 tangent segments were investigated for a total number of 144 speed measurements and 40 circular elements for a total number of 179 speed measurements. Speed data collection was carried out by using a light detection and ranging KV laser. The device emits and receives a pair of laser beams perpendicular to the road's axis not dangerous to the drivers. The vehicle speed is measured by determination of the time of vehicle passage from the first photocell to the second one. The tool was installed on a tripod beside the roadway and it was hidden from the view of drivers. In Northern Italy, 93 tangent segments were examined for a total number of 174 spots to carry out speed measurement for both travel directions, and 124 circular curves for a total number of 125 spots. The tool is placed on the roads edge at selected locations at 45° to travel direction or at 225° to the opposite travel direction. The devices record the time (date, hour, minutes and seconds), instantaneous vehicle speed (in km/h), vehicle length (in meters) and travel direction by binary variables ("direction 0" and "direction 1") for each passing vehicle. Motorcycles and trucks were eliminated from the database to assess at each road section the 85^{th} percentile of speed distribution; to respecft free flow speed, vehicles crossing the beam less than 5 seconds after the preceding one were eliminated from the database and only speed measurements with dry roads and daylight hours were accepted (Figueroa and Tarko, 2004; Fitzpatrick *et al.*, 2003; Nie and Hassan, 2007). Speed data collection on the roads in Northern Italy is largely described in a previous research-work (see Esposito *et al.*, 2011) as well as for investigated roads located in Southern Italy (see Dell'Acqua and Russo, 2011 b). In conclusion, 348 operating speed values on tangent elements and 250 V_{85} values on circular curves were obtained in Northern Italy to be used for the calibration of the operating speed prediction models; 144 V_{85} values on tangent elements and 179 V_{85} values on circular curves were acquired in Southern Italy to be used for the validation of the previous calibrated models. Road features observed on the investigated roads are synthetically shown in Table 1.

Table 1. Features observed on the Investigated Road Segments

tangent and circular curve length, meters	lane width, meters	vertical grade, percentage
horizontal curve radius, meters	shoulder width, meters	cross-slope, percentage
curvature change rate of homogeneous roadway segment (CCR_m), gon/km	curvature change rate of a single curve (CCR_s), gon/km	presence of road signs

CCR_m = sum of the absolute values of angular changes in the horizontal alignment divided by the total length of the road segment (German Standard, 1995); CCR_s = sum of the absolute values of angular changes in the horizontal circular element divided by the total length of the circular element.

Features of tangents and circular curves used during the calibration and validation phases are in Tables 2 and 3, respectively.

Table 2. Statistics of Mean Features on Tangent and Circular Curve Elements for the Calibration Procedure

Tangent element	Tangent Length [m]	CCR_m [gon/km]	V_{85} [km/h]	V_m [km/h]	Lane width [m]	Cross-Slope [%]	Vertical Grade [%]
Mean value	359.23	185.78	86.54	72.64	3.43	0.70	1.66
Min value	32.20	33.18	35.00	29.00	1.00	0.10	0.20
Max value	1279.30	662.66	117.00	100.00	4.30	2.10	5.90
Std. Dev.	263.38	170.04	16.65	14.43	0.35	0.44	1.54

Circular element	Curve Length [m]	Curve radius [m]	CCR_s [gon/m]	CCR_m [gon/km]	V_{85} [km/h]	V_m [km/h]	Cross-Slope [%]	Vertical Grade [%]	Lane width[m]
Mean value	130.61	436.41	0.37	213.07	76.33	64.86	1.73	1.65	3.46
Min value	26.74	15.00	0.01	33.18	19.00	16.00	0.30	0.20	2.60
Max value	945.67	5000.00	4.24	662.66	113.00	95.00	4.20	6.00	6.00
Std. Dev.	113.82	575.53	0.50	176.84	20.00	16.99	1.03	1.49	0.38

Table 3. Statistics of Mean Features on Tangent and Circular Curve Elements for the Validation Procedure

Tangent element	Tangent length [m]	CCRm [gon/km]	V_{85} [km/h]	V_m [km/h]	Lane Width [m]	Cross-Slope [%]	Vertical Grade [%]
Mean value	1500.10	179.89	80.55	28.59	7.37	0.40	0,90
Min value	77.19	58.83	55.03	20.15	5.12	0.05	0.10
Max value	2895.50	503.17	102.00	39.22	11.63	0.10	6.00
Std.Dev.	824.60	30.05	7.71	4.05	0.67	0.34	1.50

Circular curve element	Curve length [m]	Curve radius [m]	CCRs [gon/km]	CCRm [gon/km]	V_{85} [km/h]	V_m [km/h]	Cross-Slope [%]	Vertical Grade [%]	Lane Width [m]
Mean value	71.76	85.00	509.78	179.89	64.67	23.50	0.40	0,90	6.69
Min value	30.95	12.50	171.55	58.83	19.72	12.50	0.05	0.10	2.97
Max value	242.84	225.00	1970.03	503.17	93.50	36.00	0.10	6.00	11.68
Std.Dev.	24.14	53.00	30	170		6.00	0.34	1.50	3.52

3. Data Analysis

3.1. Speed Prediction Models on Tangents and Circular Curves

Analyzing the standard deviation (σ_c) and mean (μ_c) of the 250 V_{85} values on the circular curves, using the "3σ" method, some operating speed values were rejected. The final sample used to calibrate operating speed prediction models on circular curves is composed of 236 V_{85} values. It was noted how all the values fall within the range [μ – 3 σ; μ + 2 σ] = [15.94 km/h; 116.22 km/h]. Then, analyzing the standard deviation (σ_t) and mean (μ_t) of 348 V_{85} values on the tangent elements, some operating speed values were rejected. The final sample used to calibrate operating speed prediction models on tangents elements consisted of 327 V_{85} values falling within the range [μ – 3 σ; μ + 2 σ] = [36.40 km/h; 120.60 km/h]. Finally analyzing the standard deviation (σ_t) and mean (μ_t) of 188 V_{85} values at only middle sections of the tangents, some values were rejected and the final database is composed of 169 V_{85} values falling within the range [μ – 3 σ; μ + 2 σ] = [35.44 km/h; 119.53 km/h].

The Gauss-Newton method based on the Taylor series was used to assess the statistical significance for the estimated coefficients of the explanatory variables. All parameters of the models were significant with a 95% significance level as confirmed by the results of t-test performed for each coefficient. The best specifications of the *ordinary-last-square models* (OLS) of V_{85} [km/h] were illustrated in Tab.4 as follows:

- two operating speed prediction models on circular elements (see Eqs 1 and 2)
- one operating speed prediction model on tangent segments (see Eq.3)
- two operating speed prediction models valid both on tangents and on circular elements developed by using only speed measurements at middle sections of the road segments

(Eqs 4 and 5).

Table 4. V_{85} Prediction Models for Circular Curves and Tangent Elements

V_{85} prediction model on circular curves, in km/h	**Number of V_{85} values**	ρ^2 **[%]**
Eq(1) $V_{85} = 127.72 - 7.13 \cdot 10^{-2} \cdot CCR_m - 15.83 \cdot CCR_s^{0.15} - 6.31 \cdot Log(S)$	236	65
Eq(2) $V_{85} = 74.78 - 5.80 \cdot 10^{-2} \cdot CCR_m - 1.09 \cdot 10^{-3} \cdot CCR_s + 4.73 \cdot 10^{-6} \cdot CCR_s^2 + 4.34 \cdot W_{SL} - 15.26 \cdot W_{SH}^2 + 23.61 \cdot W_{SH} - 1673.34 \cdot (1/R)$	236	71
V_{85} prediction model on tangent elements, in km/h	**Number of V_{85} values**	ρ^2 **[%]**
Eq(3) $V_{85} = 106.62 - 5.64 \cdot 10^{-2} \cdot CCR_m - 9 \cdot Log(CCR_{s\_PC}) + 4.45 \cdot W_{SL} - 9.75 \cdot 10^{-11} \cdot D_{PC}^2 - 7.47 \cdot S + 1.98 \cdot S^2$	327	60
V_{85} prediction model valid both on tangents and circular elements, in km/h	**Number of V_{85} values**	ρ^2 **[%]**
Eq(4) $V_{85} = 78.84 - 6.32 \cdot 10^{-2} \cdot CCR_m + 2.08 \cdot W - 1254.49 \cdot (1/R) + 7.16 \cdot 10^{-6} \cdot L^2$	405	65
Eq(5) $V_{85} = 80.33 - 5.65 \cdot 10^{-2} \cdot CCR_m + 1.99 \cdot W - 1222.73 \cdot (1/R) - 2.93 \cdot 10^{-1} \cdot VG$	405	65

Symbols for the Equations 1÷5: L = length of single geometric element [m], W = roadway width [m], W_{SL} = width of lane [m], W_{SH} = width of single shoulder [m], D_{PC} = distance of the surveyed section from the end section of the previous curve, R = radius of the horizontal curve [m], CCR_m = curvature change rate of a homogeneous roadway segment [gon/km], CCRs = curvature change rate of a single curve [gon/m], $CCRs\_{PC}$ = curvature change rate of the previous curve [gon/m], S = cross-slope of the road segment at the surveyed location [%],VG = vertical grade of the road segment at the surveyed location [%].

Equations 1 and 2 show a negative correlation between the predicted V_{85} and a set of explanatory variables as the mean value of the curvature change rate for single curves (CCR_S) and for homogeneous roadway segments (CCR_m), the road cross-slope (S) and the curvature (1/R). In particular, the sign of the estimated coefficients in Equ. 2 attests how an increase in the shoulder width causes a reduction in the lane width, inevitably, and a reduction in speed, with a known cross-road configuration according to Standards. It is not possible to consider working on an explanatory variable to predict V_{85} without also considering how this variation might affect the influence of the remaining explanatory associated variables on speed phenomena and, consequently, on the predictive model.

Equation 3 shows a negative correlation between V_{85} and two explanatory variables as CCR_m and the road cross-slope; however, when the distance of the surveyed section on the tangent from the end section of the previous curve and the lane width increase, it can observe an increase of the predicted operating speed.

Equations 4 and 5 show two predictive speed models valid both on tangents and on circular curves by using the curvature variable (1/R equal to zero on tangent segments and no equal to zero on the circular curves). It can be observed a negative correlation between predicted V_{85} and three explanatory variables as CCR_m, the curvature and the vertical grade; however, when the length and roadway width of the element increase, it can observe an increase of the predicted operating speed.

3.2. Speed Prediction Models on Tangents and Circular Curves by a Division into Classes of the Database

The coefficient of determination of the previous models in Table 4 was improved by splitting in classes the operating speed measurements' database on circular curves and tangent elements. This procedure helps to decrease the standard deviation of the speeds distribution because it will refer only to the mean value of each explanatory variables.

Thus, *three operating speed models on circular elements* were developed (see Eqs. 6, 7, 8 in Tab.5). The best specifications of *ordinary-last-square models* (OLS) of V_{85} [km/h] were worked out from a set of 236 values of V_{85} producing 23 classes; according to statistical values in Table 2 and by varying the curve radius with a gap of 50m, the classes were constructed and a mean value of all explanatory variables was calculated for each class.

Thus for Equations 6, 7 and 8, the curvature change rate of single curves and of homogeneous roadway segments is negatively correlated with the predicted operating speed; in fact, an horizontal alignment with high tortuosity can cause greater reduction in speed than harmonious geometric paths. It can be noted that the weight of CCR_m is greater than CCR_s. Eq.8 illustrates an additional negative correlation compared to previous cases between predicted V_{85} and the presence of vertical sign near to the selected road section. It can be also noted that when the lane width and the length increase the operating speed can increase by different percentages since the coefficient's weight for the lane width is greater than the length's coefficient.

Two operating speed models on tangent elements were developed by OLS method with 327 determinations of V_{85} values calculated by using speed measurements at middle sections, at first and third quarter of tangent segments (see Eqs. 9 and 10 in Tab. 5) creating 18 classes; according to statistical values in Table 2 and by varying the tangent length with a gap of 50m, the classes were constructed and a mean value of all explanatory variables was calculated for each class. Therefore for Equations 9 and 10, the curvature change rate of homogeneous roadway segments and of the previous curve is negatively correlated with the predicted operating speed; it can be noted that the coefficient's weight for CCR_m variable is greater than CCR_{S_PC} variable. Eq.9 also shows a positive correlation with the tangent length. Equ.10 presents two additional negative correlations (V_{85} with vertical grade and cross-slope) compared to previous cases and just one positive correlation between V_{85} and the lane width.

Table 5. V_{85} Prediction Models by a partition in classes of database

V_{85} prediction model on circular curves, in km/h	Number of V_{85} values	Number of Classes	ρ^2 [%]
Eq(6) $V_{85} = 96.72 - 5.90 \cdot 10^{-2} \cdot CCR_m - 1.71 \cdot 10^{-2} \cdot CCR_s$	236	23	80
Eq(7) $V_{85} = 97.33 - 6.22 \cdot 10^{-2} \cdot CCR_m - 3.02 \cdot 10^{-2} \cdot CCR_s + 7.90 \cdot 10^{-6} \cdot CCR_s^2 + 2.17 \cdot 10^{-3} \cdot R$	236	23	85
Eq(8) $V_{85} = 66.85 - 2.09 \cdot 10^{-2} \cdot CCR_m - 3.19 \cdot 10^{-2} \cdot CCR_s + 8.10 \cdot 10^{-6} \cdot CCR_s^2 - 11 \cdot P_s + 5.91 \cdot 10^{-1} \cdot W_{SL}^3 + 4.61 \cdot 10^{-2} \cdot L_c - 9.43 \cdot 10^{-5} \cdot L_C^2$	236	23	91
V_{85} prediction model on tangent elements, in km/h	**Number of V_{85} values**	**Number of Classes**	**ρ^2 [%]**
Eq(9) $V_{85} = 103.22 - 8.08 \cdot 10^{-2} \cdot CCR_m - 1.10 \cdot 10^{-5} \cdot CCR_{S\_PC}^2 + 1.72 \cdot 10^{-4} \cdot L_T$	327	18	70
Eq(10) $V_{85} = 61.97 - 6.05 \cdot 10^{-2} \cdot CCR_m - 1.36 \cdot 10^{-5} \cdot CCR_{S\_PC}^2 - 15.31 \cdot VG - 9 \cdot S + 13.16 \cdot W_{SL}$	327	18	82

Symbols for the Equations 6÷10: L_T and L_c = length of single geometric element [m], W_{SL} = width of lane [m], R = radius of the horizontal curve [m], CCR_m = curvature change rate of a homogeneous roadway segment [gon/km], CCRs = curvature change rate of a single curve [gon/m], $CCRs\_{PC}$ = curvature change rate of the previous curve [gon/m], S = cross-slope of the road segment at the surveyed location [%],VG = vertical grade of the road segment at the surveyed location [%], P_S = vertical sign indicator equal to 1 if the sign exists near the selected section, 0 otherwise

4. Validation Procedure and Results

Three of the previous ten V_{85} prediction models were then tested; in particular, Equ.4 (V_{85} prediction model valid both on tangent segments and on circular curves), Equ.7 (V_{85} prediction model on circular curves) and Equ.9 (V_{85} prediction model on tangent segments) were selected for the validation by applying them on 8 two-lane rural roads in Southern Italy with features that reflect those adopted in the calibration phase (see Tab.3).

The selected models to be validated, as shown below, have the simplest structure for type and number of explanatory variables and for the shape of the performance diagram. The validation procedure was to estimate some synthetic statistical parameters as follows:

-MAD (Mean Absolute Deviation) = value equal to the sum of the absolute differences between observed and predicted operating speed values (D_i) divided by the number (n) of study sites:

$$MAD = \sum_{i=1}^{n} |D_i| \Big/ n \qquad (11)$$

-MSE (Mean Squared Error) as follows in Equation 2:

$$MSE = \sum_{i=1}^{n} D_i^2 \Big/ n$$

(12)

-I as follows in Equation 3:

$$I = \sqrt{MSE} \Big/ \left(\sum_{i=1}^{n} V_{predicted\,operating\,speed} \Big/ n \right)$$

(13)

Table 6 shows the values returned by the analysis of summarizing statistical parameters with I value less of 0.2 for all operating speed prediction models.

Table 6. Parameters returned by validation procedure

Prediction Model	Mean Error (μ)	MAD	MSE
Equ.4 (V_{85} prediction model valid both on tangents and on circular curves)	13.35	15.00	370
Equ. 7 (V_{85} prediction model on circular curves)	6.06	14.45	295
Equ. 9 (V_{85} prediction model on tangents)	11.59	14.81	310

Table 7 shows the range of residuals (difference between observed and predicted operating speed values) where μ is the mean value and σ is the standard deviation of residuals distribution: it was noted how more than half of the residuals sample is less than 15 km/h.

Table 7. Range of residuals for prediction models

Prediction Model	Residuals Range	
Equ.4 (V_{85} prediction model valid both on tangents and on circular curves)	$[\mu - 2\sigma ; \mu + 2\sigma]$	[- 14.83 km/h; 41.40 km/h]
Equ. 7 (V_{85} prediction model on circular curves)	$[\mu - 2\sigma ; \mu + 2\sigma]$	[- 26.31 km/h; 38.42 km/h]
Equ. 9 (V_{85} prediction model on tangents)	$[\mu - 2\sigma ; \mu + \sigma]$	[- 39.79 km/h; 37.28 km/h]

It can be concluded that all speed prediction models are reliable in the prediction of the real operating speed maintained by drivers on two-lane rural roads, as well as shown by the restricted distribution of residuals around the mean. This was also confirmed by the low value of the statistics indicators.

Figure 2 shows an example of a continuous operating speed profiles traced by using operating speed prediction models presented in this paper according to the increase of kilometers. In particular, different V_{85} profiles have been traced according to acquired results. It can be seen on the x-axis the distances, in meters, and on the y-axis the values of the observed V_{85}, in km/h and predicted V_{85}, in km/h, by using Equ.4 both on tangents and on circular curves, Equ.7 on circular curves and Equ.8 on tangent segments.

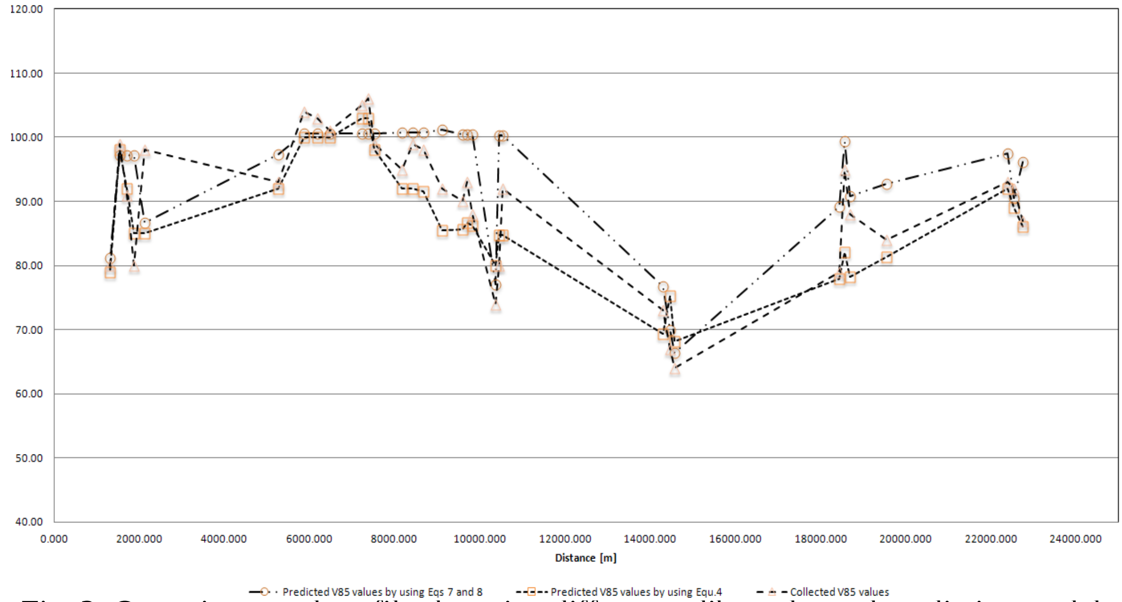

Fig. 2: Operating speed profiles by using different calibrated speed predictive models

The analysis of ρ^2 values (see Tabs 4 and 5) and the statistics in Tab. 6 show how the equations appreciably fit the empirical data. Equ.7 predicts on circular curves V_{85} values more reliable than Equ.4, while Eqs 4 and 9 are nearly equivalent in terms of ρ^2 values, MAD, MSE and I values (see Tab. 6).

The selected models are simple to be applied; in fact, the explanatory variables vary from three in the Equs.7 and 9 to four in Equ.4. Nevertheless, the application of Equ.4 for predicting V_{85} values on tangents and on circular curves is less laborious if compared with Equ.7 and 9; however, it needs for this model an improvement of the explanatory variables for increasing ρ^2 and for decreasing MAD, MSE and I statistics.

In conclusion, V_{85} profiles can be used to develop safety analyses of existing two-lane rural roads and countermeasures can be found for reducing large reductions in speed between following elements where acceptable or poor crash rates can be observed (De Luca and Dell'Acqua, 2012). Stamatiadis and Hartman (2011) highlighted that practical solutions should not be confused with or viewed as value engineering, which is typically applied as a cost-cutting approach to a project that has been designed with the aim of reducing the cost of the accepted design and its various features. Practical-solutions concept is a system-sensitive approach in which reasonable project solutions are sought so as to address more problem areas of the system within constrained financial resources.

5. CONCLUSIONS

The study described here is a revision that updates previous research work to illustrate the use of new, different variables to better analyze the performance of drivers on some Italian two-lane rural roads located in two different land contexts. Speed data collection was carried in connection with particular environmental and traffic conditions:

dry roads, free flow conditions, and daylight hours. Speed measurements were conducted by using laser detectors.

Ten operating speed prediction models were calibrated for studying driver speed beahvoiur on tangents and on circular curves by involving roads in Northern Italy. Successively, three of the previous V_{85} prediction models were selected to be validated and eight two-lane rural roads in Southern Italy were used which features that reflect those adopted in the calibration phase. The models' choice to be tested depended on the target to identify easy and not laborious final equations which can be suggested for practical applications. The reliability of the tested regression equations has been confirmed by the range of residuals (difference between observed and predicted operating speed values) and by some synthetic statistical parameters. The results confirmed that only one equation can be used to predict the operating speed both on tangents and on circular curves avoiding two different models since it was found to be reliable fitting the empirical data, statistical significant and simple and no laborious to be applied for type and number of explanatory variables.

In conclusion, V_{85} profiles can be used to develop safety analyses of existing two-lane rural roads and to suggest countermeasures that can help to improve horizontal alignment consistency and driver speed behavior. Future development of research will address to the alignment consistency analyses by investigating the relationships between operating speeds and crashes for type and severities.

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