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Speed prediction models for sustainable road safety management

Tommaso Esposito[a], Raffaele Mauro[b], Francesca Russo[a,*] and Gianluca Dell'Acqua[a]

[a]University of Napoli "Federico II", Via Claudio 21; 80125 Napoli, Italy.
[b]University of Trento, Via Mesiano 77; 38123 Trento, Italy.

Abstract

This paper illustrates an experimental analysis conducted in 2010 on statistically significant number of roadway sections belonging to two - lane rural roads in Northern Italy. The aim of this research is to develop operating speed prediction models on tangents and circular curves to perform roadway alignment consistency analysis for travel safety in context with current operating speeds. Acquired relationships were particularly interesting and different explanatory variables were introduced in the predictive models which are dependent on examined geometric roads features. These relationships constitute a new set of models about the operating speeds to design and verify roads geometric alignments adding to those already available in the scientific literature and, then, to plot speed profiles to illustrate complete driver speed behaviour on two-lane rural roads individualizing critical roadway sections where the speed differences, between road geometric components, are inappropriate.

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Keywords: driver behaviour, operating speed, prediction models, road safety, geometric design

1. Introduction

The term sustainable transport came into use as a logical follow-on from sustainable development, and is used to describe modes of transport, which are consistent with wider concerns of sustainability. To a great extent it seems today that the proposed research agendas view environmental protection and energy efficiency in the transportation domain as a separate issue from road safety. This however is not true. Traffic accidents constitute one of the major menaces to the environment, maybe bigger than the collective sum of use of oil for transportation (ECTRI, 2009). Accidents cause serious bottlenecks and disruption to the transportation network. And, vice versa, the introduction of new types of fuels and vehicles may cause significant impact on traffic safety. For example, electric or hybrid vehicles that run silently up to a certain speed may endanger pedestrian that didn't "hear them coming" or provide false concept of speed to novice drivers. On the other hand, eco-driving, due to low speeds and conservative nature, is also improving the proactive safety of the driver, so it is obvious that the connection between safety and environmental awareness is a working combination that will improve the twofold of accident reduction and CO_2 reduction immensely. Thus, road safety and environmental protection are the two sides of the same coin and can't be viewed in isolation (ECTRI, 2009). Road safety management may be improved if quantitative assessment of safety

* Corresponding author. Tel.: +39 081 7683372; fax: +39 081 7683946
E-mail address: francesca.russo2@unina.it.

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levels is carried out, in a similar way to what presently is done as regards the costs of interventions or the estimation of their future impact on mobility or on land use (Dell'Acqua *et al.,* 2010). In practice these safety assessments are required for the full application of the recently approved Directive 2008/96/EC on the safety management of road infrastructures. Research on infrastructure should aim towards "self-explanatory" road environments for the "average" vehicle drivers. More specifically, driver behaviour have been significantly under-researched to identify all the possible factors that may affect safety conditions during travel. These factors can be directly linked to personal choices, vehicle conditions, the infrastructure and its environmental features (Török, 2011). In the scientific literature there are many formulations of operating speed models on tangents and curves for two - lane rural roads and there are also several analyses of driver speed behavior entering and departing circular elements to measure deceleration and acceleration rates. Operating speed is defined as the speed at which drivers travel on a dry road in free flow conditions during daylight hours and is calculated using a specific percentile of speed distribution, typically the 85th, $V_{85.}$ V_{85} speed prediction models are useful both in the geometric and functional design and in the control of highways (see e.g. Misaghi and Hassan, 2005; Gibreel *et al.,* 2001). The number of operating speed prediction models on tangents set out in the literature generally is lower than on circular elements because driver speed behavior is more complex to analyze. In fact the users have more freedom driving on tangents segments than on circular elements, and therefore the variables that can correctly explain the phenomenon are outnumber.

Polus *et al.* developed, for example, a model to predict operating speeds on tangent segments. The sites were divided into four groups based on the 28 tangent length and the preceding and following radius of the horizontal curves. The model has introduced one independent variable that is the average radius of horizontal curves preceding and following the tangent. The regression equation was suggested for segments having curve radius smaller than 820 ft (270.6 m) and tangent length of less than 500 ft (165 m).

Later, Fitzpatrick *et al.* (2003) collected speed and geometric data in 78 sites and speed models for five different highway classes were developed. Except for the posted speed limit and the access density, no other roadway characteristic had a relationship with the operating speeds. Several experimental analyses also exist in the literature relating to driver behavior on the circular curve (e.g. Louah *et al.,* 2009) and on entering and departing circular curve. In the last case some researchers have analyzed the deceleration and acceleration motion on the transition zones appraised as regions where drivers change speed, and their extension can vary from curve to curve as will dearly be shown later. Some studies have shown for example how acceleration and deceleration actions occurred only on tangent segments and a constant speed was, subsequently, maintained by drivers on circular elements (Fitzpatrick and Collins, 2000; Ottesen and Krammes, 2000).

A complete speed – profile was studied for example by Figueroa and Tarko (2004). Using an iterative process they obtained a deceleration transition length divided as 65.5% on the approach tangent to the horizontal curve and 34.5% on the circular element, and an acceleration transition length divided as 71.6% on the departure tangent from the horizontal curve and 28.4% on the circular element. They subsequently calibrated predictive speed models on tangents and curves which are not restricted to a specific percentile, but for all percentile speeds from the 5th to the 95th in increments of five.

The aim of the research presented in this paper is the study of driver speed behaviour on two lane-rural roads by using the operating speed profiles that reflect really drivers' performance.

Since 2003 the Department of Transportation Engineering at the University of Naples and the Department of Mechanical and Structural Engineering at the University of Trento carry out a large and extensive research program based on the collection and treatment of speed data on two-lane rural highways to acquire V_{85} models. This research program has already analyzed roadways falling within the network of the Province of Salerno in Southern Italy (Dell'Acqua and Russo, 2010) and it continues at present on roadways located in Northern Italy in the Province of Belluno (Mauro and Russo, 2010). This paper concerns the first results obtained for the V_{85} models on roads located in the Province of Belluno. Thus we have achieved ten V_{85} formulas as function of several geometric variables: 6 regression equations for circular curves, 3 regression equations for tangent elements and 1 single regression equations available both for tangent and circular elements on the horizontal alignment. The last regression equation is, according to the authors of this paper, the powerful advance among the achieved operating speed prediction models here presented because it allows no complex application for the technicians due to the explanatory variables' type introduced in the model and an evaluation of driver speed behaviour both on circular curves and tangents without applying two different equations to predict the operating speeds on geometric elements.

All speed prediction models here presented are statistically significant because the residuals, between predicted and observed operating speed values, assume limited values as also confirmed by the statistical indicators. The aim of the illustration of several speed prediction models to study the driver behaviour on two-lane rural roads is to suggest different solutions that appear all statistically acceptable, but more or less complicated depending on the type and number of explanatory variables to be measured. These models are described in detail below after Data Collection review.

2. Data Collection

The analyzed two-lane rural highways, managed by "Veneto Strade" - Operative Management of Belluno, are: SP1, SP1bis, SP2, SP423, SR203, SR348, SP641, SR48, SR355 and SP251. The roads alignment analyzed in this paper are without spiral transition curves between geometric tangent and circular elements on the horizontal alignment. Table 1 in brief illustrates the general features concerning 93 tangent segments and 124 circular elements of the analyzed highways. It can be observed that on 93 analyzed tangent segments, a total number of 174 (91 + 83) locations where used to carry out speed measurements for both travel directions, while on 124 analyzed circular curves, a total number of 125 (64 + 61) locations were used to carry out speed measurement for both travel directions. The measurements were conducted by using a Radar; this device is based on the microwave emission and reception characterized by very short and high frequency electromagnetic radiations. The tool is placed on the roads edge of the selected location at 45° with respect to the travelling direction or at 225° with respect to the opposite travel direction. This device is largely described in the research - report by Mauro and Russo (2010).

Table 1 Location of survey stations

Two-lane rural highways	Total number of surveyed sections		Length [km]	Two-lane rural highways	Total number of surveyed sections		Length [km]
	located on tangent	located on curve			located on tangent	located on curve	
S.P. 1	32		22.912	S.R. 203	63		65.172
	22	10			37	26	
S.P. 1bis	50		15.435	S.R. 348	30		18.573
	27	23			16	14	
S.P. 2	21		19.419	S.R. 48	24		42.905
	14	7			14	10	
S.P. 423	12		4.945	S.R. 355	27		17.477
	7	5			16	11	
S.P. 641	9		5.957				
	4	5					
S.P. 251	31		49.135				
	17	14					
Tot.	155		117.803	Tot.	144		144.127
	91	64			83	61	

The tool was employed to investigate all selected locations, as will be further explained later, for a complete working day. The device records the time (date, hour, minutes and seconds), instantaneous vehicle speed (in km/h), vehicle length (in meters) and travelling direction expressed in binary variables ("direction 0" and "direction 1") for each passing vehicle. Motorcycles and also trucks were eliminated from the database to estimate at each section the 85th percentile of speed distribution according to some procedures in the scientific literature. In any case 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 to respect free flow conditions.

The geometric parameters observed for each roadway-section are: width shoulder and lane, radius of the horizontal curve, CCR_m of homogeneous segment, CCR_s of single circular curve, tangent and curve length, cross-slope and vertical grade of the observed roadway segment, presence of pavement distress and road signs. In order to single out the road sections with homogenous horizontal alignment characteristics to associate with a single value of environmental speed, we referred to indications of the German standard (1995). We remember that the curvature change rate of an homogeneous highway-segment (CCR_m in gon/km) is defined as the sum of the absolute values of angular changes in the horizontal alignment divided by the total length of the road segment. An homogeneous roadway segment is characterized by an almost constant slope. The curvature change rate of a single curve (CCR_s in gon/km) is defined as the sum of the absolute values of angular changes in the horizontal circular element divided by the total length of the circular element. Table 2 shows CCR_m value at each homogeneous roadway segments. Table 3 shows the descriptive statistics of the mean features observed and measured (operating speed value V_{85} and mean speed value V_m).

Table 2 CCRm value for homogeneous highway-segments

	I segment		II segment		III segment		IV segment		V segment	
	CCR_m gon/km	Length km	CCR_m gon/km	Length km	CCR_m gon/km	Length km	CCR_m gon/km	Length km	CCR_m gon/km	Length km
S.P.1 bis	72.538	15.43								
S.P. 251	428.79	49.13								
S.R. 348	106.17	18.57								
S.R. 203	142.61	54.17	447.96	10.99						
S.P. 2	322.1	16.12	47.9	3.29						
S.R. 48	562.67	28.13	113.69	14.77						
S.P. 423	338.91	2.16	71.107	1.61	340.42	1.18				
S.R. 355	148.52	7.16	360.81	2.92	108.71	1.89	554.14	5.51		
S.P. 641	84.53	2.475	708.02	0.483	272.86	1.966	662.66	1.033		
S.P. 1	68.928	5.42	33.176	8.91	188.12	4.42	44.909	2.53	71.061	1.63

Table 3 Statistics of mean features on tangent and circular curve elements

Tangent element	Tangent Length [m]	CCR_m [gon/km]	V_{85} [km/h]	V_m [km/h]	Cross-Slope [%]	Vertical Grade [%]	Lane width [m]	Shoulder width [m]
Mean value	359.23	185.78	86.54	72.64	0.70	1.66	3.43	0.54
Min value	32.20	33.18	35.00	29.00	0.10	0.20	1.00	0.00
Max value	1279.30	662.66	117.00	100.00	2.10	5.90	4.30	2.20
Std. Dev.	263.38	170.04	16.65	14.43	0.44	1.54	0.35	0.36

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]	Shoulder width [m]
Mean value	130.61	436.41	0.37	213.07	76.33	64.86	1.73	1.65	3.46	0.61
Min value	26.74	15.00	0.01	33.18	19.00	16.00	0.30	0.20	2.60	0.00
Max value	945.67	5000.00	4.24	662.66	113.00	95.00	4.20	6.00	6.00	2.00
Std. Dev.	113.82	575.53	0.50	176.84	20.00	16.99	1.03	1.49	0.38	0.37

Speed measurements were taken by placing the Radar on the middle section of each geometric element; in particular to study driver speed behavior on the tangent length greater than 200m the device was also placed, in addition to the previous specified location, at first and third quarter distance segment. For each road surveyed location one speed measurement at each travel direction has been done. 1,657,730 passed vehicles of which 913,416 in free flow conditions were recorded to reach, counting both travel directions, [2•(91+83)] = 348 samples of speed measurements for tangents and [2•(64+61)]=250 samples of speed measurements for circular curves. In conclusion we have obtained 348 determinations of V_{85} values for tangent elements and 250 determinations of V_{85} values for circular curves. As we can notice from the database proved in this section, speed data and road geometric data have a statistically significant amount and a variability that correctly describe the real system. This circumstance is a good requirement for the reliability of the V_{85} models obtained from these data and described below.

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 (operating speed values) for circular curves, using the "3σ" method, no operating speed value was rejected. It was noted how all the values fall within the range [$\mu - 3\ \sigma$; $\mu + 2\ \sigma$] = [16.33 km/h; 116.33 km/h]. Then, analyzing the standard deviation (σ_t) and mean (μ_t) of 348 V_{85} values for tangent elements, it was noted how 99% of measurements fall within the range [$\mu - 3\ \sigma$; $\mu + 2\ \sigma$] = [42.21 km/h; 120.43 km/h]. Finally analyzing the standard deviation (σ_t) and mean (μ_t) of 188 V_{85} values at middle section of tangent elements, it was noted how all the values fall within the range [$\mu - 3\ \sigma$; $\mu + 2\ \sigma$] = [30.24 km/h; 118.63 km/h]. The 3σ method derives from Čebyšëv theorem; the normal distribution of collected speed data at each surveyed location, as well as revealed in a previous work (Mauro and Russo, 2010), confirms the percentages of this theorem (at least 75% of values is between μ - 2σ and μ + 2 σ, at least 88% of values is between μ - 3σ and μ + 3 σ, at least 93% of values is between μ - 4 σ and μ + σ 4) and its application in our case study is much appropriate to statistical check the speed distribution according to the "action limits" ($\mu \pm 3\sigma$) or "attention limits" ($\mu \pm 2\sigma$).

The Gauss-Newton method based on the Taylor series (Nocedal and Wright, 1999) was used to estimate the coefficients of employed variables. All parameters of the models are significant with a 95% confidence level as confirmed by the results of t-test performed for each coefficient as well as illustrated in a previous document (Mauro and Russo, 2010). The best specifications of the ordinary-last-square models (OLS) of V_{85} [km/h] were worked out from simple sizes of determinations of V_{85} values of Tab.4.a. Three operating speed models on circular elements were developed: see Tab.4.a, Eqs 1, 2 and 3. One operating speed model on tangent elements were developed: see Tab.4.a, Eq. 4. One single operating speed model applicable on tangent and circular elements was developed; these measures refer to the middle sections of these geometric elements. The equation-form of this model is shown in Tab. 4.a, Eq. 5.

3.2. Speed Prediction Models by Layered Database

In order to improve the value of the coefficient of determination ρ^2 associated with different regression models, it was designed to split the circular curves database in classes. This procedure helps to decrease the standard deviation of speeds distribution because it will control only the average values of the explanatory variables associated with each classes. Thus, *three operating speed models on circular elements* were developed (see Eqs. 6,7,8 Tab. 4.b) . The best specifications of OLS of V_{85} [km/h] were worked out from a set of 250 determinations of V_{85} values with consequent available 24 classes. Each class is based on a curve radius constantly variable with a gap of 50 m.

Therefore for Eq. 6, to obtain a best fit of empirical data, for each class, the mean value of all curvature change rates of the single curves (CCR_S) and the mean value of all curvature change rates of homogeneous roadway segments (CCR_m) were used. To obtain for Eq.7 a best fit of observed data for each class the mean value of slopes (S), the mean value of circular curves length (L_c) and the mean value of curve radius (R) were also used. Finally, to obtain for Eq.8 a best fit of empirical data, for each class, the mean value of vertical signs' presence (P_S equal 1 if the signs exist, 0 otherwise) was used.

Table 4.a V_{85} prediction models for circular curves and tangent elements

Models	Models for	V_{85} sample size	ρ^2 [%]
For circular curves [km/h]	Eq.(1) $V_{85} = 99.024 + (\mathrm{Log}_{10} L_C) - 20.32 \cdot CCR_s + 3.034 \cdot CCR_s^2 - 6.3 \cdot 10^{-2} \cdot CCR_m - 2.49 \cdot \lvert S \rvert$	250	67
	Eq.(2) $V_{85} = 90.21 + 5.46 \cdot W_{SL} - 13.60 \cdot 10^{-2} \cdot CCR_m + 11.60 \cdot 10^{-5} \cdot CCR_m^{\ 2} - 202.15 \cdot (1/R)^{0.5}$	250	70
	Eq.(3) $V_{85} = 74.78 + 4.34 \cdot W_{SL} + 23.61 \cdot W_{SH} - 15.26 \cdot W_{SH}^2 - 5.80 \cdot 10^{-2} \cdot CCR_m - 1.10 \cdot 10^{-3} \cdot CCR_s + 4.73 \cdot 10^{-6} \cdot CCR_s^2 - 1673 \cdot (1/R)$	250	71
For tangent elements [km/h]	Eq.(4) $V_{85} = 61.95 - 9 \cdot 10^{-5} \cdot CCR_m^{\ 2} + 13.36 \cdot \mathrm{Log}_{10}(L_T) - 2.22 \cdot \lvert S \rvert$	188	62
For tangent and circular elements [km/h]	Eq.(5) $V_{85} = 69.21 - 9.2 \cdot 10^{-5} \cdot CCR^2_m + 10.918 \cdot (\mathrm{Log}_{10} L) - 425.38 \cdot (1/R) - 3.15 \cdot \lvert S \rvert - 0.16 \cdot VG$	438	63

Table 4.b V_{85} Prediction models through a partition in classes of database

Models	Models	V_{85} sample size	Number of classes	ρ^2 [%]
For circular curves [km/h]	Eq.(6) $V_{85} = 96.23 - 18.60 \cdot CCR_s - 4.49 \cdot 10^{-2} \cdot CCR_m$	250	24	80
	Eq.(7) $V_{85} = 106.53 + 10^{-6} \cdot R^2 - 7.97 \cdot CCR_S - 5.2 \cdot 10^{-2} \cdot CCR_m - 8.14 \cdot \lvert S \rvert - 0.012 \cdot L_c$	250	24	81
	Eq.(8) $V_{85} = 98.94 + 105.83 \cdot (1/R)^{0.5} - 6.35 \cdot 10^{-2} \cdot CCR_m - 5.27 \cdot 10^{-2} \cdot CCR_s + 1.43 \cdot 10^{-5} \cdot CCR_s^2 - 0.627 \cdot P_s$	250	24	84
For tangent elements [km/h]	Eq.(9) $V_{85} = 98.94 - 8.1 \cdot 10^{-2} \cdot CCR_m + 10^{-5} \cdot L_T^{\ 2}$	188	19	68
	Eq.(10) $V_{85} = 115.48 - 5 \cdot 10^{-6} \cdot L_T^{\ 2} - 0.12 \cdot CCR_m + 5.83 \cdot \lvert S \rvert - 14.02 \cdot VG$	348	19	82

Symbols for the Equations 1÷10: L_T and L_c = length of single geometric element [m], W_{SL} = width of lane [m], W_{SH} = width of single shoulder [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], S = cross-slope of roadway segment at surveyed location [%],VG = vertical grade of roadway segment at surveyed location [%],P_S = vertical signs indicator equal to 1 if the sign exist near the selected section, 0 otherwise

One operating speed models on tangent elements was developed using 188 measures (see Eq. 9 Tab. 4.b) The best specification of OLS of V_{85} [km/h] was worked out from a set of 188 determinations of V_{85} values at middle sections with consequent available 19 classes. Each class is based on a tangent length constantly variable with a gap of 50 meters. To obtain for Eq. 9 a best fit of empirical data for each class the mean value of all curvature change rates of homogeneous highway segments (CCR_m), and the mean value of tangent length (L_T) were used.

One operating speed models on tangent elements was developed employing OLS method with 348 determinations of V_{85} values at middle sections and at first and third quarter distance tangent segment with consequent available 19 classes (see Eq. 10 Tab. 4.b). Each class is based on a tangent length constantly variable with a gap of 50 meters. To obtain for Eq. 10 a best fit of empirical data for each class the mean value of slopes (S) and the mean value of the vertical grades (VG) of the was used.

4. Results

Following statistics were estimated to test the significance of all prediction models:

- *Mean error* = mean value of V_{85} speed differences (D_i) assessed between observed operating speed value and predicted operating speed value
- *MAD* (Mean Absolute Deviation) = constant value equal to the sum of the absolute D_i values divided by the number (N) of V_{85} determinations

- *MSE (Mean Squared Error)* = constant value equal to the sum of D^2_i divided N
- I = constant value equal to the square root of MSE divided by the mean predictive operating speed value

Table 5 shows the values returned by the statistical analysis.

Table 5 Summarizing statistical parameters

V_{85} Prediction Model	MAD	MSE	I
Eq. 1 (circular curves)	9.48	132.91	0.15
Equ.2 (circular curves)	8.49	120.30	0.14
Equ.3 (circular curves)	8.51	118.10	0.14
Eq. 4 (tangent elements by using middle sections)	8.82	118.04	0.13
Eq. 5 (for curve and tangent elements by using middle sections)	9.65	138.47	0.14
Eq. 6 (division in classes of circular curves database)	5.11	40.8	0.08
Eq. 7 (division in classes of circular curves database)	5.024	42.78	0.08
Eq. 8 (division in classes of circular curves database)	4.44	31.7	0.07
Eq. 9 (division in classes of tangents by using middle sections)	6.36	66.02	0.10
Eq. 10 (division in classes of tangents by using whole database)	4.26	28.09	0.06

It can be concluded that speed prediction models are statistically significant because the residuals, between predicted and observed operating speed values, assume limited values. This circumstance was confirmed by the low value of MAD and I indicators; I reflects a good prediction when it is lower than 0.2. The analysis of ρ^2 values (see Tabs 4.a and 4.b) and the statistics in Tab. 5 show how Eqs 6, 7, 8, 9 and 10 best fit the empirical data. Equation 8 is the best model to predict the V_{85} value on the circular curve elements. Indeed Eqs 6 and 7 are equivalent in terms of ρ^2 values, and of MAD, MSE and I statistics (see Tab. 5). However the Eq. 6 is easier to apply than Eq. 7 on circular elements to predict V_{85} value. In fact, Eq. 6 has two only explanatory variables instead of Eq. 7 where five explanatory variables must be assessed to apply the operating speed prediction model.

Concerning the operating speed prediction models on tangent elements, Eq. 10 (see Tab 4.b) best fits the empirical data. This equation presents a coefficient of determination ρ^2 much better than Eq. 9 (see Tab. 4.b) and a value of MAD, MSE and I statistics lower than Eq. 9 (see Tab. 5). However, this Equation is more laborious and more difficult to apply on tangent elements because it depends on the determination of 4 explanatory variables. Equation 9 is simply to apply on tangent segments because it is related to the determination of only two explanatory variables with an acceptable value of the coefficient of determination ρ^2.

To cleanly utilize and apply these operating speed prediction models on the analyzed roads segments, abacus-type for predicting V_{85} on circular curves (see Fig. 1.a) and tangent elements (see Fig. 1.b) were performed as shown below. The first two graphs refer to Eqs 6 and 8, the remaining graphs refer Eqs 9 and 10.

Each graph presents a series of straight lines as a result of suitable combinations of the independent variables employed in V_{85} prediction model.

The analysis of the diagrams of the Eqs 6, 8, 9 and 10 allowed to assume the following comments:

- Relating to the diagrams of V_{85} for circular elements (see Fig. 1.a), we have observed that the explanatory variable that most influences the driver speed behavior is CCR_m variable. Indeed Eq. 8 shows how the V_{85} diagram presents comparable values of operating speeds, setting an average value of CCR_s, both on circular curves where vertical signs near the middle sections exist and on circular curves where the vertical signs are absent. Then the presence of vertical signs on circular elements has less effect on V_{85} than CCR_m variable. The diagram of Eq. 6 confirms this result where it's obvious that this operating speed model is high influenced by CCR_m variable to vary CCRs. This circumstance is realistic because CCR_m variable represents the major or minor tortuosity of a homogeneous roads segment where the circular element can fall. The tortuosity is the factor that mostly affects measurable speed regimes.
- Relating to the diagrams of V_{85} for tangent elements (see Fig. 1.b), we have observed for Eq. 9 how the explanatory variable that most influences the driver speed behavior is the CCR_m parameter. The diagram of Eq. 9 in Fig. 1.b shows how the predicted values of V_{85} for a mean observed value of tangent length on the analyzed

highways aren't too different from the predicted values of V_{85} associated to the minimum value of tangent length on the analyzed highways. As is expected, the predicted values of V_{85} when the tangent length is maximum are clearly higher than previous cases. When the vertical grade is introduced as explanatory variable in the regression equation (see Eq. 10) we observe that higher or lower values of vertical grade for the tangent element can strongly influence the driver speed behavior. The diagram of Eq. 10 shows how the drivers on highways analyzed in this research increase V_{85} values upward on short tangents with low Vertical grade while on long and short tangents with high vertical grade the drivers reduce their V_{85}. Furthermore, the diagram of Eq. 10 illustrates how the values of Slope variable, when the values of remaining explanatory variables are fixed, slightly influence the predicted values of V_{85}. In conclusion we have observed that the explanatory variable in Eq. 9 that most influences V_{85} values is CCR_m variable, while for Eq. 10 it's clear that the vertical grade variable influences the V_{85} values most than CCR_m variable.

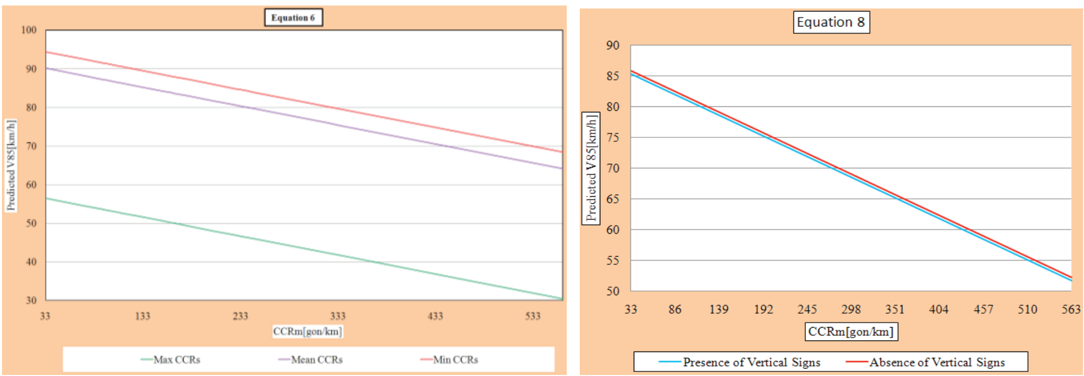

Figure 1.a. Abacus type for predicting V_{85} on circular curves by Eqs. 6, 8

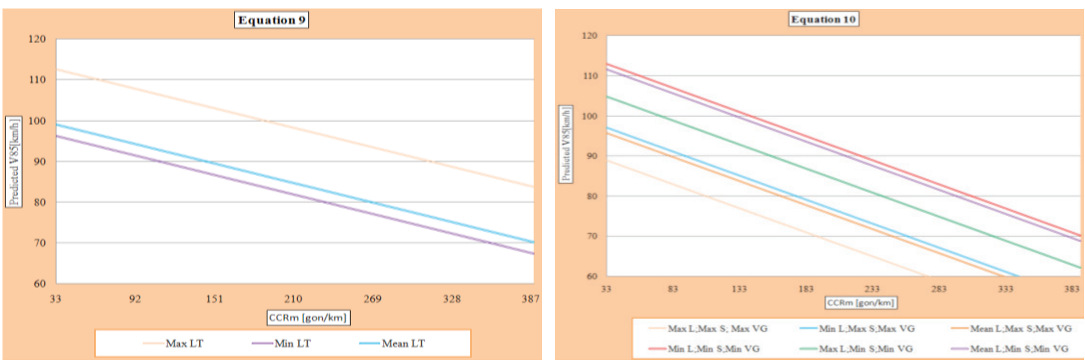

Figure 1.b. Abacus type for predicting V85 on tangent elements by Eqs. 9, 10

5. Conclusions

Existing operating speed models for design consistency in North America and Europe are mainly based on analysis of highway horizontal alignments. The prediction of operating speed is one of the key problems used to evaluate highway safety at the design stage. The models will help highway designers to predict operating speed and evaluate design consistency more accurately, and thus aid highway safety.

In this study the existing problems such as the influencing factors of road characteristics, driver perception, data collection devices and vehicle type are discussed; some research focuses on the modeling of operating speed are presented. The operating speed prediction models proposed are the first modelling results from the available database; we can stated that these regression equations quite realistically interpret the predictable driver speed beahvoiur on the analysed highways. In particular one single operating speed model applicable on tangent and circular elements was developed to be avoided two different models. Future developments are addressed to the validation of these prediction models to assess their performance to interpret situations not involved during the calibration procedure but reflecting the general features of collected data

The speed prediction models here presented can be used to evaluate the consistency of new and existing roads and in particular to carry out safety analyses of existing two-lane rural roads in Italy. In fact, assessing the real difference between the operating speed value using models that reflect the real drivers speed behavior and the speed value put forward by the Italian standard, it is possible to act on the horizontal-vertical alignment to improve the roadway design and increase safety for users where the measured speed differences are intolerable. Nevertheless further analyses will be carried out from the available database to perform complete sensitivity analyses about the available prediction models and for those to be carried out.

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References

Dragčević, V., Korlaet, Z. and Stančerić, I. (2008). Methods for Setting Road Vehicle Movement Trajectories. *The Baltic Journal of Road and Bridge Engineering,* 3(2): 57-64.

Dell’Acqua, G., Lamberti, R. and Russo, F. (2010). *Road Safety Management Using Crash Prediction Models*. International Road Federation Bulletin, Special Edition Rural Transport, Volume 1, IRF Geneva - Switzerland, pp.22-25.

Dell’Acqua, G. and Russo, F. (2010). Speed Factors on Low-Volume Roads for Horizontal Curves and Tangents. *The Baltic Journal of Road and Bridge Engineering*, 5 (2), 89-97.

European Commission, (2008). *DIRECTIVE 2008/96/EC of the European Parliament* and of the Council of 19 November 2008 on road infrastructure safety management, Official Journal of the European Union.

Figueroa, A. M., Tarko, A. P. (2004). *Reconciling speed limits with design speeds*. Final Report FHWA/IN/JTRP-2004/26, Purdue University - Joint Transportation Research Program Project No: C-36-10G File No: 8-3-7 SPR- 2661, Purdue University West Lafayette, IN 47907.

Fitzpatrick, K. and Collins, J. M. (2000). Speed Profile Model for Two-Lane Rural Highways. *Transportation Research Record*, 1737, 42-49. DOI: 10.3141/1737-06

Fitzpatrick, K., Carlson, P., Brewer, M., Wooldridge, M., Miaou, S. (2003). *Design Speed, Operating Speed and Posted Speed Practices*. NCHRP Report 504, TRB, National Research Council.

Fitzpatrick, K., Miaou, S., Carlson, P., Brewer, M., Wooldridge, M. (2005). Exploration of the Relationships between Operating Speed and Roadway Features on Tangent Sections. *Journal of Transportation Engineering,* 131 (4), 261-269.

Forum of European Road Safety Research Institutes/European Conference of Transport Research Institutes (2009). *The sustainable safety approach to Road Transport and Mobility*. FERSI/ECTRI common paper.

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*, 127 (1), 21-30.

Louah, G., Menacer, O., Dupré, G., Violette, E. (2009). *Updating French formulas for operating speeds on horizontal curves of rural two-lane highways*. Advances in Transportation Studies an International Journal, Section B 18.

Mauro, R., Russo, F. (2010). *Speed Factors on Low-Volume Roads for Horizontal Curves and Tangents in Province of Belluno*. DIMS Report, University of Trento (Italy).

Misaghi, P., Hassan, Y. (2005). Modeling Operating Speed and Speed Differential on Two-Lane Rural Roads. *Journal of Transportation Engineering*, 131 (6), 408-418.

Nocedal, J., Wright, S.J. (1999). *Numerical Optimization*. Springer Verlag.

Ottesen, J. L., Krammes., R. A. (2000). Speed Profile Model for Design-Consistency Evaluation Procedure in the United States, *Transportation Research Record,* 1701, 76-85, DOI: 10.3141/1701-10

Polus, A., Fitzpatrick, K., Fambro, D. (2000). Predicting operating speeds on tangent sections of two-lane rural highways. *Transportation Research Record*, 1737, 50-57. DOI: 10.3141/1737-07

Richtlinien für die Anlage von Strassen (1995). *Linienführung RAS-L; Forschungsgesellschaft für Strassen und Verkehrswesen*; Bonn.

Török, Á. (2011). Investigation of road environment effects on choice of urban and interurban driving speed. *International Journal for Traffic and Transport Engineering*, 1(1), 1-9.