LOCAL TESTS OF THE OPERATING SPEED MODELS FOR CURVES

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ABSTRACT

The paper aims to test operating speed models for curve sections on local two lane rural roads.

In the beginning, the most important national and international models, which enable to calculate operating speed, are summed up. The form of the prediction models and number of variables used in each of them vary considerably. The most common operating speed models, proposed by many researchers of different countries, provide V_{85} as a function of the Degree of Curvature (DC) or of the Curvature Change Rate of the single curve (CCRs). All operating speed models, considered in this paper, are developed through regression analysis of collected speeds of free passenger cars.

Afterward speed data are recorded on local curves. Different constraints have been imposed to select curve sites: rural area, relatively low traffic volume, marked and paved roadways with constant lane width, no stop control or intersections near to curve, the design speed ranges from 60 km/h to 100 km/h and the general speed limit is 90 km/h (in accordance with the "Italian Road Code"), longitudinal grades ≤ 5%.

Subsequently, the most important national and international models, which have been gathered preceding, are applied on chosen curve sections, in order to calculate V_{85}.

Speed surveys are compared with the results of the models application.

The article includes also a summary of the data collected and the results of a statistical analysis showing speed trends.

The target of the paper is to verify on local roads the applicability of the existing speed models in order to implement them in the following step of the research work.

Keywords: two-lane rural highway, speed prediction, operating speed, design consistency

1. INTRODUCTION

In the last years, in order to increase road safety, the importance given to the respect of the driver expectancy is improved. Several studies show that geometric design consistency enhances road safety conditions. The complex relationships between road features and driver behaviour play a very important role in collision occurrence. In fact, accident probability is higher where alignment consistency lacks. For this reason, different studies show that parameters, which are still present in some guidelines in force in many countries, are outdated.

The most common criteria for design consistency evaluation are based on the operating speed concept. AASHTO defines operating speed as "the speed at which drivers are observed operating their vehicles during free-flow conditions, the 85th percentile of the distribution of observed speeds is the most frequently used measure of the operating speed associated with a particular location or geometric feature"[1]. Besides, the distribution of operating speed on alignment is a quantitative measure of the general character of the road and the relationships between driver behaviour and highway. In fact, the distribution of operating speed may identify a geometric inconsistency when there is a high rate of change for successive roadway sections. Several design standards use already operating speed concept to select design speed values and/or alignment element admissible values.

The concept of geometric design consistency is also used to correlate accident risk with geometric alignment. Along horizontal curves accident rate is up to 4 times higher than tangents. For this reason, the majority of operating speed studies focus on horizontal curves of two-lane rural highways, even if there are also many tangent models.

The principal target of this paper is testing curve speed models, for two lane rural roads, on local highways using data collected on different horizontal curve sections.

Before, the most important national and international models, that permit to calculate operating speed, are reviewed. Subsequently, these models are tested on three sections of two lane rural roads. Next speed surveys are carried out. Only passenger vehicles are included in this study.

The research project, which is carried out by the Department of Land Engineering of the University of Cagliari, aims to develop a speed model between road features (e.g. CCR, available sight distance) and operating speed.

2. SPEED MODELS

Several studies show that the car speed plays an important role in accident occurrence, in particular when considerable high speed reductions are required. Therefore, the design standards of different countries require to compare design speeds of adjacent sections, in order to limit the difference between their values.

Many countries still use the design speed as base parameter to calculate the limit values of the alignment elements. On the one hand the standard of some countries are based on the operating speed concept, on the other hand the most of guidelines of the other refer to this concept only in the post-road design. Finally, several countries use the expected operating speed as base to select design speed or/and specific geometric element values and to reduce design inconsistencies.

For example, the Australian standards are based on McLean research that defines 85th percentile speed as a function of the curve radius and the desired speed, which is “the speed at which driver chooses to travel under free-flow conditions, when they are not constrained by alignment features” [2].

The form of the operating speed prediction models and number of variables used in each of them vary considerably. The most common operating speed models, proposed by many researchers of different countries, provide V_{85} as a function of the Degree of Curvature (DC) or of the Curvature Change Rate of the single curve (CCRs) or of the Radius (R). These parameters are given by the following equations:

$$DC = 100 \times (360 / 2\pi R) \qquad \text{(Eq. 1)}$$

$$CCRs = [63700 \times (\frac{L_{c1}}{2R} + \frac{L_{cr}}{R} + \frac{L_{c2}}{2R})] / L \qquad \text{(Eq. 2)}$$

(where: DC [degree/100 m], R = radius of circular curve [m], CCRs [gon/km], L_{c1} and L_{c2} = lengths of clothoids (preceding and succeeding circular curve) [m], L_{cr} = length of circular curve [m], L = overall length of curve section [km], 63700 = $200/\pi \times 10^3$).

In this paragraph several models that permit to calculate operating speed as a function of CCRs [Table 1] and curve radius are reviewed [Table 2].

Table 1 Operating speed prediction models using CCRs value

Model	Equation	R^2
McLean - Australia [2]	V_{85} = 101.2 – 0.043 CCRs	0.87
Lamm et al. – Germany [2]	$V_{85} = 10^6$ / (8270 + 8.01 CCRs)	0.73
Lamm et al. [2]	V_{85} = 95.6 – 0.0438 CCRs	0.82
Psarianos et al. – Greece [2]	$V_{85} = 10^6$ / (10150.1 + 8.529 CCRs)	0.81
Lamm et al – United States [2]	V_{85} = 93.85 – 0.05 CCRs	0.79
Krammes and Ottesen [2]	V_{85} = 103.04 – 0.053 CCRs	0.80
where: V_{85} [km/h]; CCRs [gon/km].		

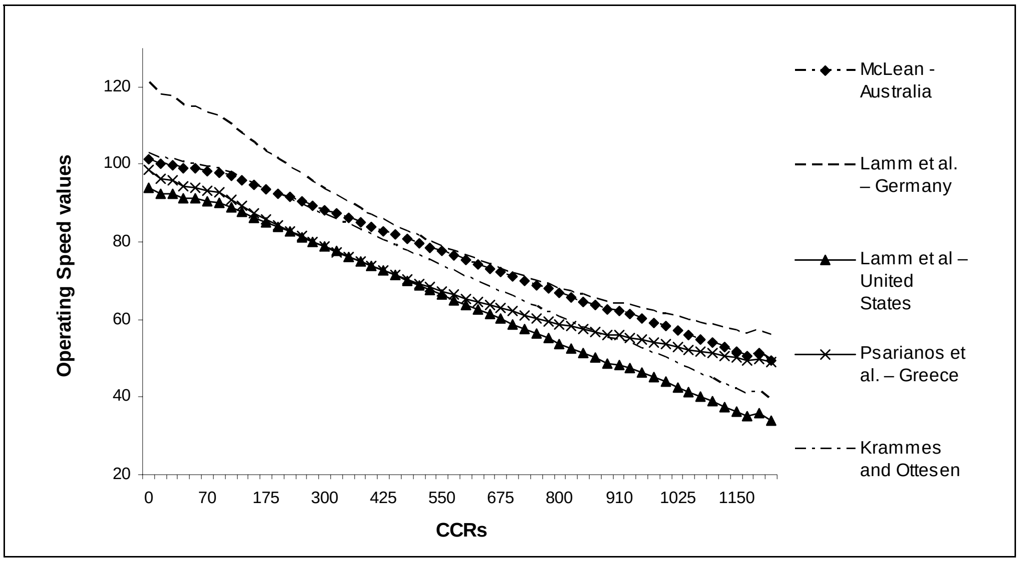

Figure 1 Graph representing analytical models where V_{85} is expressed as a function of CCRs

All operating speed models considered in this paper are developed through regression analysis of adopted speed on two lane rural roads of free passenger cars (headway of at least 5 seconds). Speed data are recorded with dry and wet pavement conditions, on longitudinal grades ≤ 6% (even if its effect is generally ignored).

In the tables, the international models that better represent local situations have been summarized.

Table 2 Operating speed prediction models using radius value

Model	Equation	R^2
Ottesen and Krammes [3]	$V_{85} = 103.66 – 1.95 \cdot (1746.38 / R)$	0.80
Kannelaidis et al. [4]	$V_{85} = 129.88 – (623.1 / \sqrt{R})$	0.78
Lamm et al. [2]	$V_{85} = 94.398 – (3188.656/R)$	0.79
where: V_{85} [km/h]; R [m].		

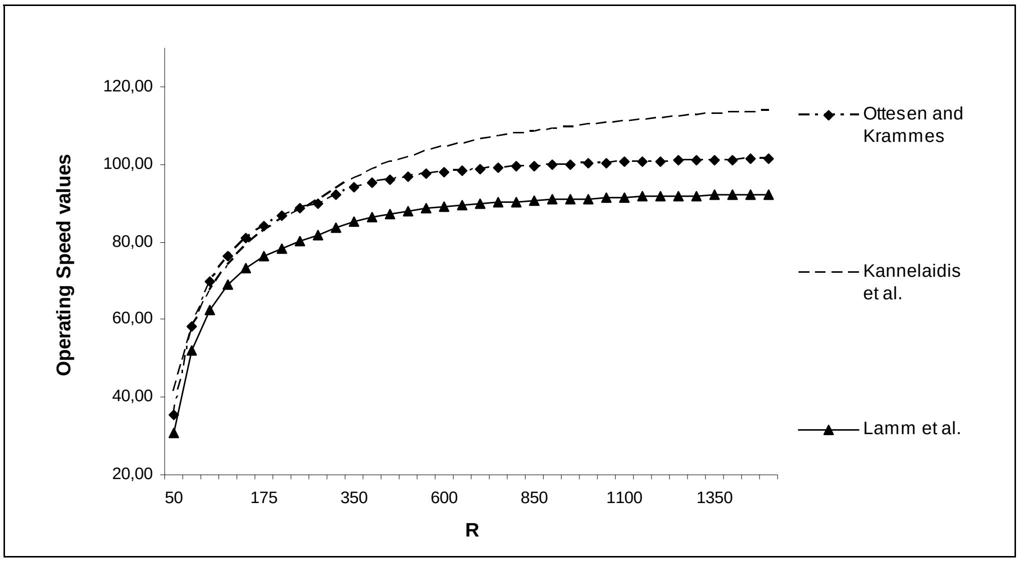

Figure 2 Graph representing analytical models where V_{85} is expressed as a function of horizontal radius, R

2.1 Italy

A study, carried out by the Department of Civil Engineering of the University of Trieste, proposes an operating speed prediction model for curves and tangents. The researchers define also environmental speed: as the maximum speed that can be reached on tangents or very large radius curves belonging to a homogeneous road section identified by an analysis of the curvature change rate, CCR [5]. They provide a prediction model to obtain the operating speed as a function of the horizontal radius and the environmental speed, which is obtained as a function of the road section geometric features. Starting with Australian study, speed environment represents the speed which drivers go at when they are not conditioned by traffic or by features of the single road elements [5]. The environmental speed value depends on the road section geometric characteristics, available sight distance, frequency of junctions and accesses, terrain type, carriageway width, and so on.

$$V_{env} = 200.97 \times CCR - 0.16 \quad \text{(Eq. 3)}$$

(where: $R^2 = 0.87$, V_{env} [km/h], CCR [gon/km])

All data are collected during daylight hours under dry pavement condition and in the presence of low traffic. The researchers consider roads with the usual cross sections of Italian two-lane rural roads: with two lanes (3,25 ≤ lane width ≤ 3,75 m), with two paved shoulders (0 ≤ shoulder width ≤ 1,50 m), with the longitudinal grade ≤ 4.00% (even if prediction models are not influenced by grades).

They test the influence of the length of the curve, the radius of the preceding curve, the length of the preceding tangent and the super-elevation. In the prediction of speed value on curve the most significant are the radii of the curves (R) and the environmental speed (V_{env}) of the homogenous section.

$$V_{85} = V_{env} / (1 + 4.75 / R \times 0.58) \qquad \text{(Eq. 4)}$$

(where: R^2 = 0.88, R = the curve radius [m], V_{env} and V_{85} [km/h]).

Most speed prediction models estimate the operating speed on horizontal curves using two-dimensional alignment variables. A few models consider the effects of vertical grades on speed; some specify a range of grades in which it is valid.

3. LOCAL TESTS

The preliminary aim of this research is to collect vehicle speeds on a particular site, in order to test V_{85} models that have been explained above. Several two-lane rural highway segments are chosen for data collection. The following constraints have been imposed for the selection of curve sites: rural area, relatively low traffic volume, marked and paved roadways with constant lane width, no stop control or intersections near to curves, maximum longitudinal grade 4,00 %. All data are collected during daylight hours, in good weather conditions and with a dry pavement. The data collecting excludes non-passenger cars and vehicles with less than 5 second headway from the previous vehicle (free flow). The speed surveys are carried out using a radar speedometer. Road alignments is made up of tangent and circular curves, there are not clothoids. In fact, highways chosen are designed with preceding guidelines within them clothoids was not mentioned.

3.1 Site n. 1 – S.S. n. 547

The curve section is located along the S.S. n. 547. The cross-section is made up of two lanes that are 3,50 m wide, no paved shoulders which are 1,00 m wide, Longitudinal grade is 3,75 %.

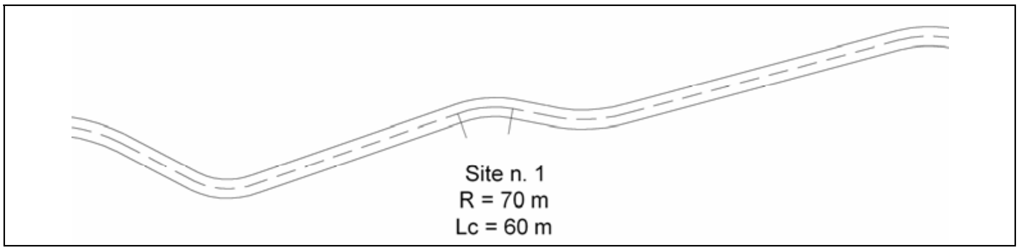

Figure 3 Plan of site n. 1 – S.S. n. 547

The speed data are collected at a middle point of circular curve (R = 70 m). A total of 253 individual speed observations are collected on both directions. The operating speed registered is 61 km/h.

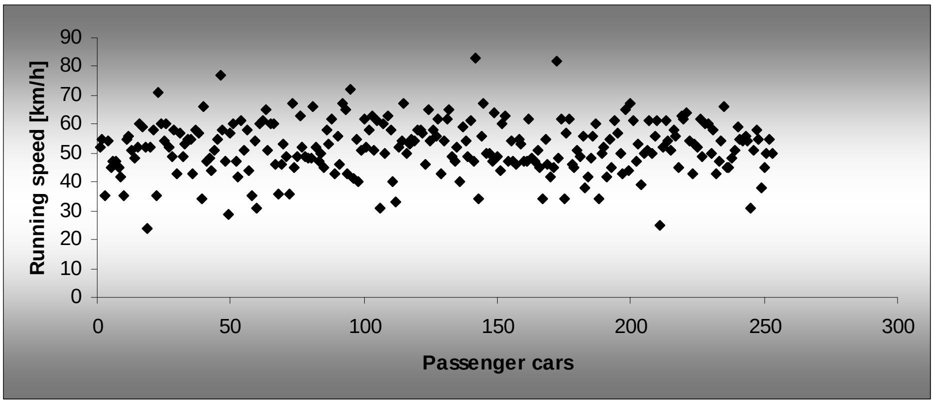

Figure 4 Speed distribution on site n. 1

3.2 Site n. 2 – S.S. n. 125

The curve section is located along the S.S. n. 125. The cross-section is made up of two lanes that are 3,25 m wide, no paved shoulders which are 0,50 m wide. Longitudinal grade is 2,70 %.

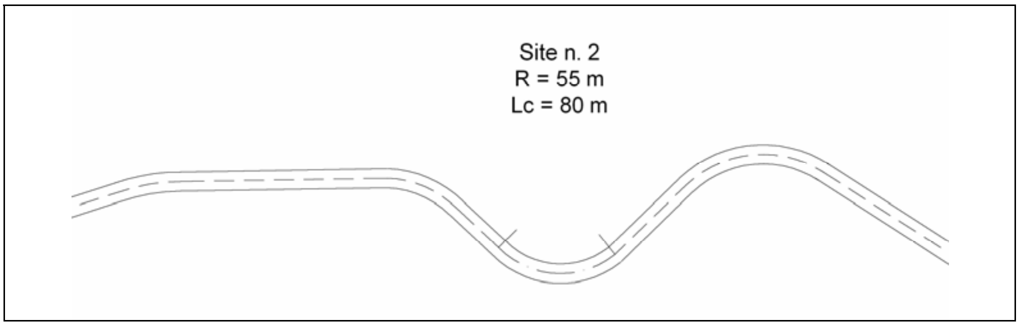

Figure 5 Plan of site n. 2 – S.S. n. 125

The speed data are collected at middle point of circular curve (R = 55 m). A total of 168 individual speed observations are collected on both directions. The operating speed registered is 49 km/h.

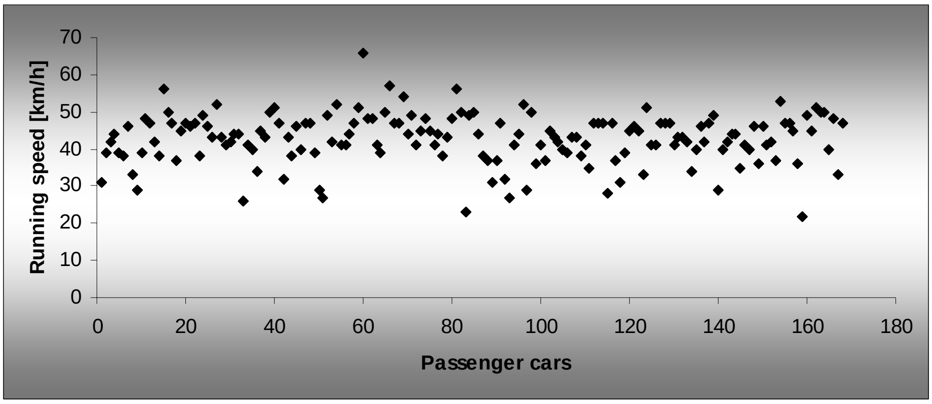

Figure 6 Speed distribution on site n. 2

3.3 Site n. 3 – S.S. n. 125 (new section)

The cross section of the roads are equal to those recommended by the new Italian guidelines for two-lane rural roads (type C1) [6]: it is 10.5 m width (two lanes width 3.75 m and two shoulders width 1.50 m). All the geometric elements of the horizontal and vertical alignments are designed according to the Italian design guidelines [6]. The general speed limit is 90 km/h (in accordance with the "Italian Road Code").

The speed data are collected on a middle point of the circular curve (R = 1500 m). A total of 208 individual speed observations are collected on both directions. The horizontal curve is preceded and succeeded by clothoids.

The operating speed registered is 129 km/ h.

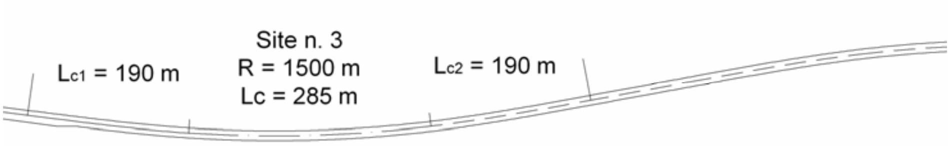

Figure 7 Plan of site n. 3 – S.S. n. 125

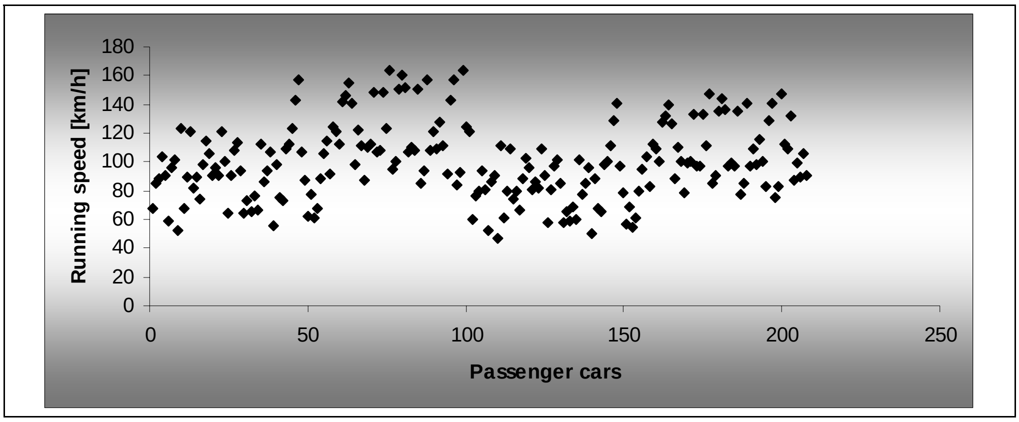

Figure 8 Speed distribution on site n. 3

All results are summarized in the Table 3

Table 3 Operating speed registered on several sites

	R	L	CCRs	i	V_{85}
Site n.1	70	60	910	3,75	61
Site n.2	55	80	1158	2,70	49
Site n.3	1500	285	30	3,00	129
where: L = length of horizontal curve [m], V_{85} = operating speed [km/h]; CCRs = Curvature Change Rate of the single curve [gon/km]; R = curve radius[m]; i = longitudinal grade [%].					

For the preliminary estimation of operating speed, the predicting model, which have been found in literature, are used. The results are summarized in the Table 4.

The paper wants to test, on some significant sections, several national and international models in order to implement the most significant with another variables, for example available sight distance.

The comparison between speeds observed on curve sections shows that the V_{85} collected is not perfectly in accordance with the results of the different relationships that are analysed above, even if they are similar.

It is most important to underline that although two sites have a relatively small radius, the operating speed models results are similar to speed collected.

Instead it is significant that on the site located in the road designed in accordance with new Italian design standards [6] operating speed gathered is bigger than ones calculated using analytical models.

Table 4 Operating speed values

Model	Equation	Site n.1 V_{85} (surveyed) 61	Site n.2 V_{85} (surveyed) 49	Site n.3 V_{85} (surveyed) 129
McLean Australia	$V_{85} = 101.2 - 0.043$ CCRs	62	51	100
Lamm et al. Germany	$V_{85} = 10^6 / (8270 + 8.01$ CCRs$)$	64	57	118
Psarianos et al.	$V_{85} = 10^6 / (10150.1 + 8.529$ CCRs$)$	56	50	96
Lamm et al. United States	$V_{85} = 93.85 - 0.05$ CCRs	48	36	92
Krammes and Ottesen	$V_{85} = 103.04 - 0.053$ CCRs	55	42	101
Ottesen and Krammes	$V_{85} = 103.66 - 1.95 \cdot (1746.38 / R)$	55	42	101
Kannelaidis et al.	$V_{85} = 129.88 - (623.1 / \sqrt{R})$	55	46	114
University of Trieste	$V_{env} = 200.97 \cdot CCR^{-0.16}$	68	65	116
	$V_{85c} = V_{env} / (1 + 4.75 / R^{0.58})$	48	44	109
where: V_{85} [km/h]; V_{env} [km/h] CCRs [gon/km]; R [m]				

The table underlines like the models considered are linked with local road environment. In fact there are high differences among several results. For this reason, drawing up a model, locally valid, could be necessary. The target of this first step of project research is to know local validity of some operating speed models.

4. CONCLUSION

Finally the aim is improving these prediction models or drawing up a new model. Therefore it will be necessary to enlarge sample data and to consider some other independent variables, as for instance available sight distance. An experimental survey is actually ongoing.

Once such variables as category of the road, characteristics of the traffic, and so on, have been identified, we can determine some relationships, which are valid not only locally. As a consequence, it is opportune to widen the sample of roads studied.

Further surveys will be carried out in order to complete the test of the model explained above. The aim of the analysis was to investigate the relationship between the operating speed and the geometric features, into the studies of several countries, in order to create an operating speed model, where the V_{85} is expressed as a function of CCR and available sight distance.

This paper represents a first step, of our research project, that, starting from the existing models, wants to create a model locally valid. The following step will be select other sites to know the models, which represent better the driver behavior on rural roads, which are designed in accordance with the new Italian Road Guidelines.

ENDNOTES

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