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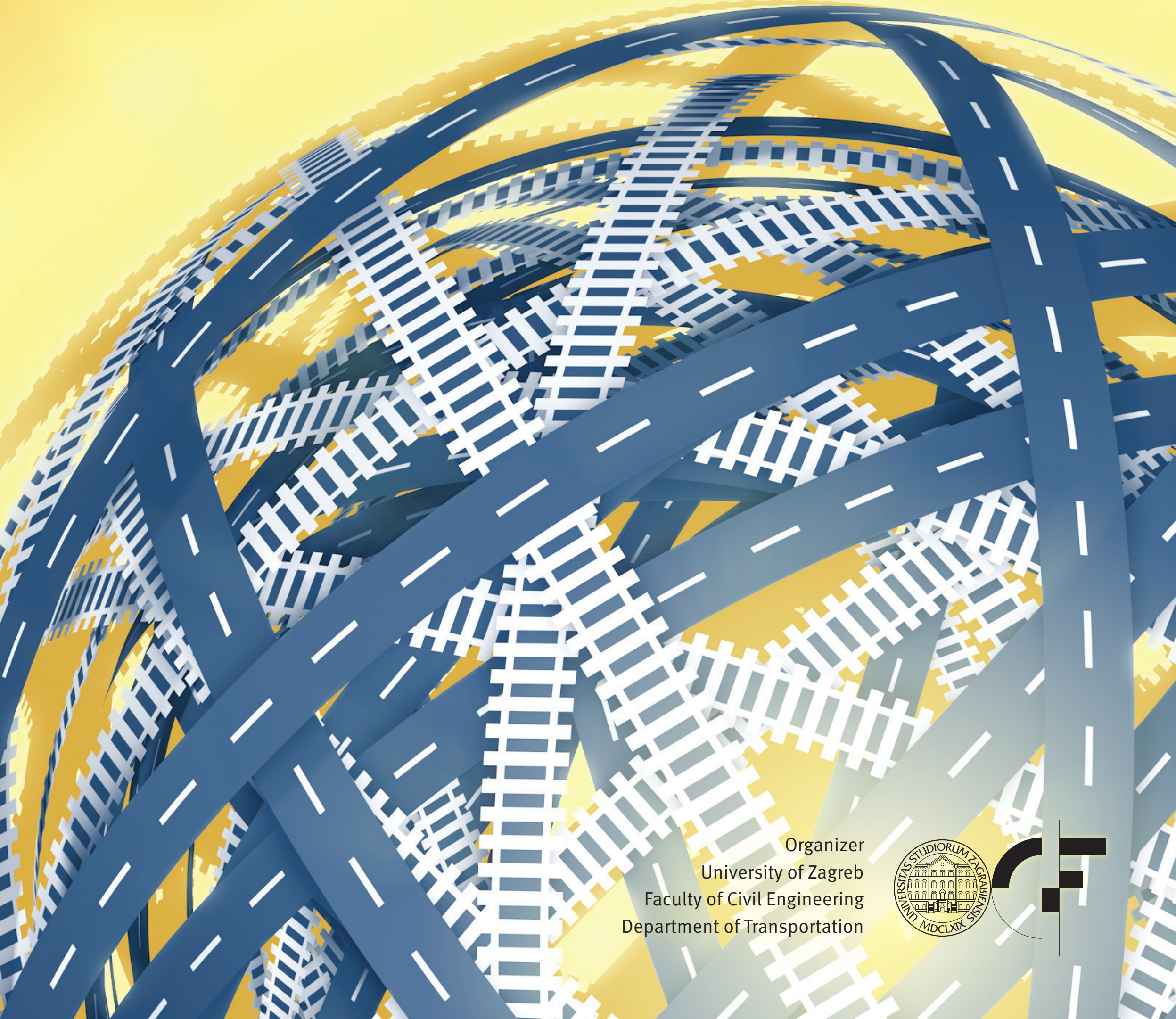
Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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OPERATING SPEED MODELS ON TANGENT SECTIONS OF TWO-LANE RURAL ROADS

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Abstract

This paper presents model for predicting operating speeds on tangent sections of two-lane rural roads. The speed data of 20 drivers were continuously recorded along an 18 km long section of a state road D1. The data were used for determination of maximum operating speeds on tangents and their comparison with speeds in the middle of tangents i.e. speed data used in most of operating speed studies. Analysis of continuous speed data indicated that the spot speed data are not reliable indicators of relevant speeds. After that, operating speed models for tangent sections were developed. There was no significant difference between model developed using speed data in the middle of tangent sections and model developed using maximum operating speeds on tangent sections. All developed models have higher coefficient of determination then models developed on spot speed data. So, it was concluded that the method of measuring has more significant impact on the quality of operating speed model than the location of measurement.

Keywords: operating speed, rural roads, spot speed data, model for prediction

1 Introduction

One of the main causes of accident occurrence is the lack of geometric design consistency in terms of maintaining the desired travel speed [1-7]. A consistent road design ensures coordinated successive elements producing harmonized driver behaviour with no surprising events. There are many measures for design consistency evaluation among which the operating speed approach can be named as the most efficient measure [8].

In the past few decades many operating speed studies around the world have been conducted [9]. Majority of studies resulted in operating speed models on horizontal curves while there have been only a few attempts to develop speed models on tangents. There is an opinion that it is easier to model the operating speed on curves because of the strong correlation with the curvature of the alignment element [10] while the tangent speed depends on too many parameters [11], so it is hard to establish a reliable model.

The coefficient of determination R^2 of curve speed models using just radius or curvature of the alignment element as explanatory variable is usually greater than 0.7. Including the approach tangent speed as an independent variable, R^2 increases to more than 0.85 [12]. The results of speed models on tangent sections are not so good. In the analysis of 162 tangent sections on two lane rural highways [11] it wasn't possible to develop a model capable to describe the operating speed in the middle of tangent section because of its dependency on the elements before and after the section. So, researchers separated the tangents in four groups according to tangent length and sharpness of the preceding and the following curve. The corresponding coefficients of determination ranged from 0.55 to 0.84.

Federal Highway Administration (FHWA) developed speed profile models for lower speed highways (up to 64 km/h) for use in Interactive Highway Safety Design Model ISHDM 2010 release. Separate models were developed for short (< 45 m) and long tangents. Resulting R^2 were pretty low. Coefficient of determination for short tangents model was 0.49 (the predicting variables were posted speed and radius of the curve). For longer tangents the posted speed, roadside hazard and length of tangent were found to impact the operating speed. Coefficient of determination of this model was 0.29. Ottesen and Krammes [13] developed operating speed model in curves with the approach tangent speed as an independent variable. Because it wasn't possible to develop an appropriate model for long tangents, a constant value of 97.7 km/h was considered as the desired speed on long tangents.
Although numerous studies have been developed in order to determine operating speeds, most of them were based on spot speeds and certain assumptions about drivers' behavior. The lowest speeds along the horizontal curves and highest speeds along tangents are considered to be the desired drivers' speeds. The researchers collected speed data at specific locations of a roadway, mostly at the middle point of horizontal curves and tangents, or 200 m before the end of tangents [14] using a radar gun or a similar device. Due to the lack of data, many models used the assumption of a constant speed along the horizontal curve. These assumptions may not be realistic [15]. Except for the unrealistic assumptions of driver behaviour, there are also some other disadvantages of spot speed data measuring, like cosine error, drivers changing their behaviour in the presence of test equipment, and human error when reading data from the device display [8].
Because of many shortcomings of spot speed measurement and with the development of technology, more and more researchers focus on continuous speed data. In the past decade, several operating speed studies have been conducted based on continuous measured data using a GPS device [10], [15], [16]. In this paper is analyzed whether shortcomings of spot speed measurement have impact on a quality of operating speed model.

2 Data collection

Test rides with vehicles equipped with a 10Hz GPS data logger, which measures speed, position, curvature, acceleration and heading, were carried on a 20 km long road segment of state road D1 (Figure 1).
The analyzed road segment is a two-lane rural state road with a relatively low traffic volume (the average annual daily traffic is about 1400 veh/day) and no intersections with major roads. The test rides were recorded during the day under optimal weather and free flow conditions, i.e. the headway between the test vehicle and the preceding or the following vehicle was greater than 5 seconds, in order to reduce the conditions not related to the geometry of the alignment [12], [14], [17].
Geometric characteristics of the road segment were obtained from the main road design and were verified using detailed geodetic as-built alignment data. Operating speed prediction models were developed based on the speed data from an 18 km long road segment, and the model validation was made with the data from an 2 km long segment of the road. The analyzed 18 km long section consists of 64 horizontal curves with radii varying from 85 to 1010 m and 64 tangents with lengths varying from 10 to 683 m. Geometric characteristics of the analyzed road segment are presented in Table 1.
The test driver sample consisted of 20 people with ages ranging from 23 to 60 years and with different driving experiences (from 5 to more than 30 years). The test vehicles were personal cars of different types and ages.
The values and locations of the maximum speeds on tangents section were determined from each ride's continuous speed profile. Also, the speeds in the middle of tangent section as well the speeds 200 m before the end of long tangents were recorded.

Figure 1 Analyzed segment of the state road D1

Table 1 Geometric characteristics of the analyzed road segment

Element	Geometric characteristics	Min	Max	Mean	St. Dev.
Curve	Radius [m]	85	1010	300	229
	Length [m]	40	440	147	99
	Deflection [°]	4	118	41	28
	Elevation [%]	2	7	3.4	1.4
Tangent	Length [m]	0	683	101	110
Spiral	Length [m]	0	60	32	10
Hor. Alignment	Grade [%]	0.5	6	2.1	1.5

The values of operating speeds V_{85} determined from the continuous speed data collected on the 18 km long road segment were used for analyzing the locations and values of speeds on tangents relevant to the development of operating speed models. After defining the relevant speeds, the operating speed prediction models for tangent sections were developed based on the geometric characteristics of the road.

3 Analysis of data

3.1 Speeds on tangent sections

On short tangents the maximum speeds are dispersed all over tangent length, depending on the preceding and the following curve radius, as well as on the driving style of each driver. It wasn't possible to find a general rule for the location of the maximum free flow speeds. On long tangents (>150 m) most of the maximum operating speeds are located in the middle of the tangent. Table 2 presents the data about tangent length (T), the radius of curve before and the radius of curve after the tangent (R_{bef} and R_{aft}), the location of the maximum operating speed, the maximum operating speed (V_{85_max}), the operating speed 200 m before the end of the tangent (V_{85_200}) and the operating speed in the middle of the tangent (V_{85_middle}) for some of the long tangents. Location 1 represents the maximum speed achieved in the first part of the tangent length, location 2 is for the second part and location 3 is for the third part of the tangent. The maximum difference between V_{85_middle} and V_{85_max} is 4%. The maximum difference between V_{85_middle} and V_{85_200} is 2%.

Table 2 Speed data on long tangents.

Tangent No.	T [m]	R_{bef}	R_{aft}	location	V_{85_max}	V_{85_200}	V_{85_middle}
T18	336	350	250	2	87,8	86,6	97,7
T41	683	610	350	3	106,0	102,0	115,4
T43	230	840	320	1	98,4	97,9	109,1
T49	370	900	600	2	99,3	97,8	109,0
T51	470	350	310	2	94,9	92,4	104,8

The continuous data collected in this study showed that the assumptions that drivers reach their highest speeds in the middle of tangents, or 200 m before the end of tangent, and reach their lowest speeds in the middle of horizontal curves, are not realistic, in general. The average difference is 2% while the maximum difference is 4%.

Based on the results of data analysis, it can be assumed that the disparity of locations and values of the minimum and maximum speeds and other spot speed data measurements shortcomings could be a reason for low correlation between the operating speed on tangents and the geometric characteristics of the road for the models developed on spot speed data. Therefore, in this study, operating speed models for the maximum values of speed on tangents as well as for the speeds in the middle of the tangents were developed and compared.

4 Operating speed models on tangent sections

Operating speeds models for tangent sections are developed based on two sets of data. The first data set represents the maximum operating speeds on tangent sections, and the second set represents operating speeds in the middle of the tangents.

Operating speed models on tangent sections usually use linear regression, including variety of geometric characteristics of the alignment [11]. The independent variables chosen for the analysis in this study are tangent length (T), radius of the previous and following curve (R_{bef} and R_{aft}), deflection angle of the previous and following curve, length of the previous and following curve, length of the previous and following spirals and grade.

Stepwise multiple linear regression indicated tangent length T, radius of the previous curve R_{bef} and radius of the following curve R_{aft} as statistically significant independent variables. Other variables did not have significant impact on the coefficient of determination. Several models were examined and the best fit model for predicting the maximum operating speeds on tangent section was:

$$\hat{V}_{85}^{T} = 13 + 6{,}92 \cdot \ln R_{bef} + 3{,}69 \cdot \ln R_{aft} + 2{,}97 \cdot \ln T \quad (1)$$

The model shows a high coefficient of determination $R^2 = 0.85$ as well as an adjusted coefficient of determination $R^2_{adj} = 0.85$. In addition each coefficient has a high t-statistic with p value less than 0.0001, indicating the significant contribution of both variables to the model. Logarithmic function is used because it can describe the dependence between speed and tangent length better than a linear function. Namely, increasing the length of a short tangent results in significant increase in speed, while increasing the length of long tangents results in minor increase of speed, and this is described well by the logarithmic function. The quality of the model is further evaluated using mean absolute percentage error (MAPE) defined as:

$$\mathrm{MAPE} = \sum_i \left| \frac{\hat{V}_{85}^T - V_{85}^T}{V_{85}^T} \right| \tag{2}$$

The overall MAPE for the data from the 18 km long segment is 3.1% and the maximum individual absolute percentage error (APE) is 11.5%.
Validation of the model is performed on the 2 km long test section outside the section used for model development. The MAPE of the model is 1.9 % and the maximum individual APE is 4.1%. The second set of data, i.e., the operating speeds in the middle of tangent, resulted in slightly different model parameters, but with same R^2 and MAPE as the described model. It indicates that it does not make much of a difference which recorded data is used for the development of tangent speed model.
The obtained results of models are very good, especially in comparison with the models developed on spot speed data measured by a laser gun. Thus, it can be concluded that the method of measurement has a more significant impact on the quality of tangent speed prediction than the location of measurement. That is, the spot speed data collected by a radar gun or a similar device could be biased by the cosine error, drivers changing their behaviour in the presence of test equipment and the human error when reading data from the device display. Therefore, the continuous speed profile of drivers of different sex, age and experience driving their own cars represents the most reliable basis for developing tangent speed models. On the other hand, the continuous speed measurement is harder to carry out because of the need for a high number of test drivers which have to be properly chosen in order to represent the entire population in the sense of sex, age, driving experience and vehicle types. This study shows that continuous speed data can be used to develop a reliable model for prediction of operating speeds on tangents sections of various lengths, from short tangents in which vehicles face insufficient length to reach high speeds (so called non-independent tangents), to long independent tangents which permit vehicles to accelerate up to free-flow operating speeds.

5 Conclusions

This paper presents operating speed models on tangent sections based on the collected continuous speed data measured by a 10 Hz GPS device. Unlike spot speed methodologies, continuous speed data allows determination of the locations and unbiased values of the relevant operating speeds on tangents. Most previous speed models were based on the assumption that drivers reach their highest speeds in the middle of tangents. The continuous data collected in this study showed that these assumptions are not realistic. The locations of highest speeds on tangents differ from driver to driver and depend on the geometric characteristics of the preceding and the following elements of horizontal alignment.
However, the developed speed models showed that there is no significant difference in model parameters and coefficients of determination when the maximum speeds on tangents, or when the speeds in the middle tangents were used. Thus, it can be concluded that the method of measurement has a more significant impact on the quality of the tangent speed prediction than the location of measurement. That is, the spot speeds measured by a radar gun or a similar device has shortcomings such as the cosine error, drivers changing their behaviour in the presence of test equipment and human error when reading data from the device display, none of which is the case with the data from the continuous speed profile.
The developed operating speed models on tangents resulted in a high level of reliability. The advantage of the developed tangent speed model in comparison with other developed models is in that it can predict speeds on short and long tangents very reliably. These speeds can be used for evaluation of road design consistency. Another advantage is in that the developed models are based on the continuous speeds measured under true driving conditions for drivers of different age, aggressiveness and driving experience, driving their own cars of different type and age.

References

[1] Abdel-Aty, M.A., Radwan, A.E.: Modeling traffic accident occurrence and involvement. Accident Analysis & Prevention 32(5), 633-642. DOI:10.1016/S0001-4575(99)00094-9,2000.

[2] Hassan, Y.: Highway Design Consistency – Refining the State of Knowledge and Practice. Transportation Research Record 1881, 2004. Transportation research Board, National Research Council, Washington DC, pp. 63-71. doi: 10.3141/1881-08.

[3] Polus, A., Matter-Habib, C.: New Consistency Model for Rural Highways and Its Relationship to Safety. J.Transp. Eng., 2004., pp. 286-293, doi: 10.1061/(ASCE)0733-947X(2004)130:3(286).

[4] Ikeda, T., Mori, N.: Analysis of correlation between roadway alignment and traffic accidents. Third International Symposium on Highway Geometric Design 2005., TRB's Conference Recording series, pp. 69-88.

[5] Haynes, R., Lake, I., Kinghamb, S., Sabel, C., Pearce, J., Barnett, R.: The influence of road curvature on fatal crashes in New Zealand. Accident Analysis and Prevention, 40(3), 2008, pp. 843–850. doi:10.1016/j.aap.2007.09.013.

[6] Cafiso, S., Di Graziano, A., Di Silvestro, G., La Cava, G., Persaud, B.: Development of comprehensive accident models for two-lane rural highways using exposure, geometry, consistency and context variables. Accident Analysis & Prevention, 42(4), pp. 1072-1079. Doi :10.1016/j.aap.2009.12.015, 2010.

[7] De Luca, M., Dell'Acqua, G.: Freeway Safety Management: Case Studies in Italy, Transport 27(3) 2012., pp. 320-326. http://dx.doi.org/10.3846/16484142.2012.724447

[8] Misaghi, P., Hassan, Y.: Modeling operating speed and speed differential on two lane rural roads. J. of Transp. Eng., 2005, pp. 408-418, doi: 10.1061/((ASCE)0733-947X(2005)131:6(408).

[9] Modeling Operating Speed: Synthesis Report. Transportation Research Circular number E-C151, Transportation Research Board, 2011.

[10] Cafiso, S., Cerni, G.: New approach to defining continuous speed profile models for two-lane rural roads. Transportation Research Record 2309, Transportation research Board, National Research Council, Washington DC, pp. 157-167. doi:10.3141/2309-16, 2012.

[11] Polus, A., Fitzpatrick, K., Fambro, D.B.: Predicting operating speed on tangent sections of two lane rural highways. Transportation Research Record 1737, 2000. Transportation research Board, National Research Council, Washington DC, pp. 50-57, doi: 10.3141/1737-07.

[12] Bonneson, J.A.: Side Friction and Speed as Controls for Horizontal Curve Design. J. Transp. Eng., pp. 473-480, doi: 10.1061/(ASCE)0733-947X(1999)125:6(473).

[13] Ottesen, J., Krammes, R.A.: Speed-Profile Model for a Design Consistency Evaluation Procedure in the United States. Transportation Research Record 1701, 2000. Transportation research Board, National Research Council, Washington DC, pp. 76-85, doi: 10.3141/1701-10.

[14] Fitzpatrick, K. et al.: Design Speed, Operating Speed, and Posted Speed Practices. NCHRP, report 504, 2003.

[15] Wang, J.: Operating Speed Models for Low Speed Urban Environments Based on In-Vehicle GPS Data, Dissertation, Georgia Institute of Technology, 183 p., 2006.

[16] Pérez Zuriaga, A.M.: Characterisation and Modelling of Operating Speed on Conventional Roads Using Naturalistic Observation of Light Vehicles. Universitat Politècnica de València, Department of Transport Infrastructure and Engineering, doctoral thesis, 2012.

[17] Said, D., Hassan, Y., Abd El Halim, A.O.: Comfort thresholds for horizontal curve design. Canadian Journal of Civil Engineering, Volume 36, Number 9, 2009, pp.1391-1402, doi: 1391-1402, 10.1139/L09-075.