DEVELOPMENT OF A GLOBAL INERTIAL CONSISTENCY MODEL TO ASSESS ROAD SAFETY ON SPANISH TWO-LANE RURAL ROADS

Corresponding Author:
David Llopis-Castelló
PhD Researcher
Highway Engineering Research Group (HERG)
Universitat Politècnica de València
Camino de Vera, s/n 46022, Valencia, Spain
Tel: (34) 96 3877374
E-mail: dallocas@doctor.upv.es

Other Authors:
Francisco Javier Camacho-Torregrosa
Assistant Professor
HERG
Universitat Politècnica de València
E-mail: fracator@tra.upv.es

Alfredo García
Professor
HERG
Universitat Politècnica de València
E-mail: agarciag@tra.upv.es

Submission Date: 11th December 2017

ABSTRACT

The most important factors for road crash occurrence are infrastructure, vehicle, and human factors. In fact, infrastructure and its interaction with human factor have been thoroughly studied in recent years through geometric design consistency, which can be defined as how drivers' expectations and road behavior relate.

Global consistency models were calibrated in the last decade to assess road safety on an entire homogeneous road segment. However, none of them include the underlying consistency phenomenon in their formulation.

Recently, a new model was developed based on the difference between the inertial operating speed profile, which represents drivers' expectancies, and the operating speed profile, which represents road behavior. While the operating speed represents the estimated operating speed for every location along the road, the inertial operating speed aggregates for every station the operating speed effect along some distance already covered by drivers. The authors hypothesized that this 'aggregation effect' was connected to drivers' expectancies, which proved to be true based on the best model fitted. However, the exact distance (or time) that should be considered to estimate the inertial operating speed still remains unknown. This paper aims to complete this model, analyzing how the inertial operating speed varies depending on different distances and periods of time. This impact is measured considering the reliability of the corresponding consistency model. The paper also covers how the inertial operating speed should be determined along the final distance or time. For this, a total of 184 homogeneous road segments along 650 kilometers in Spain were used.

Keywords: *geometric design consistency, road safety, operating speed, inertial operating speed, driver's behavior*

1. INTRODUCTION

Road safety is one of the major concerns in our society. In fact, approximately 1.2 million people die and 50 million are injured in road crashes every year. This makes road crashes the main cause of death for people aged 15-29 (WHO, 2015).

In Spain, 1,291 fatalities occurred on rural roads in 2016, of which more than 70% occurred on two-lane rural roads. Although the number of crashes has been in decline on rural roads since the beginning of the century, the fatalities have increased in recent years on two-lane rural roads. In addition, this type of road represents approximately 90% of the road network in this country, so two-lane rural roads play a pivotal role in road safety (DGT, 2017).

The most important factors for road crash occurrence are infrastructure, vehicle, and human factors. Particularly, the infrastructure factor is responsible for over 30% of road crashes (Treat et al., 1979). In fact, crashes tend to concentrate at certain road elements. For this, infrastructure and its interaction with human factor have been thoroughly studied in recent years through geometric design consistency, which can be defined as how drivers' expectations and road behavior relate.

Road behavior can be defined as the general performance of its alignment (e.g. sharpness, design speed, etc.). Drivers tend to perform according to the road geometry, but the expectancies based on the road segment immediately covered also play an important role. Thus, a consistent road provides a harmonious driving free of surprises, whereas an inconsistent road design might produce numerous unexpected events to drivers, leading to anomalous behavior and increasing the likelihood of crash occurrence.

Among the different methods to assess geometric design consistency, the most commonly used is based on the analysis of the operating speed profile (Gibreel et al., 1999). Operating speed is frequently defined as the 85th percentile of the speed distribution for passenger cars under free-flow conditions with no external restrictions (V_{85}). One important advantage of its use is the possibility to estimate it using operating speed models.

There are two types of consistency models: local and global. Local models focus on localized issues, such as sudden speed reductions or large differences between the design and operating speeds. Those models are ideal to identify where road crashes are more likely to occur. On the other hand, global consistency models examine the overall speed variation throughout an entire road segment. Although they do not indicate where crashes are prone to take place, they can be introduced into a Safety Performance Function (SPF) to predict the number of crashes on an entire road segment.

To this regard, several researchers have tried to relate the number of crashes to different variables related to risk exposure (traffic volume and road length), geometry, consistency, and road environment by means of SPFs. Among those studies which incorporate the consistency as an explanatory variable, all of them concluded that the level of consistency has a major influence on road crash occurrence (Anderson et al., 1999; Ng and Sayed, 2004; Awatta et al., 2006; Montella et al., 2008; Cafiso et al., 2010; de Oña et al., 2013; Quddus, 2013; Wu et al., 2013; Garach et al., 2014; Camacho-Torregrosa, 2015; Montella and Imbriani, 2015; Garach et al., 2016).

The first global consistency model was developed by Polus and Mattar-Habib (2004), which was based on two parameters: relative area (Ra) and operating speed dispersion (σ). The first parameter was defined as the area bounded by the operating speed profile and the average operating speed, divided by the length of the road segment. The same parameters were used by Garach et al. (2014) to calibrate a new consistency model on Spanish two-lane rural roads (Table 1).

Later, Camacho-Torregrosa (2015) developed another global consistency model considering two operational parameters: the average operating speed ($\overline{V_{85}}$) and the average deceleration rate ($\overline{d_{85}}$). The first parameter is the average value of the operating speed along the entire road segment, measured in m/s. The second one is the average value of the decelerations of the same operating speed profile, in m/s^2. Additionally, this research analyzed the influence of the selection of homogeneous road segments on the estimation of road crashes (Table 1).

Regarding this, the selection of the road segment is critical for the application of global consistency models. Selected road segments must be homogeneous, because the results depend on its selection (Resende and Benekohal, 1997; Cafiso et al., 2010; García et al., 2013a; Camacho Torregrosa, 2015).

TABLE 1 Previous global consistency models

Global consistency model	Consistency parameter (C)	Consistency level		
		Good	Fair	Poor
Polus and Mattar-Habib (2004)	$2.808 \cdot e^{-0.278 \cdot Ra \cdot \frac{\sigma}{3.6}}$	$C > 2$	$1 < C \leq 2$	$C \leq 1$
Garach et al. (2014)	$\frac{195.073}{\left(\frac{\sigma}{3.6} - 5.7933\right) \cdot (4.1712 - R_a) - 26.6047} + 6.7826$	$C > 2$	$1 < C \leq 2$	$C \leq 1$
Camacho-Torregrosa (2015)	$\sqrt[3]{\frac{V_{85}}{d_{85}}}$ $(s^{1/3})$	$C \geq 3.25$	$2.55 \leq C < 3.25$	$C < 2.55$

However, none of these consistency models include the underlying consistency phenomenon in their formulation, i.e., they do not contain a variable which represents and estimates drivers' expectancies.

To this regard, García et al. (2013b) defined a new speed concept: the inertial operating speed (V_i). This speed is used to represent drivers' expectancies and was defined as the average operating speed along the preceding 1,000 m road segment. Conversely, road behavior was associated with the operating speed (V_{85}). A new local consistency parameter, the Inertial Consistency Index (ICI), was defined as the difference between V_i and V_{85}. Therefore, the larger this index, the greater the difference between drivers' expectancies and road behavior, being crashes more likely to appear.

However, this definition of the inertial operating speed does not match the drivers' expectancies acquirement process, which is closely related to Short-Term Memory (STM). To this regard, STM is gradually in decline over time, being the information lost in approximately 18 seconds (Revlin, 2012).

Drivers do not recall with the same intensity all locations of the previous road section. Therefore, the first and final parts of the section should not be equally considered to determine the inertial operating speed. In addition, given two homogeneous road segments with different average operating speeds, the periods of time needed to cover the same distance differ.

Recent studies have been used to identify how the inertial operating speed should be calculated on Italian two-lane rural roads (Llopis-Castelló et al., 2017 and 2018). As a conclusion, an inertial operating speed estimated as the weighted average operating speed based on time was able to better represent drivers' expectancies than a V_i based on distance and calculated as a simple average of the operating speed. In addition, a global consistency model was developed based on the difference between the inertial operating speed profile and the operating speed profile. As a result, this consistency model allowed a more accurate estimation of the number of crashes than the previous global models mentioned above.

Due to the successful performance of the inertial consistency models calibrated in Italy, this study presents an attempt to enhance the accuracy of the estimation of the inertial operating speed by examining a greater number of road sections and considering more weighting distributions. As a result, a new global consistency model is presented.

2. OBJECTIVES AND HYPOTHESES

The main objective of this research is to develop a new global consistency model comparing the difference between the inertial operating speed and the operating speed with the number of crashes on Spanish two-lane rural roads.

To this regard, the inertial operating speed was studied considering new weighting distributions to get as close as possible to Short-Term Memory behavior. This will allow identifying how the inertial operating speed should be calculated to estimate drivers' expectancies in a more accurate way.

The underlying hypothesis is that an inertial operating speed profile based on time will allow a more accurate estimation of the number of crashes than those based on distance. Likewise, the greater the difference between inertial operating speed profile and operating speed profile, the worse the consistency.

3. METHODOLOGY AND DATA DESCRIPTION

3.1. Methodology

The methodology of this study was similar to those used in Llopis-Castelló et al. (2018a and 2018b). Two-lane rural road sections were selected. Next, the geometry for each road section was recreated by means of the methodology proposed by Camacho-Torregrosa et al. (2015), which uses an algorithm based on the heading direction. The operating speed profiles were estimated considering the models developed by Pérez-Zuriaga (2012), which were calibrated for Spanish two-lane rural roads with the same characteristics than those road sections considered in this research. From this, different inertial operating speed profiles were calculated for each road segment considering different distances, periods of time, and weighting distributions. Crash and traffic data were also obtained. Finally, the relationship between crashes and consistency was studied calibrating several Safety Performance Functions. As a result, the inertial operating speed profile that better represents drivers' expectancies was identified, and consistency thresholds were defined.

3.2. Road segments

A total of 98 two-lane rural road sections located in the Valencian Region (Spain) were selected for the study. This required the geometric recreation of more than 650 km of highway resulting in 184 homogeneous road segments, which were identified by means of the following procedure.

First, road segments were divided into sections with similar traffic volume and cross-section. Major intersections also influence drivers' expectancies, so they were also considered for segmentation. Finally, each road section was divided according to its geometric behavior using the German methodology, which is based on the analysis of the Curvature Change Rate (*CCR*). This parameter is defined as the rate between the sum of the absolute deflection angles and the length of the road segment. Figure 1 shows how this last step is carried out: a profile of the cumulative absolute deflection angle versus the road station must be plotted. In this way, homogeneous road segments can be distinguished according to similar *CCR* behavior.

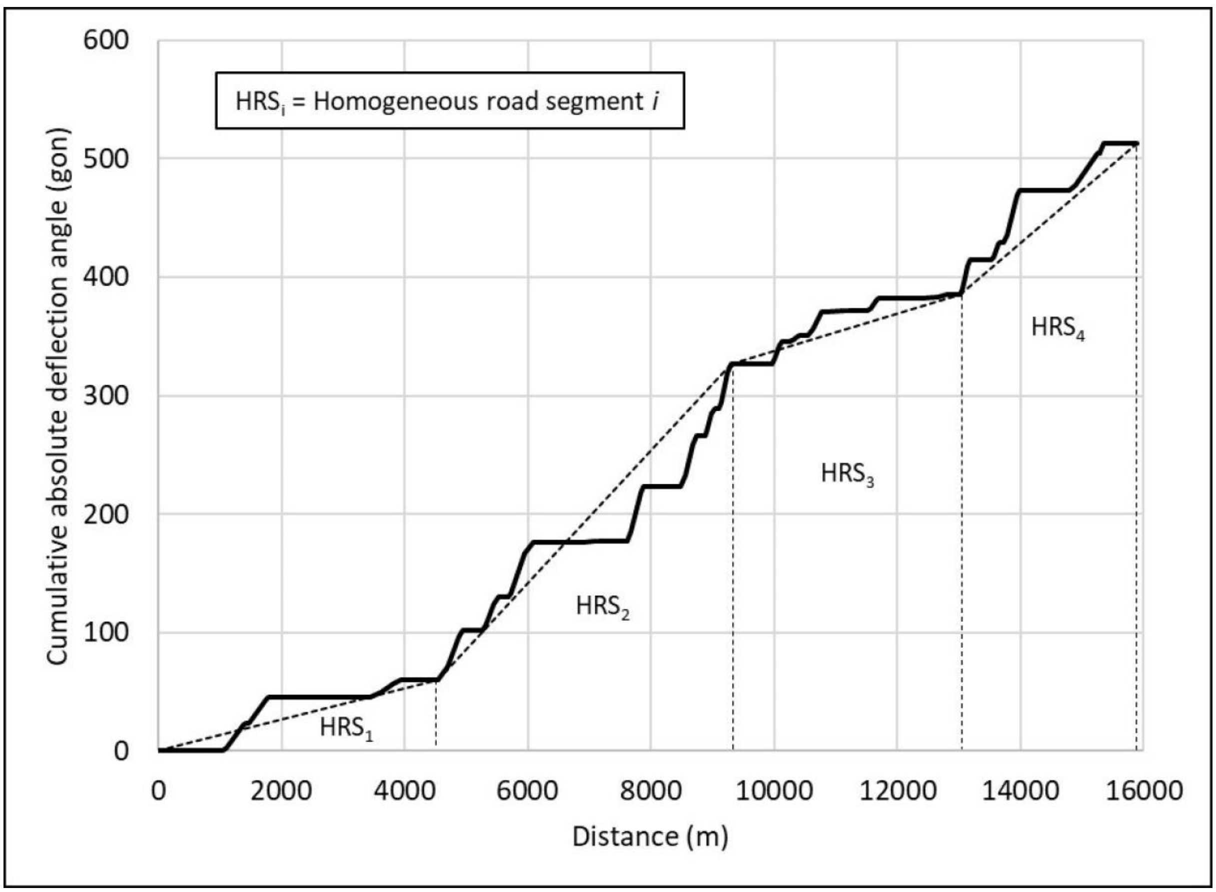


FIGURE 1 Identification of homogeneous road segments.

Table 2 shows the main geometric characteristics of the studied homogeneous road segments. In addition, most of them present similar cross-section features with lane widths between 3.00 and 3.50 m, and shoulder widths between 0.5 and 1.50 m. Their longitudinal grade did not exceed 5%.

TABLE 2 Statistical summary of the homogeneous road segments

	Minimum	Maximum	Average	Standard deviation
Length (m)	1,146	10,851	3,535	1,593
CCR (gon/km)	0	1,078	209	101.91
AADT (vpd)	465	10,817	2,641	2,065
Crashes	0	48	7.57	7.53

3.3. Traffic and crash data

Traffic volume and crash data were provided by the Department of Housing, Public Works, and Spatial Planning of the Valencian Regional Government and the General Directorate of Traffic (Dirección General de Tráfico, DGT) of the Spanish Government, respectively. Thus, the Annual Average Daily Traffic (*AADT*) volumes and the number of fatal-and-injury crashes were identified for each homogeneous road segment.

AADT was defined as the average traffic volume from 2002 to 2011. In this way, the homogeneous road segments presented an *AADT* ranging from 465 to 10,817 vpd (Table 2). Additionally, the variability of the traffic volume over time was analyzed through the coefficient of variation (*CV*) for each homogeneous road segment. As a result, the mean *CV* and its standard deviation were 21% and 10%, respectively. Therefore, the traffic variation along the studied years can be considered low.

Only fatal-and-injury crashes were considered in the same period of time. The cause of every crash was reviewed to only include those related to geometry (e.g., crashes caused by vehicles entering the road from minor roads or driveways were removed from the analysis, since their cause is not the road geometry per se). As a result, a total of 1,392 reported crashes were considered (Table 2).

3.4. Speed profiles

3.4.1. Operating speed profiles

The operating speed profile for each road segment was estimated using the operating speed profile model developed by Pérez-Zuriaga (2012), which was calibrated based on speed data collected on Spanish two-lane rural roads with the same characteristics of the road sections considered in this study (Table 3). As a result, the operating speed was obtained meter by meter (Figure 2).

TABLE 3 Speed models developed by Pérez-Zuriaga (2012)

Type of road element		Equation
Horizontal curve		$V_{85,C} = 106.863\text{-}\ 60.1185/\mathrm{e}^{0.00422596 \cdot R}$
Tangent	$L \geq 700$ m	$V_{85,T} = \sqrt{-1{,}464.72 + 351.288 \cdot \sqrt{L}}$
	$L < 700$ m & $R_1 \leq 600$ m	$V_{85,T} = 0.362739 \cdot V_{85,C1} + 59.6982/e^{-0.0000472302 \cdot GM}$
	$L < 700$ m & $R_1 > 600$ m	$V_{85,T} = =\sqrt{7{,}399.27 + 3.03956 \cdot L}$
Acceleration rate		$a_{85} = 1/(\text{-}1.49325 + 0.548458 \cdot \ln(R))$
Deceleration rate		$d_{85} = \sqrt{-0.0652071 + 201.174/R}$

where $V_{85,C}$ is the operating speed on horizontal curves (km/h); $V_{85,T}$ is the operating speed on tangents (km/h); a_{85} is the acceleration rate (m/s^2); d_{85} is the deceleration rate (m/s^2); $V_{85,C1}$ is the operating speed on the previous horizontal curve (km/h); R is the radius of the horizontal curve (m); R_1 is the radius of the previous horizontal curve (m); R_2 is the radius of the successive horizontal curve (m); L is the length of the tangent (m); and GM is the following geometric index (m^2):

$$GM = \frac{L \cdot (R_1 \cdot R_2)^{0.5}}{100}$$

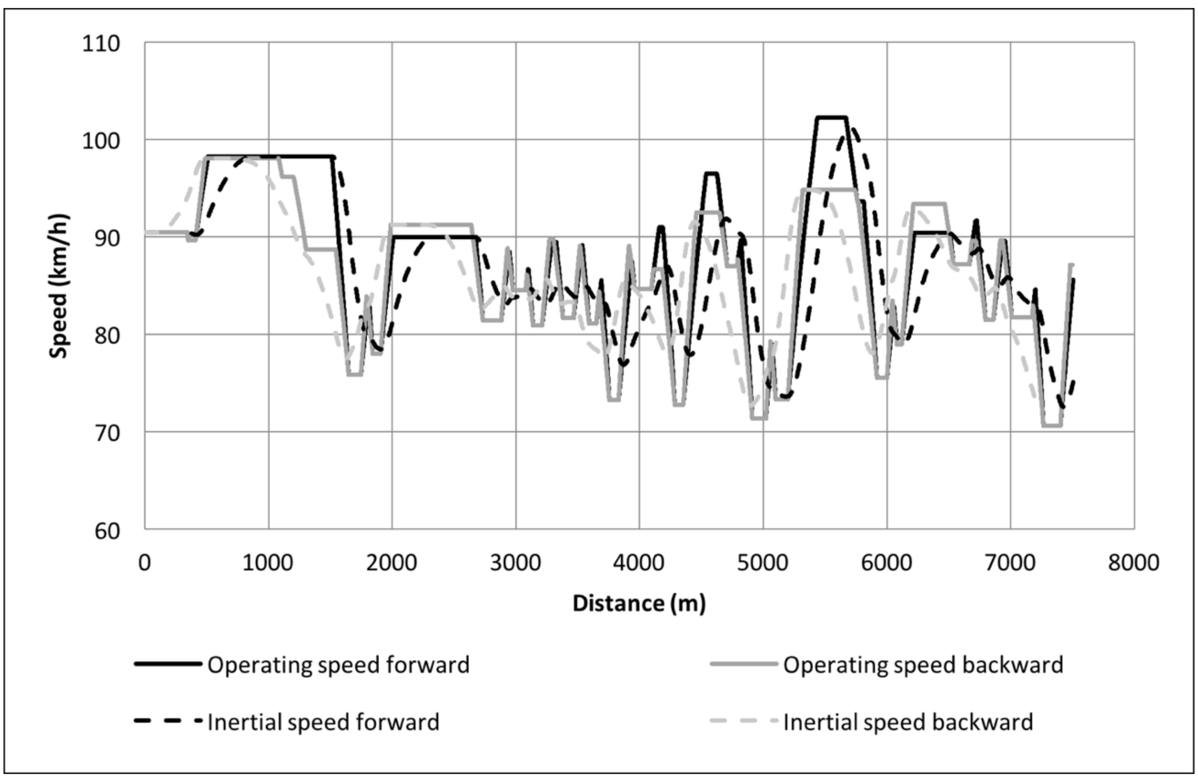


FIGURE 2 Speed profiles

3.4.2. Inertial speed profiles

The inertial operating speed profile was calculated for every road segment on the basis of its operating speed profile. To do this, the inertial operating speed was calculated for every station as the weighted average operating speed of the preceding road section by means of the following equation:

$$V_{i,k} = \frac{\sum w_j \cdot V_{85,j}}{\sum w_j} \qquad (1)$$

where $V_{i,k}$ is the inertial operating speed (km/h) at station k; $V_{85,j}$ is the operating speed at station j; and w_j is the weighting factor at point j. Depending on the range covered by j, the result of the operating speed will vary.

Inertial operating speeds were determined with the following distance and time parameters:

- Distances (L) between 300 m and 800 m with a step of 100 m
- Periods of time (t) between 10 s and 40 s, with a step of 5 s

In addition, 11 weighting distributions were considered. The weighting distributions were based on a parabolic functional form (ax^2+bx+c). These distributions could take values from 0 to 1, increasing as the station j gets closer to the critical section k, with these constraints:

- $w_j = 0$ for the first station j considered for the calculation. It is the threshold between the zone that has not been included in the calculation (because it has no influence on driver's behavior), and the zone under consideration.
- $w_j = 1$ for $j = k$. It means that the station where the driver actually is located at a certain moment has to be the most important for the expectancy formation.

As a result, the parabolic function can only take certain a, b, and c parameters. Moreover, it can be rewritten as a function of a single parameter α, which varies between 0 and 10 (Figure 3). In this equation, n is the number of intervals considered in the calculation. The number of the intervals (n) depended on whether the calculation was carried out considering a distance (L), in meters; or a period of time (t), in seconds. In the first case, n was equal to L (i.e., the calculation was performed meter by meter), whereas in the second case, n was equal to $10 \cdot t$, so the inertial operating speed was calculated considering intervals of 0.1 s.

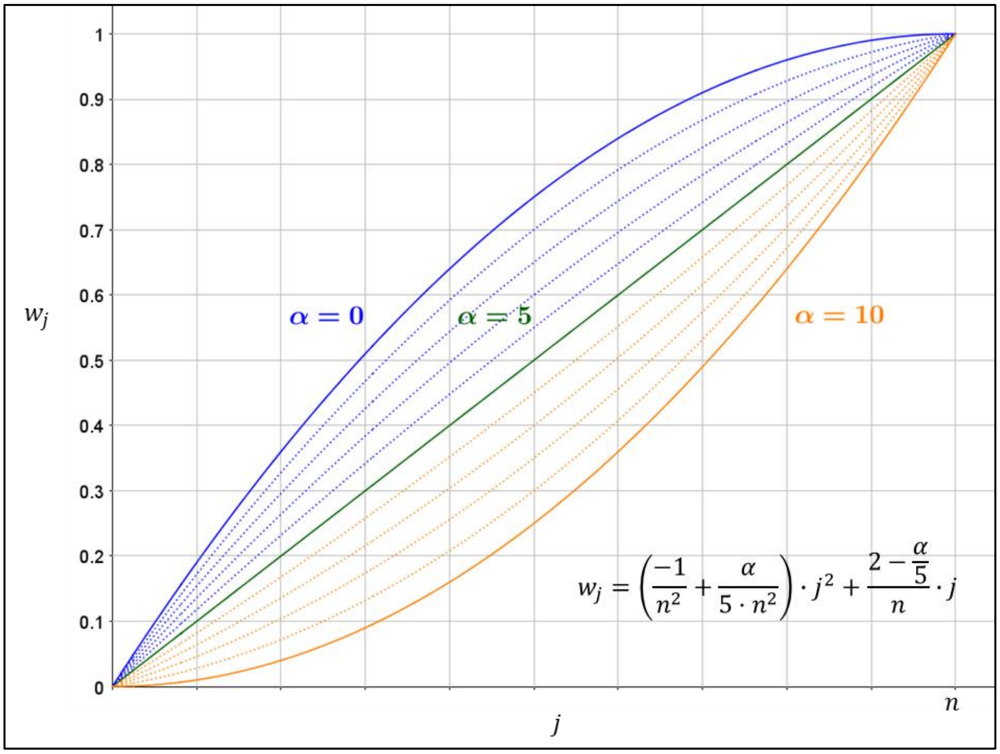


FIGURE 3 Weighting distributions.

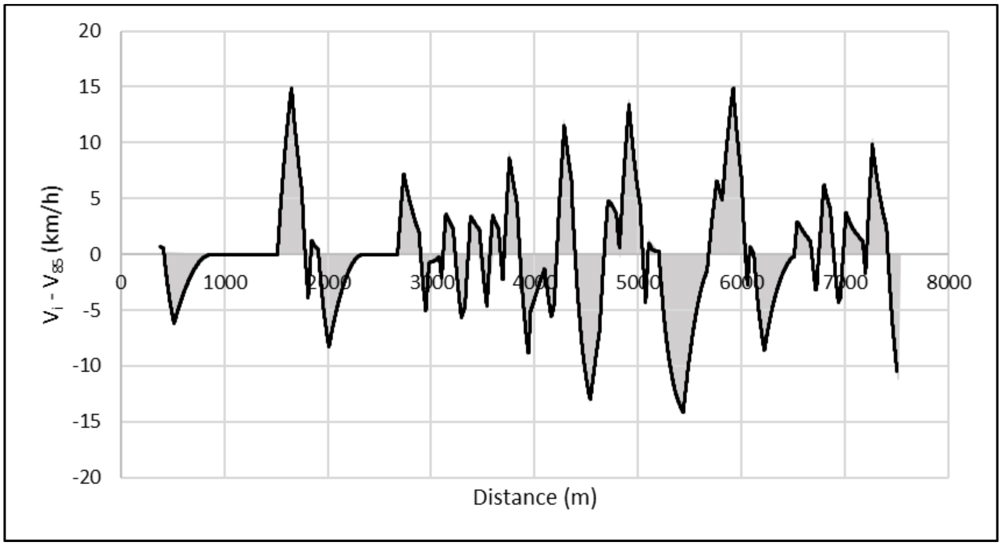
As a result, 143 ((6 distances + 7 periods of time) x (11 weighting distributions)) inertial operating speed profiles were obtained for each homogeneous road segment. As an example, Figure 2 shows the operating speed profile and its corresponding inertial operating speed profile considering 15 s and a linear weighting distribution for one of the road segments under study.

3.5. Consistency parameters

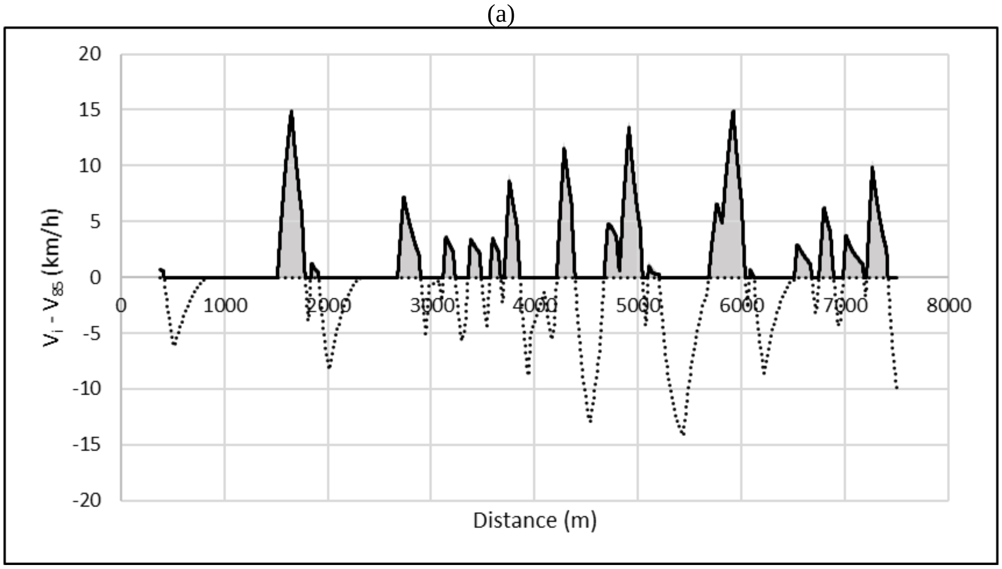
The consistency parameters depend on several variables defined from the difference between V_i and V_{85} (Llopis-Castelló et al., 2017 and 2018). As an example, Figure 4 shows the speed differences between both speed profiles only considering forward direction. According to this definition, a positive difference means that drivers' expectancies might not be achieved, because drivers' speed is lower than the speed they were maintaining in the last section. Therefore, the likelihood of crashes increases with the magnitude of these differences.

The consistency parameters were based on the combination of the following, simpler parameters for every road segment (Figure 4):

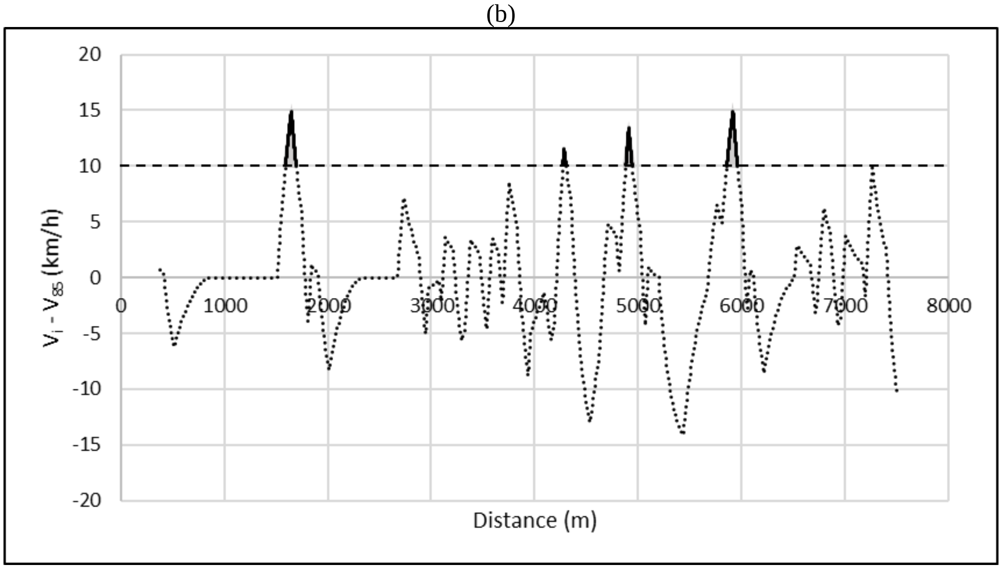
- *A* (m·km/h): area bounded by the difference between V_i and V_{85}, and the x axis (shaded area in Figure 4a).
- *L* (m): length of the road segment.
- *σ* (km/h): standard deviation of the difference between V_i and V_{85} (standard deviation of the profile in Figure 4a).
- *A(+)* (m·km/h): area bounded by the difference between V_i and V_{85} considering only the positive differences (shaded area in Figure 4b).
- *L(+)* (m): length of the road segment considering only the positive differences between V_i and V_{85} (length of the road segment highlighted in Figure 4b).
- *σ(+)* (km/h): standard deviation of the difference between V_i and V_{85} considering only the positive differences (standard deviation of the profile in Figure 4b).
- *A(> x km/h)* (m·km/h): area bounded when the difference between V_i and V_{85} is higher than x km/h (shaded area in Figure 4c).



(a)



(b)



(c)

FIGURE 4 Consistency variables: (a) A, L and σ; (b) A(+), L(+) and σ(+); and (c) A(> x km/h).

Table 4 summarizes the consistency parameters (Llopis-Castelló et al., 2017 and 2018). All of them are expressed in terms of speed (km/h), making their interpretation easier compared to other consistency models. In all cases, a higher value of the parameter indicates a lower consistency level.

TABLE 4 Consistency parameters

Parameter	Equation
1	$\sqrt{\frac{A(+)\cdot\sigma}{L}}\ [km/h]$
2	$\sqrt{\frac{A\cdot\sigma}{L}}\ [km/h]$
3	$\frac{A(+)}{L(+)}\ [km/h]$
4	$\frac{A(>10\ km/h)}{L}\ [km/h]$
5	$\frac{A(>15\ km/h)}{L}\ [km/h]$
6	$\frac{A(>20\ km/h)}{L}\ [km/h]$
7	$\sqrt{\frac{A(+)\cdot\sigma(+)}{L(+)}}\ [km/h]$
8	$\sqrt{\frac{A(+)\cdot\sigma}{L(+)}}\ [km/h]$

4. ANALYSIS

A total of 1,144 Safety Performance Functions (SPF) were calibrated to identify how the inertial operating speed should be calculated. This was the result of the combination of the 143 inertial operating speed profiles and 8 consistency parameters.

A SPF is an expression that relates risk exposure and consistency to the number of crashes. Following common practice, generalized linear modelling techniques were used to fit these functions (Equation 2), and a negative binomial distribution was assumed, since it is an appropriate solution with overdispersed, count data (Lord et al., 2010).

$$\boldsymbol{Y_{i,10} = e^{\beta_0} \cdot L^{\beta_1} \cdot AADT^{\beta_2} \cdot e^{\beta_3 \cdot C}} \quad (2)$$

where $Y_{i,10}$: fatal-and-injury crashes on the road segment in 10 years; β_i: regression coefficients; L: length of the road segment (km); *AADT*: Average Annual Daily Traffic (vpd); and *C*: consistency parameter (km/h).

In this expression, *AADT* is not set as an offset variable (i.e., crash rate decreases with traffic volume, which is generally accepted and meets SPFs developed by other researchers). However, the length is neither set as an offset variable, which is quite more controversial. At a first glance, this expression form is not adequate, since the estimated amount of crashes depends on how the road network is divided into road segments. This controversial expression has also been used by other researchers (Mehta and Lou, 2013; Srinivasan et al., 2016; Garach et al., 2016; Camacho-Torregrosa, 2015; Llopis-Castelló et al., 2018a and 2018b). The key is that SPFs not showing the length as an offset variable must also indicate how the road network should be divided into road homogeneous segments – thus, there is just a single possible outcome of road crashes. In fact, Camacho-Torregrosa (2015) demonstrated that more accurate SPFs could be calibrated considering the length as an elasticity term. Furthermore, he classified homogeneous road segments into two categories: constrained and free. Constrained road segments are those that begin – or end – in an urban zone or major intersection. Otherwise, the road segment is free. Therefore, at constrained road intersections drivers are aware of entering into a new road segment, with new characteristics. As a result, they subconsciously pay more attention to the road behavior (in order to create their new expectancies), leading to lower crash rates. After some distance, this expectancy-acquisition process vanishes, so crash rates increase. This leads to a SPF in which the exponent affecting the length is higher than 1. On the other hand, at the beginning of free road segments, drivers are not aware of the change of the road segment, so they compare the new road behavior to the ad hoc expectancies formed along the previous road segment. Therefore, more crashes are expected at the beginning of these kind of road segments. After travelling some distance, they readapt their expectancies to the new road behavior, so crash rates tend to decrease. Therefore, the exponent affecting the length was found to be lower than 1. In fact, for long road segments, the crash rate outcome was found to be nearly the same for free and constrained road segments.

The *AIC* (Akaike Information Criterion) index was obtained for all regressions as a measure of goodness of fit. The smaller the *AIC* value, the better the model. Additionally, the Root Mean Square Error (*RMSE*) and the Mean Absolute Error (*MAE*) were calculated for the most accurate models (Table 5).

However, it is well known that crashes are highly affected by the exposure. Thus, a single-exposure SPF was previously calibrated to determine how important the inclusion of the consistency term is for crash prediction:

$$y_{i,10} = e^{-5.05097} \cdot L^{0.84111} \cdot AADT^{0.76993} \qquad AIC = 998.97 \qquad (3)$$

To this regard, most of the calibrated SPFs which jointly considered risk exposure and consistency produced a lower *AIC* value than the single-exposure SPF, so the level of consistency had a major influence on road crash occurrence.

The consistency parameters showing better results were parameters 7 and 8. These parameters were mainly obtained by means of the positive differences between the inertial operating speed profile and the operating speed profile. The only difference between both parameters was that parameter 7 was calculated considering $\sigma(+)$, whereas parameter 8 depended on σ (Table 4). This meant that the positive difference between both speed profiles was able to represent where drivers' expectancies were not achieved. Although parameter 8 showed lower *AIC* values than parameter 7, parameter 7 presented the lowest values of *RMSE* and *MAE* (Table 5).

Regarding the calculation of the inertial operating speed, different segment lengths resulted in reasonable results. To analyze this phenomenon more thoroughly, the homogeneous road segments were divided into free and constrained segments according to Camacho-Torregrosa (2015). In this way, constrained road segments showed better results using 500 m, whereas free segments performed better with 400 m (Table 5).

However, the best results regarding time did not depend on the type of road segment. To this regard, the inertial operating speed profile was calculated considering 15 s.

Therefore, a time-based inertial operating speed profile led more consistent results than the calculation of this profile based on distance. This might be due to the mean operating speed, which was different for each type of road segment. Then, different distances are achieved for the same period of time.

Finally, the weighting distributions were studied. As a conclusion, the best consistency models used weighting distributions with values of the parameter α between 5 and 10.

TABLE 5 Best consistency models

Model*	Consistency parameter		β_0 -	β_1 ln *L*	β_2 ln *AADT*	β_3 *C*	Overdispersion θ	*AIC*	*RMSE*	*MAE*
(a) All road segments										
$L_{500,5}$	7	Estimate	-13.4366	1.01182	0.83972	0.1322	6.07	974.02	4.27	3.03
		Pr(>|z|)	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$4.58\cdot10^{-8}$				
$t_{15,10}$	7	Estimate	-13.7030	1.02146	0.85711	0.18027	6.04	976.06	4.21	3.04
		Pr(>|z|)	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$1.99\cdot10^{-7}$				
$L_{500,5}$	8	Estimate	-14.0447	1.04579	0.88047	0.11514	6.08	972.64	4.32	3.07
		Pr(>|z|)	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$2.3\cdot10^{-8}$				
$t_{15,10}$	8	Estimate	-14.1939	1.04805	0.89429	0.15059	6.00	974.49	4.30	3.11
		Pr(>|z|)	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$6.85\cdot10^{-8}$				
Single-Exposure	-	Estimate	-10.8612	0.8411	0.76993	-	4.57	998.97	4.78	3.45
		Pr(>|z|)	$< 2\cdot10^{-16}$	$6.77\cdot10^{-14}$	$< 2\cdot10^{-16}$	-				
(b) Constrained road segments										
Model	Consistency parameter		β_0 -	β_1 ln *L*	β_2 ln *AADT*	β_3 *C*	Overdispersion θ	*AIC*	*RMSE*	*MAE*
$L_{500,5}$	7	Estimate	-13.7677	1.04793	0.84720	0.12926	5.22	771.64	4.71	3.41
		Pr(>|z|)	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$4.71\cdot10^{-6}$				
$t_{15,10}$	7	Estimate	-14.0603	1.06023	0.86447	0.17752	5.17	773.41	4.66	3.43
		Pr(>|z|)	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$1.37\cdot10^{-5}$				
$L_{500,5}$	8	Estimate	-14.2337	1.07095	0.88229	0.11156	5.21	770.95	4.78	3.45
		Pr(>|z|)	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$2.72\cdot10^{-6}$				
$t_{15,10}$	8	Estimate	-14.4481	1.07935	0.89706	0.14725	5.14	772.48	4.76	3.50
		Pr(>|z|)	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$< 2\cdot10^{-16}$	$6.96\cdot10^{-6}$				
Single-Exposure	-	Estimate	-10.9108	0.85442	0.76618	-	4.12	788.96	4.85	3.48
		Pr(>|z|)	$< 2\cdot10^{-16}$	$2.26\cdot10^{-11}$	$< 2\cdot10^{-16}$	-				
(c) Free road segments										
Model	Consistency parameter		β_0 -	β_1 ln *L*	β_2 ln *AADT*	β_3 *C*	Overdispersion θ	*AIC*	*RMSE*	*MAE*
$L_{400,0}$	7	Estimate	-11.5246	0.83835	0.72643	0.18064	116	204.86	2.16	1.76
		Pr(>|z|)	$8.96\cdot10^{-8}$	$2.43\cdot10^{-5}$	$7.62\cdot10^{-7}$	$6.67\cdot10^{-4}$				
$t_{15,6}$	7	Estimate	-11.6067	0.83255	0.74202	0.22636	168	203.79	2.14	1.72
		Pr(>|z|)	$4.75\cdot10^{-8}$	$2.12\cdot10^{-5}$	$3.86\cdot10^{-7}$	$3.93\cdot10^{-4}$				
$L_{400,0}$	8	Estimate	-12.5705	0.91496	0.79753	0.14399	69	204.93	2.19	1.82
		Pr(>|z|)	$8.86\cdot10^{-8}$	$1.15\cdot10^{-5}$	$4.44\cdot10^{-7}$	$8.45\cdot10^{-4}$				
$t_{15,6}$	8	Estimate	-12.6155	0.90608	0.80286	0.17887	80	204.02	2.18	1.77
		Pr(>|z|)	$4.79\cdot10^{-8}$	$1.02\cdot10^{-5}$	$2.29\cdot10^{-7}$	$5.10\cdot10^{-4}$				
Single-Exposure	-	Estimate	-8.3791	0.7015	0.5710	-	11.18	212.49	2.24	1.80
		Pr(>|z|)	$2.98\cdot10^{-4}$	$2.33\cdot10^{-3}$	$7.22\cdot10^{-4}$	-				

Variable is significant when Pr(>|z|) < 0.05
*Model is defined by $X_{i,j}$, where *X* is *L* when the model is based on distance and *t* when the model is based on time; *i* represents the distance (m) or time (s) used for the calculation of the inertial operating speed; and *j* is the value of *α* considered in the weighting distribution.

5. GLOBAL CONSISTENCY MODEL

A new global consistency model was proposed based on the previous results. In this way, the consistency parameter 7 was preferred as the global consistency parameter compared to parameter 8. This was because all variables used by parameter 7 were based on the positive differences between V_i and V_{85}, which represent where drivers' expectancies were not fulfilled. Therefore, this parameter is more consistent than parameter 8 and better represents the studied phenomenon.

Likewise, a time-based inertial operating speed profile was proposed. Thus, the inertial operating speed should be calculated at each point of the alignment as the weighted average operating speed of the preceding 15 s considering a linear weighting distribution. This distribution was selected because of its simplicity.

Thus, Equation 4 shows the Safety Performance Function which allows estimating the number of crashes on an entire homogeneous road segment. It should be highlighted that this SPF also showed favorable values of goodness of fit (*AIC*=978; *RMSE*=4.39; *MAE*=3.11).

$$Y_{i,10} = e^{-6.6479} \cdot L^{1.02645} \cdot AADT^{0.86684} \cdot e^{0.14774 \cdot C} \qquad (4)$$

The quality of fit was also studied from the Cumulative Residuals (CURE) Plots (Hauer and Bamfo, 1997; Lord and Persaud, 2000). This method consists of plotting the cumulative residuals for each independent variable. The aim is to graphically observe how well the function fits the data set. The CURE method has the advantage of not being dependent on the number of observations, as many other traditional statistical procedures are. In general, a good CURE plot is one that oscillates around 0. Thus, a good fit is given when the residuals do not stray beyond the ±2σ* boundaries.

It can be observed that the plots against each explanatory variable did not stray beyond the ±2σ* boundaries (Figure 5). Therefore, the proposed SPF is a useful tool to estimate the number of crashes on Spanish two-lane rural roads.

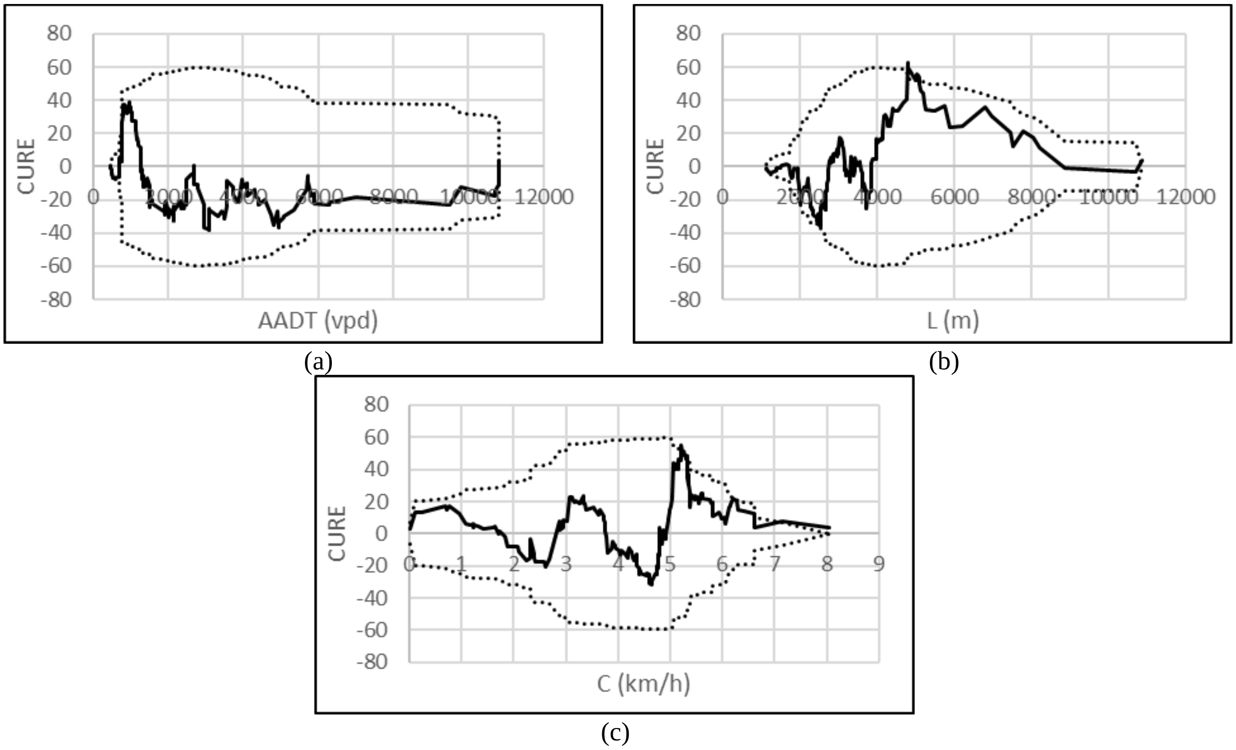


FIGURE 5 CURE plots: (a) *AADT*; (b) Length; (c) Consistency.

Figure 6 shows the relationship between the global consistency parameter (*C*) and crash rates, which were calculated considering observed crashes. To this regard, crash rate increases with the consistency parameter. These results are consistent with the studied phenomenon, since the higher the difference between drivers' expectancies and road behavior, the higher the likelihood of crash occurrence.

Three consistency levels were defined by means of a cluster analysis. Regarding this, the studied road segments were classified into three groups considering the values of the consistency parameters through a k-means clustering, which used the squared Euclidean distance as a measure of cluster scatter. As a result, a homogenous road segment has a good consistency level when the consistency parameter *C* is lower than 2.75 km/h, a poor consistency level when *C* is higher than 4.5 km/h, and a fair consistency level in all other cases (Figure 6 and Figure 7).

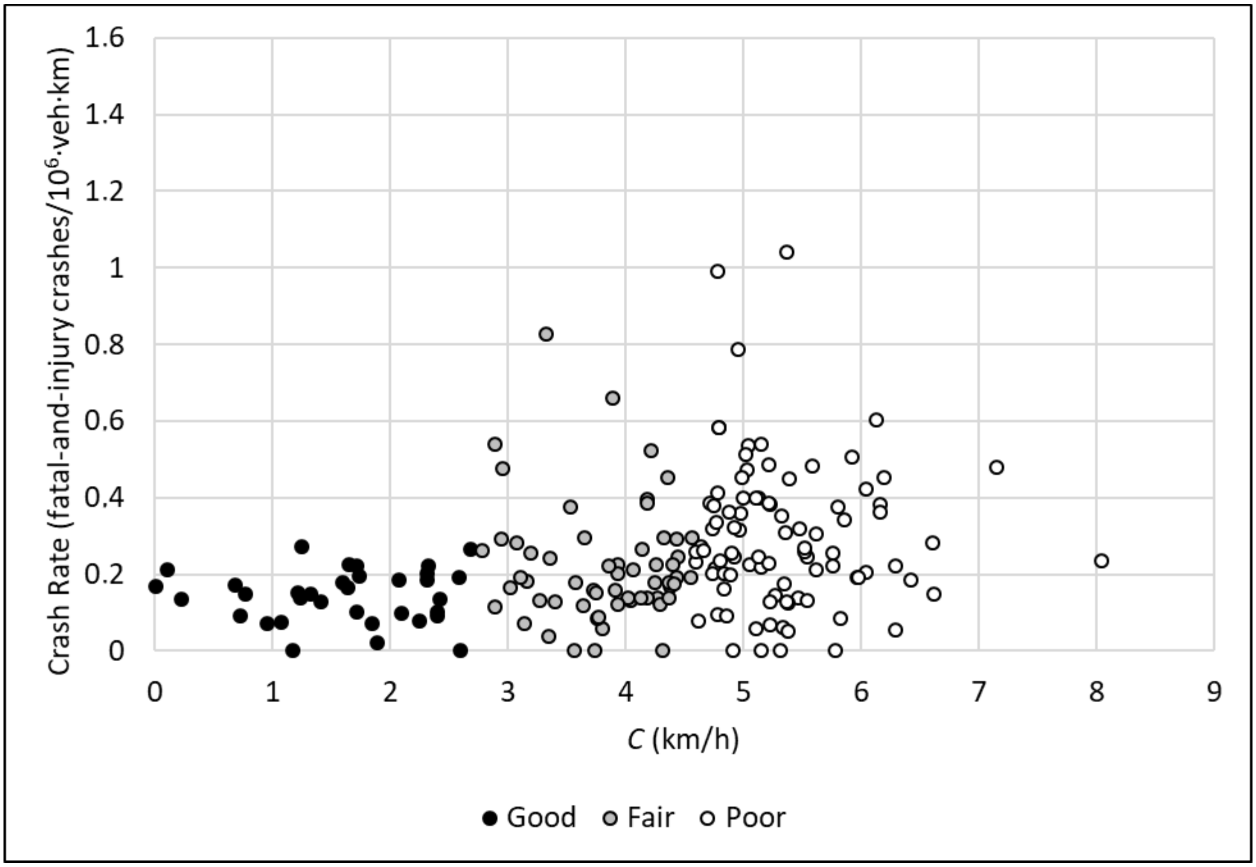


FIGURE 6 Global consistency model Vs. Crash rates.

In addition, the average crash rate was analyzed considering the defined consistency thresholds (Figure 7). A statistical test showed significant differences between these consistency levels at a 90% confidence level, so the proposed global consistency model can properly assess road safety on an entire road segment, and distinguish between the proposed consistency thresholds.

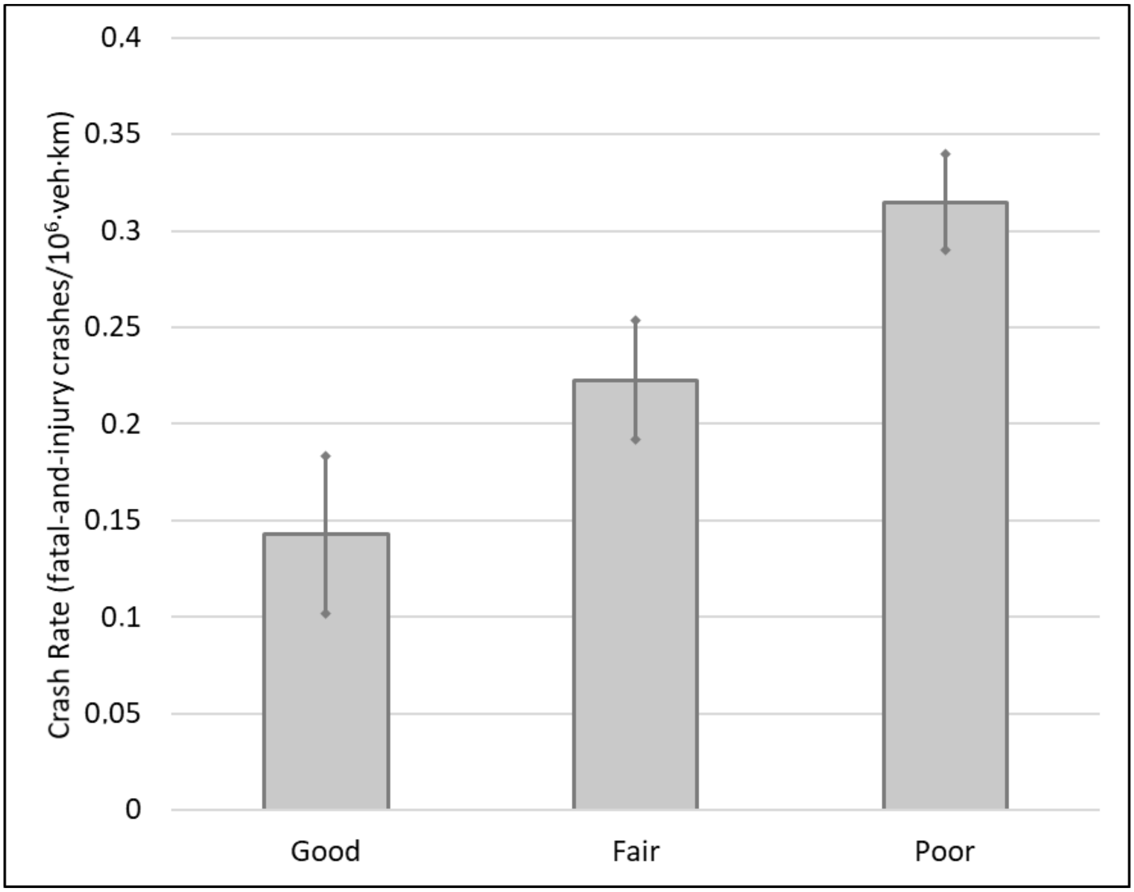


FIGURE 7 Average crash rate Vs. Consistency level.

6. DISCUSSION

6.1. Drivers' expectancies acquirement process

A time-based inertial operating speed profile showed more robust results than those based on distance. This is consistent with the results obtained on Italian highways (Llopis-Castelló et al. 2018) and validates the hypothesis that drivers' expectancies acquirement process is closely related to Short-Term Memory (STM). In addition, the best results were achieved considering 15 s, which was very close to 18 s referred by Revlin, (2012) for Short-Term Memory.

On the other hand, this period of time is lower than 25 s which was obtained on Italian two-lane rural roads (Llopis-Castelló et al., 2018). This might be associated with driver workload. To this regard, the average Curvature Change Rate (*CCR*) of the homogeneous road segments used in this research (209 gon/km) was higher than those observed on Italian highways (91gon/km), hence requiring a higher driver workload.

However, the proposed SPF in this study was applied to Italian two-lane rural roads considered by Llopis-Castelló et al. (2018a and 2018b). Thus, it should be highlighted that the indexes of goodness of fit obtained (*RMSE*=22.5; *MAE*=15.45) were similar to those obtained applying the SPF developed with Italian data (*RMSE*=21.64; *MAE*=13.75).

In addition, the relationship between the proposed consistency parameter and crash rates was analyzed (Figure 8). The results obtained were consistent with those observed in this research, i.e., the higher the consistency parameter, the higher the crash rate. As a conclusion, the new model revealed a favorable performance on Italian two-lane rural roads.

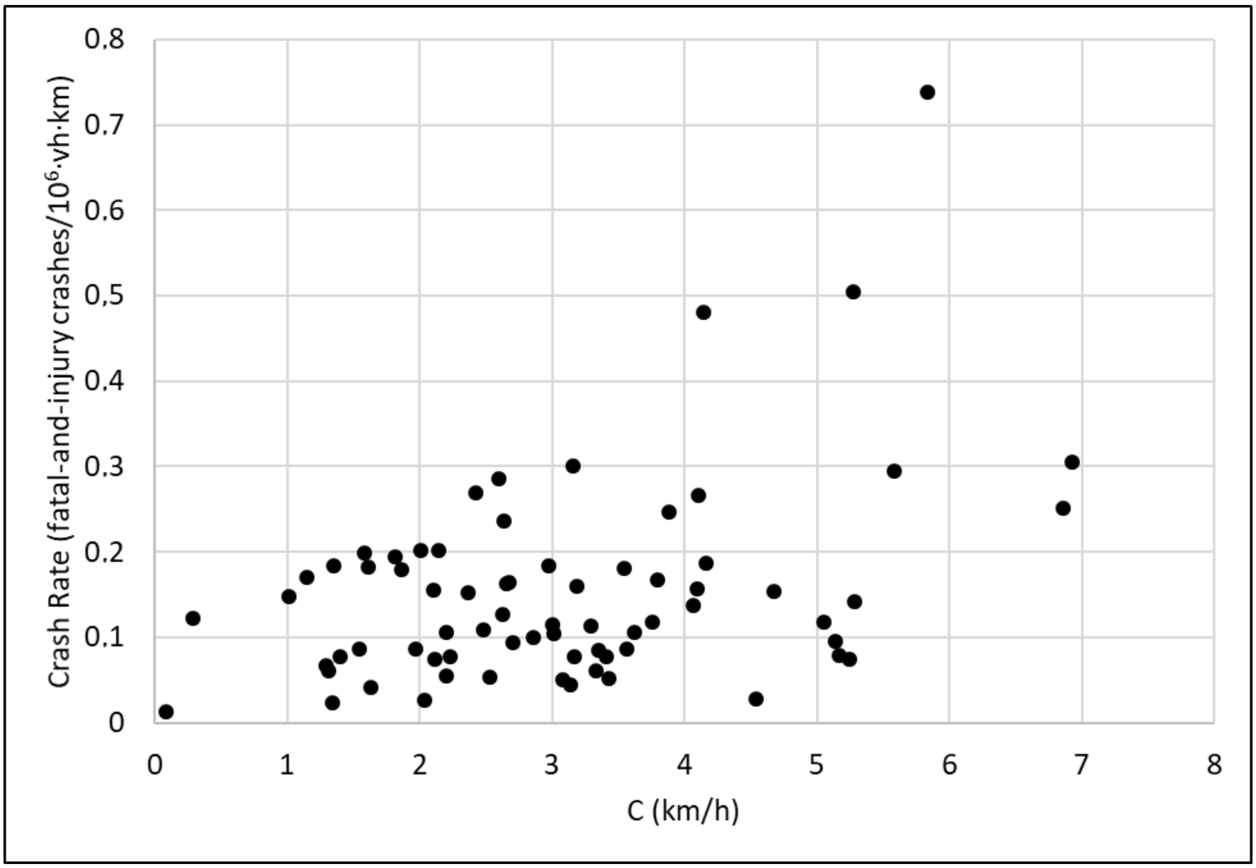


FIGURE 8 Global consistency model Vs. Crash rates on Italian highways.

6.2. Consistency parameter

The consistency parameter *C* is based on the combination of the following, simpler parameters: $\sqrt{\frac{A(+)\cdot\sigma(+)}{L(+)}}$.

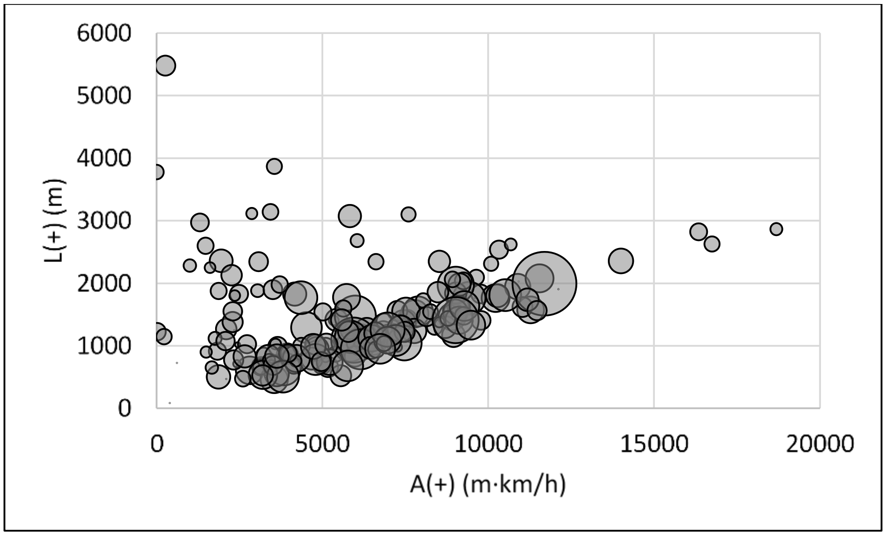
A(+) is the bounded area within the V_i and V_{85} profiles considering only the positive differences, *L(+)* is the length of the road segment for which V_i is higher than V_{85}, and *σ(+)* is the standard deviation of the difference between V_i and V_{85} profile considering only the positive differences.

Figure 9 shows the relationship between these parameters, where each point is a homogeneous road segment (size is related to crash rate). In this way, the biggest points were concentrated for great values of *A(+)* and low values of *L(+)* (Figure 9a). This is consistent with the definition of the consistency parameter, since a large *C* is associated with a lower consistency level and, consequently, the likelihood of crash occurrence is greater.

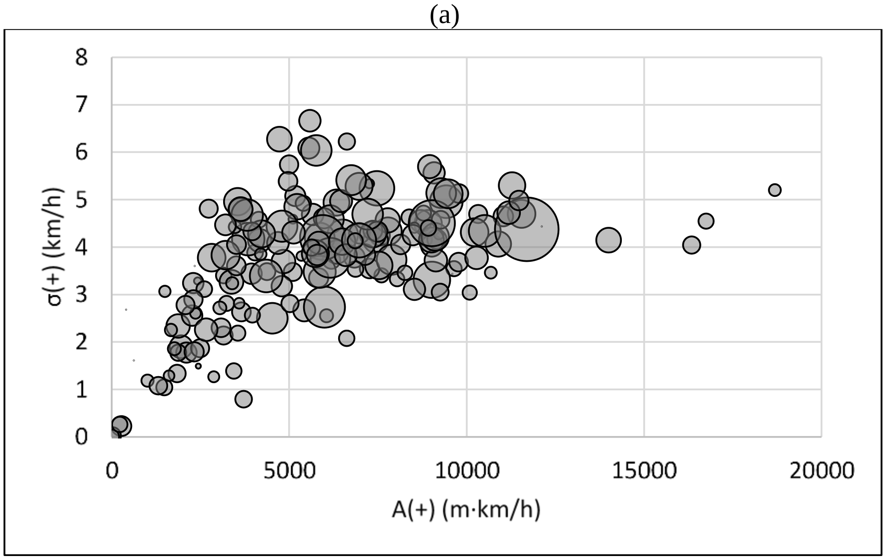
Likewise, the greater the *A(+)* or *σ(+)*, the larger the crash rate (Figure 9b). To this regard, both variables are directly proportional to *C*, so an increase of any of them leads to a greater likelihood of crash occurrence, i.e., a lower consistency level.

Finally, the relationship between *L(+)* and *σ(+)* was also studied (Figure 9c). This is not as intuitive as the previous ones due to *A(+)* is the main variable, i.e., *L(+)* and *σ(+)* help to better understand the studied phenomenon. For example, given two homogeneous road segments with similar *A(+)*, the segment showing either lower *σ(+)* or larger *L(+)* will be more consistent. Related to this, road segments with greater crash rates are concentrated for higher *σ(+)* and lower *L(+)*.

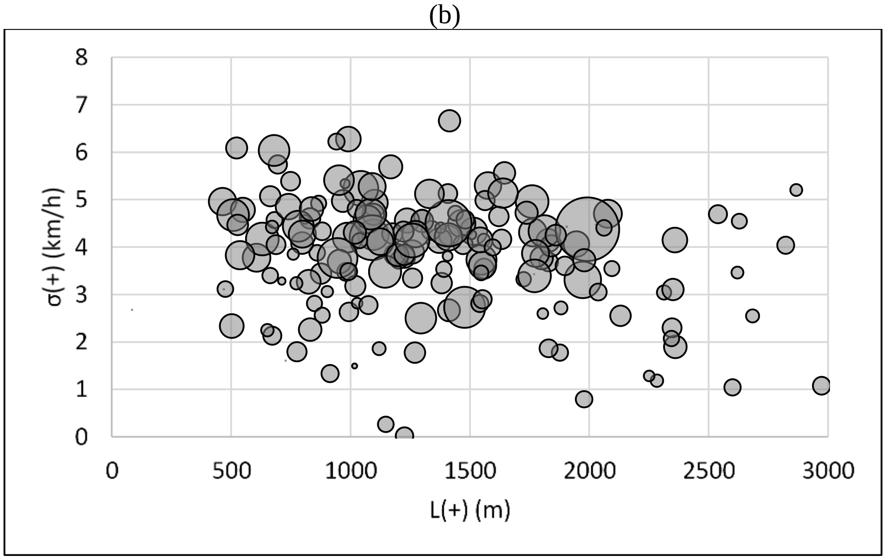
As a conclusion, the variables which define the new global consistency parameter can properly quantify how drivers' expectancies and road behavior relate. Therefore, the proposed parameter *C* is a good surrogate measure of geometric design consistency.



(a)



(b)



(c)

FIGURE 9 Consistency parameter analysis.

6.3. Validation of the proposed global consistency model

The new global consistency model was validated considering 26 homogeneous road segments different from the road segments used for the calibration of the model. These were randomly selected among a total of 105 homogeneous road segments. Table 6 shows a summary of the main characteristics of these road segments.

TABLE 6 Statistical summary of the homogeneous road segments used for the validation

	Minimum	Maximum	Average	Standard deviation
Length (m)	1,054	5,472	2,803	1,237
CCR (gon/km)	8.69	697.07	164.76	160.06
AADT (vpd)	518	7,022	2,411	1,754
Crashes	0	31	6.69	7.66

The geometry of these road segments was recreated by means of the methodology proposed by Camacho-Torregrosa et al. (2015), whereas the operating speed profile of each of them was estimated considering the operating speed models developed by Pérez-Zuriaga (2012). According to the results obtained previously, the inertial operating speed profiles were calculated through the weighted average operating speed of the preceding 15 seconds considering a linear weighting distribution.

Finally, the consistency parameter C was obtained for each homogeneous road segment. The correlation between this parameter and crash rate was analyzed (Figure 10). The average crash rates for fair and poor consistency levels obtained in the validation process were similar to those obtained in the calibration of the model, whereas the average crash rate for a good consistency level in the validation was larger than that obtained in the calibration. This is due to the few homogeneous road segments with good consistency level.

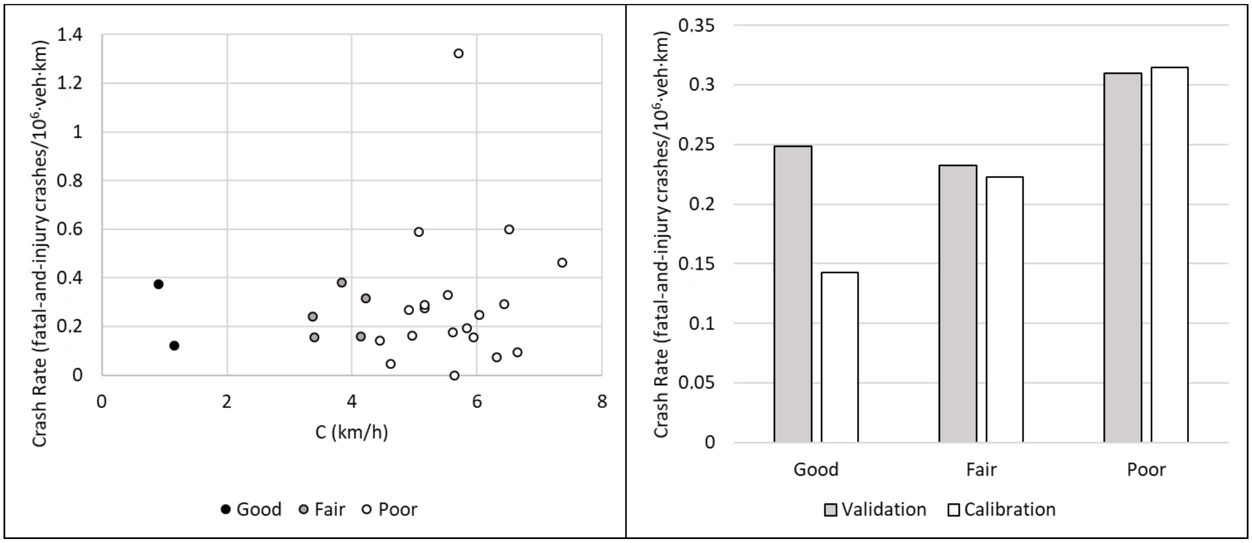


FIGURE 10 Validation of the consistency model: Crash Rate Vs. Consistency.

Additionally, the relationship between the observed and predicted crashes was analyzed by comparing the parameters of goodness of fit (*MAE* and *RMSE*) obtained in the validation and calibration process (Figure 11). To this regard, the predicted fatal-and-injury crashes were estimated considering the SPF defined for the new consistency model (Equation 4). Both *MAE* and *RMSE* were lower in the validation process, which verifies the sturdiness of the new consistency model.

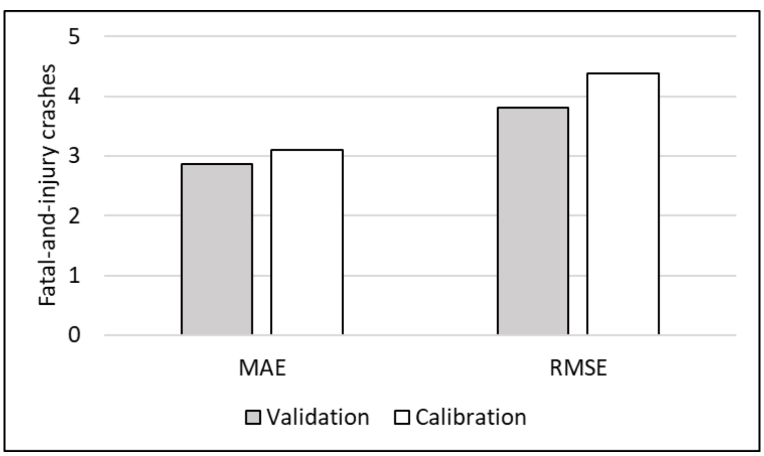


FIGURE 11 Validation of the consistency model: Observed crashes Vs. Predicted crashes.

As a conclusion, the proposed global consistency model assesses properly the consistency level and can be used to estimate the number of fatal-and-injury crashes on an entire homogeneous road segment.

6.4. Comparison with previous consistency models

The new global consistency model was compared with the models developed by Polus and Mattar-Habib (2004), Garach et al. (2014), and Camacho-Torregrosa (2015). All consistency parameters were obtained for each homogeneous road segment and the average crash rate was calculated for each consistency level (Figure 12). To do this, only the homogeneous road segments used for the validation of the model were considered.

As mentioned above, only two homogeneous road segments showed good consistency, so this consistency level was not considered in the analysis. Thus, the consistency models which can better represent the studied phenomenon are the models developed by Camacho-Torregrosa (2015) and the model proposed in this research, since significant statistical differences were identified between the average crash rate for a fair and poor consistency level at a 95% confidence level. However, the models proposed by Polus and Mattar-Habib (2004) and Garach et al. (2014) resulted in very similar average crash rates for these consistency levels. In addition, the average crash rate observed for a fair consistency was greater than that for a poor consistency considering the model developed by Polus and Mattar-Habib (2004), which is not consistent with the studied phenomenon.

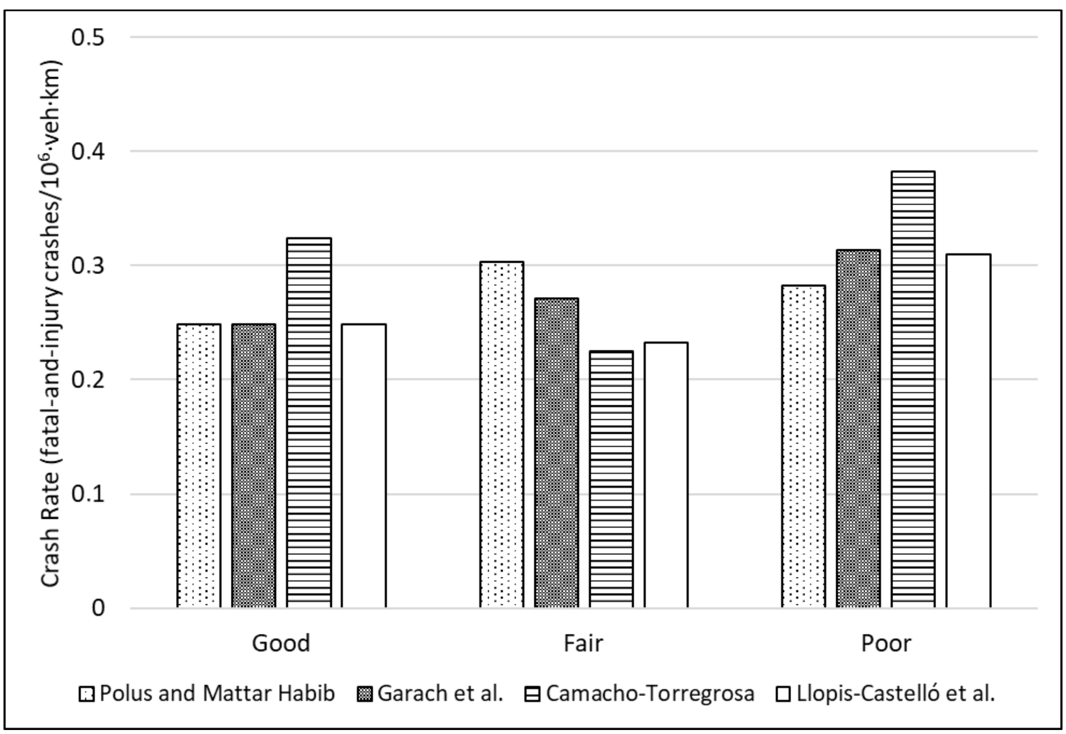
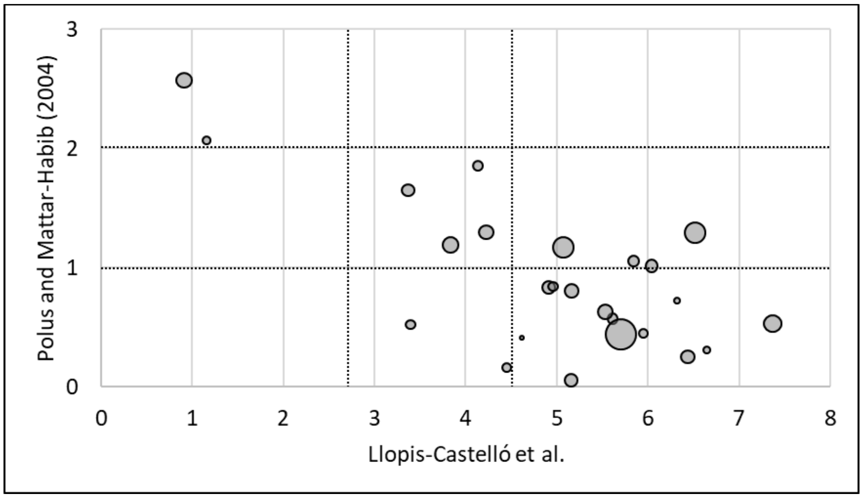


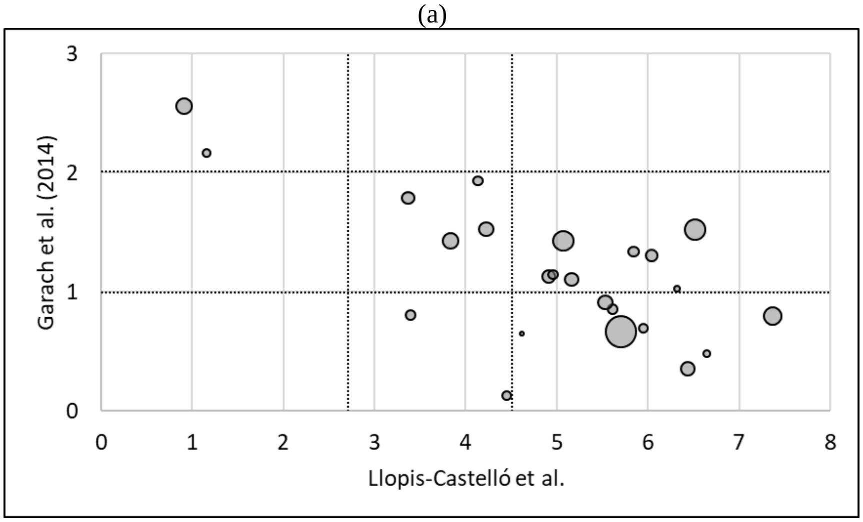
FIGURE 12 Average crash rate Vs. Consistency level of previous models.

To better understand these results, the relationship between the proposed consistency parameter and the consistency parameters developed by the other authors was analyzed. In Figure 13, each point is a homogeneous road segment and its size represents its crash rate. The larger the size, the greater the crash rate. Likewise, the dotted lines represent the consistency thresholds of the different consistency models.

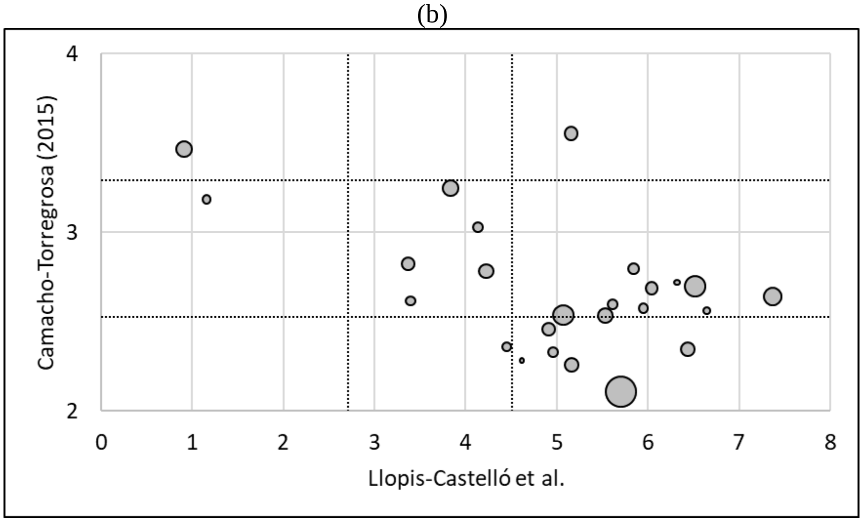
Thus, it was identified that the consistency models developed by Polus and Mattar-Habib (2004) and Garach et al. (2014) presented points with very different size within the same consistency level. Particularly, some homogeneous road segments with high crash rates were labeled with a fair consistency level. This explained that the average crash rates for this consistency level were larger than those obtained with the proposed consistency model in this research and the model developed by Camacho-Torregrosa (2015). In addition, the model proposed by Polus and Mattar-Habib et al. (2004) defined some homogeneous road segments with low crash rates with a poor consistency level, which explained why the average crash rate associated with this consistency level was much lower than those obtained from the other models.



(a)



(b)



(c)

FIGURE 13 Proposed consistency parameter Vs. Previous consistency parameters: (a) Polus and Mattar-Habib (2004); (b) Garach et al. (2014); (c) Camacho-Torregrosa (2015).

6.5. SPF based on consistency Vs. SPF based on alignment indexes

Finally, the new SPF based on consistency was compared with a SPF based on the geometric parameter Curvature Change Rate (*CCR*), which represents how winding a homogenous road segment is. To this regard, a great *CCR* is related to homogeneous road segments with shorter tangents and sharper curves, which usually leads to greater speed variations.

Table 7 shows the statistical adjustment for the SPF based on *CCR* and consistency. As a result, the SPF based on consistency is able to more accurately estimate the number of crashes, since the parameters of goodness of fit for the SPF based on *CCR* are significantly greater than those obtained for the new global consistency model. Additionally, *CCR* resulted in a non-significant variable because the parameter Pr(>|z|) was higher than 0.05.

TABLE 7 Statistical adjustment – Global consistency models

		β_0 -	β_1 ln *L*	β_2 ln *AADT*	β_3 *CCR*	Overdispersion θ	*AIC*	*RMSE*	*MAE*
SPF based on *CCR*	Estimate Pr(>|z|)	-5.1064 $< 2\cdot10^{-16}$	0.85071 $7.15\cdot10^{-14}$	0.77578 $< 2\cdot10^{-16}$	$3.069\cdot10^{-6}$ 0.99	4.52	993.85	4.7789	3.4499
Llopis-Castelló et al.	Estimate Pr(>|z|)	-6.6479 $< 2\cdot10^{-16}$	1.02645 $< 2\cdot10^{-16}$	0.86684 $< 2\cdot10^{-16}$	0.14774 $5.47\cdot10^{-7}$	5.83	978.00	4.3937	3.1078
Variable is significant when Pr(>|z|) < 0.05.									

7. CONCLUSIONS AND FURTHER RESEARCH

This paper presents a new global consistency model based on the difference between the inertial operating speed profile and the operating speed profile for road safety assessment on Spanish two-lane rural roads.

The main objective of this study was to identify how the inertial operating speed should be calculated, which is a surrogate measure of drivers' expectancies. To this regard, distances between 300 m and 800 m with a step of 100 m, periods of time between 10 s and 40 s with a step of 5 s, and 11 weighting distributions were analyzed. Thus, 143 inertial operating speed profiles were calculated for each homogeneous road segment. Likewise, 8 consistency parameters were studied, so a total of 1,144 Safety Performance Functions were calibrated.

The new consistency model was defined as $\sqrt{\frac{A(+)\cdot\sigma(+)}{L(+)}}$ (parameter 7), being *A(+)* the bounded area within the V_i and V_{85} profiles, *σ(+)* the standard deviation of the difference between V_i and V_{85} profile, and *L(+)* the length of the road segment for which V_i is higher than V_{85}. Related to this, the inertial operating speed profile was defined as the weighted average operating speed of the preceding 15 seconds considering a linear weighting distribution, which is consistent with drivers' expectancies acquirement process.

Additionally, it was identified that the SPFs calibrated by means of a time-based inertial operating speed profile showed more consistent results than those obtained through distance-based speed profiles. This allowed validating the results obtained for Italian two-lane rural roads (Llopis-Castelló et al., 2018b).

A Safety Performance Function was proposed to estimate the number of crashes on an entire homogeneous road segment and consistency thresholds were defined. In this way, a homogenous road segment have a good consistency level when the consistency parameter (C) is lower than 2.75 km/h, a poor consistency level when C is higher than 4.5 km/h, and a fair consistency level otherwise.

Finally, the proposed model was compared with those developed previously by other authors. As a conclusion, the models developed by Polus and Mattar-Habib (2004) and Garach et al. (2014) were not able to properly estimate the consistency level of the road segments included in this study. Conversely, the proposed model presented a high correlation with the model developed by Camacho-Torregrosa (2015). However, the new model showed better fitting. Therefore, the proposed global consistency model better describes the phenomenon than the previous models.

New tools were developed which can be used by highway engineers to incorporate road safety to the geometric design of both new Spanish two-lane rural roads and improvements of existing highways.

Despite the important improvement over previous consistency approaches, there are some limitations remaining. The relative short length of homogeneous road segments, combined with the removal of PDO crashes, made it necessary to consider such a long period of time (10 years). Otherwise, crashes would not be Negative Binomial distributed. Shorter periods of time would be preferred, but other more complex and/or less accurate distributions should be applied instead. In addition, this consistency model applies to a limited range of cross-section and longitudinal characteristics of two-lane rural roads. Different models could be calibrated for other road types, including, e.g., low volume roads. Although the same methodology could be applied, changes in probability distribution and functional forms might be expected, because of the different crash distributions.

ACKNOWLEDGMENTS

The study presented in this paper is part of the research project titled "CASEFU - Estudio experimental de la funcionalidad y seguridad de las carreteras convencionales" (TRA2013-42578-P), subsidized by the Spanish Ministry of Economy, Industry and Competitiveness and the European Social Fund. In addition, the authors would like to thank the Department of Housing, Public Works and Spatial Planning of the Valencian Regional Government and the Traffic Department of the Spanish Government, which provided traffic and crash data, respectively.

REFERENCES

1. Anderson, I., K. Bauer, and D. Harwood. Relationship to safety of geometric design consistency measures for rural two-lane highways. Transportation Research Record: Journal of the Transportation Research Board, 1999, no 1658, p. 43-51.
2. Awatta, M., Y. Hassan, and T. Sayed. Quantitative evaluation of highway safety performance based on design consistency. Advances in Transportation Studies, 2006, vol. 9.
3. Cafiso, S., A. Di Graziano, G. Di Silvestro, G. La Cava, and B. Persaud. Development of comprehensive accident models for two-lane rural highways using exposure, geometry, consistency and context variables. Accident Analysis & Prevention, 2010, vol. 42, no 4, p. 1072-1079.
4. Camacho Torregrosa, F. J. Development and calibration of a global geometric design consistency model for two-lane rural highways, based on the use of continuous operating speed profiles. Universitat Politècnica de València, Valencia (Spain), 2015.
5. Camacho-Torregrosa, F. J., A. M. Pérez-Zuriaga, J. M. Campoy-Ungría, A. García, and A. P. Tarko. Use of Heading Direction for Recreating the Horizontal Alignment of an Existing Road. Computer-Aided Civil and Infrastructure Engineering, 2015, vol. 30, no 4, p. 282-299.
6. de Oña, J., Garach, L., Calvo, F., García-Muñoz, T. Relationship between Predicted Speed Reduction on Horizontal Curves and Safety on Two-Lane Rural Roads in Spain. Journal of transportation engineering, 2013, 140(3), 04013015.
7. Dirección General de Tráfico (DGT), 2017. http://www.dgt.es/es/seguridad-vial/estadisticas-e-indicadores/
8. Garach, L., F. Calvo, M. Pasadas, and J. de Oña. Proposal of a New Global Model of Consistency: Application in Two-Lane Rural Highways in Spain. Journal of Transportation Engineering, 2014, vol. 140, no 8, p. 04014030.
9. Garach, L., J. de Oña, G. López, and L. Baena. Development of safety performance functions for Spanish two-lane rural highways on flat terrain. Accident Analysis & Prevention, 2016, vol. 95, p. 250-265.
10. García, A., D. Llopis-Castelló, F. J. Camacho-Torregrosa, and A. M. Pérez-Zuriaga. New consistency index based on inertial operating speed. Transportation Research Record: Journal of the Transportation Research Board, 2013b, no 2391, p. 105-112.
11. García, A., Llopis-Castello, D., Perez-Zuriaga, A.M., Camacho-Torregrosa, F.J. Homogeneous Road Segment Identification Based On Inertial Operating Speed. In Transportation Research Board 92nd Annual Meeting, 2013a, No. 13-3545.
12. Gibreel, G. M., S. M. Easa, Y. Hassan, and I. A. El-Dimeery. State of the art of highway geometric design consistency. Journal of Transportation Engineering, 1999, vol. 125, no 4, p. 305-313.
13. Hauer, E., and J. Bamfo. Two tools for finding what function links the dependent variable to the explanatory variables. Proceedings of the ICTCT 1997 Conference, Lund, Sweden. 1997.

14. Llopis-Castelló, D., F. Bella, F. J. Camacho-Torregrosa, and A. García. New consistency model based on inertial operating speed profiles for road safety evaluation. Journal of Transportation Engineering, 2018a, 144(4), 04018006.
15. Llopis-Castelló, D., F. Bella, F. J. Camacho-Torregrosa, and A. García. Time-based calibration of the inertial operating speed to enhance the assessment of the geometric design consistency. Transportation Research Record: Journal of the Transportation Research Board, 2018b, Accepted.
16. Lord, D., and B. N. Persaud. Accident prediction models with and without trend: application of the generalized estimating equations procedure. Transportation Research Record: Journal of the Transportation Research Board, 2000, no 1717, p. 102-108.
17. Lord, D., and F. Mannering. The statistical analysis of crash-frequency data: a review and assessment of methodological alternatives. Transportation Research Part A: Policy and Practice, 2010, vol. 44, no 5, p. 291-305.
18. Mehta, G., and Lou, Y. (2013). "Calibration and Development of Safety Performance Functions for Alabama." *Transportation Research Record: Journal of the Transportation Research Board*, Volume 2398, 75–82.
19. Misaghi, P., Hassan, Y. Modeling Operating Speed and Speed Differential on Two-Lane Rural Roads. Journal of Transportation Engineering, 2005, 131(6), 408-418.
20. Montella, A., and L. L. Imbriani. Safety performance functions incorporating design consistency variables. Accident Analysis & Prevention, 2015, vol. 74, p. 133-144.
21. Montella, A., L. Colantuoni, and R. Lamberti. Crash prediction models for rural motorways. Transportation Research Record: Journal of the Transportation Research Board, 2008, no 2083, p. 180-189.
22. Ng, J., and T. Sayed. Effect of geometric design consistency on road safety. Canadian Journal of Civil Engineering, 2004, vol. 31, no 2, p. 218-227.
23. Pérez-Zuriaga, A.M. Caracterización y modelización de la velocidad de operación en carreteras convencionales a partir de la observación naturalística de la evolución de vehículos ligeros. Universitat Politècnica de València, Valencia (Spain), 2012.
24. Polus, A., and C. Mattar-Habib. New consistency model for rural highways and its relationship to safety. Journal of transportation engineering, 2004, vol. 130, no 3, p. 286-293.
25. Quddus, M. Exploring the relationship between average speed, speed variation, and accident rates using spatial statistical models and GIS. Journal of Transportation Safety & Security, 2013, vol. 5, no 1, p. 27-45.
26. Resende, P., and R. Benekohal. Effect of roadway section length on accident modeling traffic congestion and traffic safety. The 21 st Century Conference, ASCE, Chicago, IL. 1997.
27. Revlin, R. Cognition: Theory and practice. Palgrave Macmillan, 2012.
28. Srinivasan, R., Colety, M., Bahar, G., Crowther, B., and Farmen, M. (2016). "Estimation of Calibration Functions for Predicting Crashes on Rural Two-Lane Roads in Arizona." *Transportation Research Record: Journal of the Transportation Research Board*, Volume 2583, 17–24.
29. Treat, J. R., N. S. Tumbas, S. T. McDonald, D. Shinar, and R. D. Hume. Tri-level study of the causes of traffic accidents: Executive summary (National Technical Information Services Technical Report No. DOT HS-805 099). Bloomington: University of Indiana, 1979.
30. WHO. Global status report on road safety 2015. World Health Organization, 2015.
31. Wu, K.-F., E. T. Donnell, S. C. Himes, and L. Sasidharan. Exploring the association between traffic safety and geometric design consistency based on vehicle speed metrics. Journal of Transportation Engineering, 2013, vol. 139, no 7, p. 738-748.