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Development of a global inertial consistency model to assess road safety on Spanish two-lane rural roads

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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 km in Spain were used.

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, 1291 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 (Dirección General de Tráfico (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

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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 et al., 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).

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 1000 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 s (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,b). 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

Table 1
Previous global consistency models.

Global consistency model	Consistency parameter (C)	Consistency level		
		Good	Fair	Poor
Polus and Mattar-Habib (2004)	$2.808 \bullet e^{-0.278 \bullet Ra \bullet \frac{\sigma}{3.6}}$	C > 2	1 < C ≤ 2	C ≤ 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 ≤ 2	C ≤ 1
Camacho-Torregrosa (2015)	$\sqrt[3]{\frac{\overline{V_{85}}}{\overline{d_{85}}}}$ ($s^{1/3}$)	C ≥ 3.25	2.55 ≤ C < 3.25	C < 2.55