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Naturalistic driving data collection to investigate into the effects of road geometrics on track behaviour

G. Cerni [a], M. Bassani [b,*]

[a] Department of Civil and Environmental Engineering, Università degli Studi di Perugia, 93, via G. Duranti, Perugia I 06125, Italy
[b] Department of Environment, Land and Infrastructures Engineering (DIATI), Politecnico di Torino, 24, corso Duca degli Abruzzi, Torino I 10129, Italy

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ABSTRACT

Road designers assume that drivers will follow the road alignment with trajectories centred in the lane, and move at the design speed parallel to the road centreline (i.e., the horizontal alignment). Therefore, they assume that if the horizontal alignment indicates the "designed trajectory", the driving path indicates the "operating trajectory". However, at present, they do not have the necessary tools to measure the relationship between the designed alignment and possible vehicle trajectories.

The paper has two objectives: (a) to develop an understanding of the root causes of differences between road alignment and vehicle trajectories; and (b) to define and calibrate a model that estimates the local curvature of trajectories on the basis of the designed horizontal alignment.

The two objectives were pursued by carrying out a naturalistic survey using vehicles equipped with high precision GPS in real-time kinematics (RTK) mode driven by test drivers on road sections of known geometric characteristics. The results provide an insight into the effects of road geometrics on driver behaviour, thus anticipating possible driving errors or unexpected/undesired behaviours, information which can then be used to correct possible inconsistencies when making decisions at the design stage.

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1. Introduction

In every roadway project, the designer assumes that drivers will follow the road alignment with trajectories centred in the lane, and move at the design speed parallel to the road centreline (i.e., the horizontal alignment). The designer selects the most appropriate geometric alignment elements, which consist of tangents and curves (Fig. 1a). Where appropriate or indeed compulsory for some standards (AASHTO, 2010; Repubblica Italiana, 2001a), approaching flatter circular arcs (Fig. 1b) or spirals (Fig. 1c) are used to obtain a gradual change in alignment curvature between the tangent and more acute circular arcs. The aim is to achieve a harmonious combination of geometric characteristics that will conform to driver expectations and their driving abilities.

According to Messer (1980), geometric features or combinations of adjacent features that surprise the driver lead to unsafe driving conditions. Observations confirm that drivers make fewer errors when the road geometry conforms to their expectations. Since the '80s, road engineers have used the term "design consistency" with respect to methodologies aimed at conforming the alignment of a road to the driver's expectations (Post et al., 1981).

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* Corresponding author.
E-mail addresses: gianluca.cerni@unipg.it (G. Cerni), marco.bassani@polito.it (M. Bassani).

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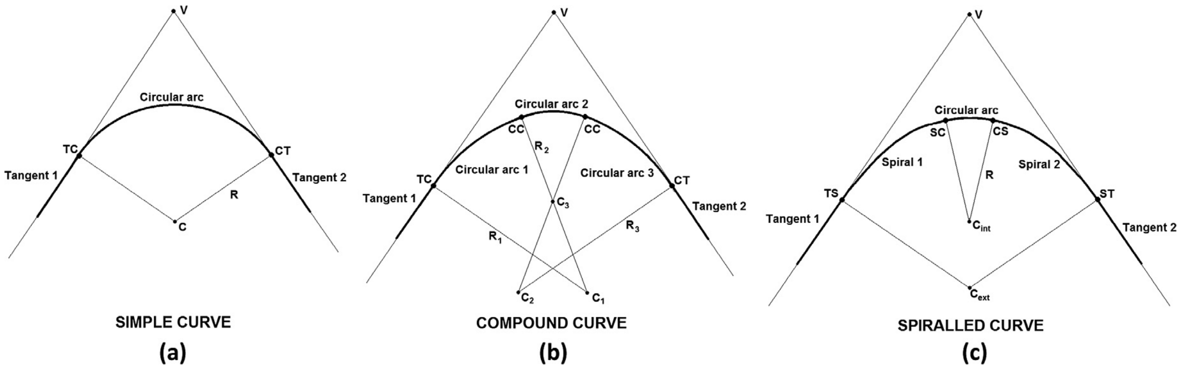

Fig. 1. Simple (a), compound (b), and spiralled (c) curves connecting tangents (curve termini are: TC = tangent to curve, CT = curve to tangent, CC = curve to curve, SC = spiral to curve, CS = curve to spiral; curve centres are: C = centre for simple curves, C_1-C_2-C_3 = centres for compound curves, C_{int} = centre of the inner circular arc, C_{ext} = centre of the whole curve).

To assess the "design consistency" of a new or existing alignment, Lamm et al. (1999) proposed minimizing operating speed variations and any differences between operating and design speeds, as well as the differences between the operating speeds between successive speed-influencing geometric features. The most practical technique used is represented by the speed profile, in which operating and design speeds are plotted as a function of the alignment chainage. In the last twenty years, the Lamm criteria and/or similar approaches have been used in a number of standards and guidelines (Transportation Research Circular, 2011).

Lamm et al. (1995) supported their inferences by noting that the design inconsistencies of a road are associated with a sudden change in its geometric characteristics, which can surprise drivers and lead to significant variations in speed and, sometimes, to driver errors. In their opinion, any divergence between operating and design speed is a consequence of the geometric differences between the actual road alignment and expected driving path.

Accordingly, in the last twenty years designers and researchers have regarded the degree of variation between operating and design speed as a measure of design consistency. Operating speeds can be simply measured in the field with a variety of methodologies and technologies. Furthermore, literature provides several predictive operating speed models thus avoiding the need to carry out spot speed surveys on roads. In a situation where the design speed is not readily available from original project documents, it can be inferred from road geometric data (Donnell et al., 2009).

However, the use of operating and design speeds appears straightforward when performing a consistency assessment of existing highway sections (Fitzpatrick et al., 2000). Glennon and Harwood (1978) ignored this method when coming up with their conceptual framework for design consistency. This opened the door to alternative methods based on driver's workload (Hancock et al., 1990), and on the assessment of vehicle operations and trajectories.

For example, Messer (1980) used the lateral placement of a vehicle in the lane and drivers' erratic manoeuvres as a means to detect design inconsistencies. Spacek (2005) used measuring posts to detect driving direction as well as transverse distances of the vehicles from the pavement edge. Fitzsimmons et al. (2013) used pneumatic road tubes set-up in a Z-configuration to collect lateral deviation values from a reference line placed at a fixed distance from the horizontal markings. Others have used video recognition techniques at intersections (Messelodi et al., 2005; Mussone et al., 2013) as well as along road sections (Coifman et al., 1998).

Currently, vehicle-tracking surveys for a variety of research purposes are carried out with Global Positioning Systems (GPS) and Inertial (INS) sensors, as well as with hybrid technology combining both sensors (Williams et al., 2012; Tang et al., 2016). These technologies are sufficiently accurate and accessible to provide good quality data on vehicle tracking, in addition to speed and travel time (Patire et al., 2015).

In this context, the paper proposes a new methodology for the comparison of road alignments and vehicle trajectories in order to assess any design inconsistencies of existing roads. To this end, a number of test drivers were involved in field measurement activities along three road sections of two-lane rural highways. Medium class cars equipped with a GPS receiver were employed to collect spatial positioning data.

Curvature diagrams are used here to compare road alignment and vehicle trajectory (i.e., driving path). Curvature trajectories were determined as the inverse of the radius passing through three consecutive surveyed points. Driving path curvatures were first averaged, then compared to the curvature obtained from the as-built horizontal alignment recorded in road cadastre databases (Repubblica Italiana, 2001b). In this approach, it is implicitly assumed that if the horizontal alignment indicates the "designed trajectory", the driving path indicates the "operating trajectory". Hence, from their comparison, the geometric consistency of road alignment can be evaluated.

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