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Driver perception of roadside configurations on two-lane rural roads: Effects on speed and lateral placement

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ABSTRACT

This paper reports the results of a driving simulator study which sought to analyze the effect that: (a) three roadside configurations on a two-lane rural road lined with trees have on speed and lateral position of the driver, depending on different cross-sections as well as geometric elements; (b) the beginning of the guardrail barrier has upon the driver's behavior whenever this occurs on the left curve, right curve or tangent.

A two-lane rural road lined with trees was designed and implemented in an advanced-interactive driving simulator. Two different cross-sections (with and without a shoulder), which were combined with three roadside configurations (only trees, trees and barriers, trees and barriers having undergone a treatment), were tested. Six road scenarios were then analyzed. Thirty-six drivers (33 were deemed to be valid and used for the analysis) drove in the simulator using these scenarios and the speed and lateral placement values were collected.

Statistical analysis showed that the driver behavior was only affected by the cross-sections and geometric elements but not by roadside configurations. Although the presence of trees along the road represents a factor that increases the severity of run-off-road accidents, drivers do not change their behavior when barriers are not present.

Concerning the effects of the beginning of the barrier, MANOVA revealed a main effect for roadside configuration on lateral position but not on speed. There was also a clear tendency of drivers to "cut" both the right curves as well as the left curves in order to minimize the speed reduction in the tangent–curve–tangent transition. These main results allow useful suggestions to be made as regards safety measures for improving road safety on two-lane rural roads lined with trees.

1. Introduction

It is common knowledge that driving a vehicle is a complex activity in which numerous factors come into play: the driver with his psychological–physical makeup, vehicle performance, other vehicles on the road together with a road's geometric features. The interplay of such factors makes driving a dynamic control task in which drivers select the relevant information provided by the road environment (the combination of vehicle–other road users), make decisions and perform appropriate controls in order to drive safely. In this process of risk control and adaptation to the driving conditions, the information that the road imparts to the driver is essential for him in order to adjust his driving control parameters and avoid risky behavior.

A road's capacity to communicate adequate information to the driver forms the focus of the road design philosophy that is known in literature as the self-explaining road (Theeuwes and Godthelp, 1995). This approach to designing roads relies on a road's intrinsic design elements to encourage drivers to adopt the best possible behavior with a minimal need for signage. Consequently, in accordance with the concept of self-explaining road, determining how drivers' behavior is affected by design elements, such as tangents, curves and their succession along the alignment as well as by cross-sectional features, is crucial.

There are several studies in the literature which have examined the effect of geometric elements and their succession along the alignment. These, whilst employing diverse approaches and techniques, have sought to evaluate the design consistency of alignments. Numerous definitions of design consistency have been reported in scientific literature and in all instances, despite slight differences in wording, there has been an general consensus that highway design consistency is deemed to be "one that ensures that successive geometric elements are coordinated in a manner to produce harmonious driver performance without surprising events" (Gibreel et al., 1999).

Concerning cross-section elements (in particular shoulders and lane width), a great deal of research has examined the effects on freeway free-flow speeds as defined in the Highway Capacity

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Manual (TRB, 2010) and their influence on operating speeds, which have been employed in carrying out evaluations of design consistency (Fitzpatrick et al., 2001, 2005; Bella, 2005a; TRB, 2007). Some of the research carried out has stressed the important role that roadside elements such as vegetation, trees and guardrail barriers play in our perception of the road edge, driver speed and the driver's perception of safety (Naderi et al., 2006; Van der Horst and De Ridder, 2007; Stamatiadis et al., 2007, 2010) (see Section 2).

Despite the potential of such roadside elements to serve as a tool for improving road safety, a better understanding is needed of how driver behavior is affected by cross-section and roadside configurations (such trees and barriers). More specifically, in addition to the configuration of cross-sections, the influence that roadside elements have on driver behavior also needs to be analyzed in function of the different geometric elements of the road alignment such as the curves of various radii and tangents. This need is especially important for two-lane rural roads lined with trees, which, in addition to being the most prevalent in many European countries, are often characterized by the presence of trees which are very close to the roadside, as well as by a large number of accidents. Roughly 30,000 people were killed in run-off-road collisions (single vehicle accidents) on rural roads in 16 European Union countries over the 1999–2008 decade (ERSO, 2011). It is therefore crucial that the study of drive behavior on these roads be delved into further in order to deduce useful suggestions for road safety improvement.

The present study seeks to provide a contribution to this topic. More specifically, the study was aimed at:

- testing the effect that guardrail barriers (with varying treatments) on two-lane rural roads lined with trees have on driver speed and lateral position, depending on different cross-section configurations (the presence or absence of a shoulder) as well as various geometric features (tangents or curves, curve radius);
- evaluating the effect that change in roadside configurations (such as the beginning of the guardrail barrier) has upon driver behavior, whenever this occurs on different geometric elements of the road alignment (curve or tangent);
- providing useful suggestions for a more efficient design of roadside configurations in function of the geometric features of the elements of the road alignment.

An experimental study using the Inter-University Research Center for Road Safety (CRISS) advanced-interactive driving simulator was conducted for these purposes.

The Risk Compensation Hypothesis (Summala, 1996; Fuller and Santos, 2002) was deemed to be the appropriate consolidated conceptual framework for the purpose of analyzing driver behavior in different roadside configurations as well as different cross-sections.

According to the Risk Compensation Hypothesis, the driver is inclined to react to changes in the road environment and that this reaction occurs in accordance with his/her motives (Summala, 1996). This behavioral model is based upon the assumption that the driver actually controls the safety margin in a dynamic driving situation, and only when the risk threshold is exceeded, or is expected to be exceeded, does it influence behavior. The model involves a 'subjective risk' which alarms and influences driver decisions when the safety-margin threshold is surpassed (Summala, 1996). Consequently, if the safety-margin threshold is exceeded, the driver acts upon the driving control parameters, reduces his speed and/or modifies the lateral position of his vehicle on the road, so as to bring the safety margin within the accepted threshold.

According to the Risk Compensation Hypothesis, the expected effects of guardrail barriers on two-lane rural roads lined with trees should consequently be an increase in the speed and a reduced distance from the roadside, compared to the condition in which there is no barrier (unprotected trees). This increase in speed should be induced by the perception of lesser risk owing to the presence of the guardrail barrier, compared to the condition with unprotected trees. The reduced distance from the roadside should derive from the awareness of the lesser risk entailed by the presence of the guardrail barrier. This notwithstanding, the presence of the guardrail barrier, might induce the driver to move toward the center of the road compared to the position maintained in the condition in which there is no barrier as a result of the distance from the roadside of the nearest object having been reduced (Michie and Bronstad, 1994; Ben-Bassat and Shinar, 2011).

These effects should be expected in the hypothesis that the subjective risk perceived by the driver is consistent with the objective risk associated with the two different configurations (protected and unprotected trees). In the case in which the perceived risk is not consistent with the objective risk, other results might be obtained. In particular, if the two conditions (presence and absence of barrier) are assumed by the driver as being equivalent in terms of risk perception, the same behavior is expected.

The expected effects of shoulder should be an increase in speed as well as in the distance from the road axis compared to those recorded on the cross-section without a shoulder. This increase in speed should stem from the fact that the driver, in the presence of the shoulder, perceives that there is a greater safety margin for correcting of his own path whenever unexpected events occur (Godley et al., 2004). The increase of the distance from the road axis should have been caused by the greater distance from the object on the right side as well as from the greater width of the road (lane and shoulder) which the driver would perceive as available (Summala, 1996; Stamatiadis et al., 2009).

Concerning the effect of the beginning of guardrail, one should expect a decrease in speed at the beginning of the guardrail barrier and a movement of the driver toward the center of the road, compared to the position on the condition without barrier (Van der Horst and De Ridder, 2007). These effects should be due to the perception of the beginning of the guardrail barrier on the right side as being a particularly dangerous obstacle in the event of a crash.

This study was carried out to test these hypotheses as well as to check if interaction effects between factors (roadside configurations and cross-section configurations) were present and if the effects were different for different geometric elements of the alignment.

2. Literature review

2.1. Effects of roadside elements

Several studies have been carried out with the aim of analyzing the effect of roadside configurations on driver behavior. A recent pilot study using a driving simulator (Naderi et al., 2006) sought to establish the methodological basis for a larger, more comprehensive research project on the effects of the contextual roadside landscape on driving performance. Based on participants' replies to a questionnaire which was administered immediately after drives on the road, with and without trees, in rural and urban conditions, a positive effect on driver perception of safety of roads lined with trees was found. However, no performance results in terms of speed or lateral positions were reported.

Stamatiadis et al. (2007, 2010) using case-wise visual evaluation model found that vegetation type and density have a significant effect on driver discomfort (it rises as the density and type of vegetation increases) and thus have the potential to influence operating speeds.

A significant research into the effect that trees have on driver's speed and paths using a simulator was carried out by Van der Horst