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Effect of shoulder width, guardrail and roadway geometry on driver perception and behavior

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ABSTRACT

Roadway design is one of the most significant factors that affect driving behavior and perceived safety. The current study tests the combined effects of three roadway design elements – shoulders width, guardrail existence and roadway geometry (curvature) – on objective driving measures (speed and lane position), and subjective measures (perceived safe driving speed and estimated road safety).

Twenty two drivers participated in an experiment with a driving simulation. In the first part objective driving data were collected, and in the second part subjective paper–pencil evaluations were requested of the perceived safety of 30 different scenarios that were previously experienced in the simulator. The scenarios consisted of the various combinations of the three roadway design elements.

The results showed a significant effect of roadway geometry on both objective and subjective measures. The shoulders width had a significant effect on actual speed, on lane position, and on perceived safe driving speed, but only when a guardrail was present.

These findings illustrate the perceptual role of a guardrail in defining the perceived safety margins that various shoulder widths provide. When a guardrail is absent, the width of the shoulder loses much of its benefits and effects on driving behavior. The results also demonstrate that roadway geometry can be used to reduce driving speeds, but at the same time it can have a negative effect on maintaining a stable lane position in sharp curves. Thus, controlling the width of road shoulders and the placement of guardrails seems to be a safer approach to speed and lane position control.

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1. Introduction

Driver behavior is affected by a variety of elements, including the driver's personality, experience, and attitude, and the roadway environment (Shinar, 2007; Rudin-Brown et al., 2009). Roadway design is an important element of the environment, and it includes among others the lane and shoulder width, median width, clear zone, horizontal and vertical alignment, and roadside landscape. All of these factors of roadway design can influence drivers' perception and therefore influence their driving behavior (Martens et al., 1997; Janssen et al., 2006). Several studies have shown that roadway design is associated with accident rate (e.g., Knuiman et al., 1993; Hadi et al., 1995; Karlaftis and Golias, 2002; Polus et al., 2005), however only a few studies directly investigated the effect of roadway design on driver behavior (e.g. De Waard et al., 1995; Martens et al., 1997; Stamatiadis et al., 2007) through controlled manipulations.

Safe and well designed roads should be user-centered, should minimize the likelihood of going off the road and free of conflicts among different road users (cars, motorcycles, bicycles, and pedestrians). But, this safe design can also unintentionally create a situation where drivers feel too safe and therefore allow themselves to increase speed, reduce attention, and suffer from boredom and drowsiness. Therefore, the road should be designed in a way that will still convey the risk of unsafe behaviors (Shinar, 2007).

Driving speed, for example, is one of the behaviors affected by the driver's perception of the road's safety, and it is not necessarily compatible with the road's design speed (Misaghi and Hassan, 2005). If a road design is very forgiving – i.e., wide shoulders, wide lanes, and no curves – the drivers' confidence will rise and they will compensate by speeding (Shinar, 2007). But, if the speed chosen is not appropriate in a given situation, it may result in lose control and run-off-road accidents (Janssen et al., 2006).

Lower speeds can be achieved by several measures such as speed limit signs, speed bumps, roundabouts, road markings, and roughness of road surface (Martens et al., 1997). However, when roads are properly designed, in terms of road and lane width, curvature and the like, drivers slow down voluntarily and do not feel that

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the particular road design was meant to lower their speed. In these cases, the traffic environment and road design are "self-explaining" (Theeuwes and Gosthelp, 1995). The current study focuses on the effects of three roadway design features on drivers' speed and lane position – paved shoulders width, roadway geometry, and the presence of guardrails.

1.1. Shoulder width

Roadway paved shoulders have several functions, including emergency stop and pull off, and recovery area for driver errors (AASHTO, 2004, in Stamatiadis et al., 2009). Narrow shoulders can create a dangerous situation where the driver will not have recovery area in case of lane deviation and they therefore increase the likelihood of off-road collisions (Kraus et al., 1993). But, wide shoulders may also create a dangerous situation. A previous study has shown that approximately ten percent of fatal freeway crashes are related to vehicles stopped on shoulders (Hauer and Lovelly, 1984, in Hauer, 2000). Karlaftis and Golias (2002) attempted to quantitatively assess the effects of various highway characteristics on accident rates, using a database that contained five years (1991–1995) of accident data for Indiana along with the traffic and geometric characteristics for the location of each accident. The authors found that lane width variable was one of the most important factors affecting accident rates in two-lane roads. In addition, paved shoulders width was also associated with accidents: as the shoulder width increases (up to 7.5 m), the accident rate decreases (Choueiri et al., 1994).

Shoulder width can also have conflicting effect on driving behavior. On one hand, several studies have found that narrowing roads and lanes – either in reality or perceptually – can be used as a measure to slow driving speed (Shinar et al., 1980; Kolsrud, 1985; Van Smaalen, 1987 in Martens et al., 1997; Godley et al., 2004), and thus create safer driving behavior. There are two possible explanations for the effect of road and lane width on driving speed. The first explanation is that wider shoulders give the driver a sense of security and space for correcting errors (Hauer, 2000; Stamatiadis et al., 2009). In contrast, narrower roads are perceived as less tolerant and therefore more dangerous. This leads drivers to use speed control as a mean to avoid danger or risky situations (Summala, 1996).

The second possible explanation for slower driving speeds on narrow roads stems from the increase in driver workload. De Waard (1995) argued that driving in a narrow lane requires more mental effort from the driver than driving in a wide lane, because of the need to keep the vehicle in the lane. Also, higher speeds involve high rates of flow of information and require greater mental effort.

These findings, which associate narrow roads with lower speed and safer driving behavior, contradict studies that found a negative effect of narrow shoulders on safe driving behavior, by affecting the driver's ability to maintain safe lane position. In an early study, Rinde (1977, in Dewar and Olson, 2001) examined crash rates on 37 two-lane roads in California with three different shoulder widths of 2, 4, and 8 feet. He found that narrow shoulders led drivers to steer away from the right shoulder and drive closer to the center of the road, thus increasing the likelihood of a head-on collision (Rinde, 1977, in Dewar and Olson, 2001). Some other studies also found that accident rate decreases as shoulder width increases in a two-lane roadway (e.g., TRB special report 214, 1987, in Rosey et al., 2009; Hadi et al., 1993; Zegeer and Council, 1995).

1.2. Roadway geometry

Driving speed, lane position and accident rate can also be affected by roadway geometry. Horizontal curves reduce the visibility distance, limit driver's ability to anticipate the course of the road ahead and thus increase uncertainty (Martens et al., 1997). It is well known that a negative relationship can be found between curve radius and accident rate, especially run-off-the-road accidents (Choueiri et al., 1994; Takeshi and Nozomu, 2005), Shoulder width and curve radii can also affect the driver's sight distances (Choueiri et al., 1994). Green et al. (1994), using the UMTRl Driving Simulator tested the relationship between roadway geometry and driver performance and found that the variability (specifically the standard deviation – SD) of the drivers' lateral position was affected by lane width and by sight distance. They also found that as the lane became wider, SD of lateral position increased, and when the sight distance increased the SD of lateral position decreased. Interestingly they found no effect of lane width or sight distance on mean speed or on SD of speed, results that were explained by the visibility of the speedometer to the participants during the experiment (Green et al., 1994). Another simulation study that examined the effect of roadway geometry on driving performance found that as curve's radius decreases, the demands on vehicle control increase resulting in more corrections, that in turn affect lane position; and inversely, when speed was lowered vehicle control was improved (Van Winsum and Gosthelp, 1996).

Roadway geometry can also affect the driver's safety perception. In an on-site experiment conducted in Greece, three nonconsecutive road sections containing various curves were used to examine risk perception regarding different road design elements. The results indicated that roadway curvature highly affected drivers' risk (or safety) perception. Thus, a straight road was perceived as less risky than curved one (Kanellaidis et al., 2000).

1.3. Guardrail existence

The third feature of road design examined here is guardrail existence. Guardrails, placed along the right hand edge of the paved road surface are generally effective in reducing both accident rates and accident severity (Michie and Bronstad, 1994; Elvik, 1995; Lee and Mannering, 2002). One possible reason for guardrails' effectiveness in reducing accident rates may be that guardrail can also be perceived as a roadside hazard (Lunenfeld and Alexander, 1990; Michie and Bronstad, 1994) and therefore it influences driving behavior.

Van der Horst and de Ridder (2007), using a driving simulator found that when a guardrail appeared on the side of the road, drivers tended to move away from it, but only if an emergency lane (that can be considered as 3.5 m shoulder), was not present. In this study, guardrails always appeared with trees that were placed in different distances from the guardrail, but none of the conditions presented a guardrail without trees. Thus, it is difficult to assess the effects of the guardrails in and of themselves. The authors found no effect of guardrail type or size on driving behavior.

A serious limitation of all the studies and conclusions cited above on the effects of road design on driver behavior is that they are based on correlational studies of existing situations and are therefore prone to various confounding factors. To the best of our knowledge, the effect of controlled direct experimental manipulation of shoulder width on driving behavior has never been examined. In addition, studies that did use a driving simulator concentrated on one feature of roadway design and did not evaluate the combined effects of different features. Therefore, in the current study, a driving simulator was used in order to manipulate and simultaneously examine the effects of all three features of roadway design on driving behavior. We hypothesize that in addition to main effects that were found in previous studies, there will also be some interaction effects among the different features.

The validity of driving simulators as a tool for the analysis of driver behavior has been established in several previous studies (e.g. Kemeny and Panerai, 2003; Bella, 2005, 2008; Rosey et al., 2009; Rudin-Brown et al., 2009). In particular, the high validity

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