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Interrupted versus uninterrupted flow: A safety propensity index for driver behavior

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ABSTRACT

The objective of this paper is to develop a quantitative safety propensity index (SPI) that captures the overall propensity of a given surrounding environment to cause unsafe driving. The study is conducted in two different flow conditions: interrupted and uninterrupted. Using structural modeling techniques, the index can be estimated from observed geometric, weather-related, vehicular, driver-related, and traffic-related characteristics. To illustrate the adopted approach, extensive effort was conducted to "sync" data from different sources including the Virginia Department of Transportation and the FARS/GES crash data libraries. The Virginia Department of Transportation provided traffic data for 10 freeway sections with interrupted flow and 9 highway sections with interrupted flow in the Northern Virginia area, USA. Two different structural equations models were found allowing insights to the safety impact of different surrounding elements/dimensions. The SPI provides (a) a basis for quantifying the effects of the aforementioned characteristics on safety, (b) a basis for comparing the differences between the factors affecting safety in different flow scenarios and (c) ranking the corresponding roadway sections/locations for improved safety performance. The framework and methodology used to develop this index have the potential to support safety policy analysis and decision making.

1. Introduction

Roadway infrastructure impacts driving behavior which, in turn, has significant implications when analyzing vehicle to vehicle interactions and assessing macroscopic transportation network performance. Previous studies have separately assessed different characteristics (infrastructure, driver, vehicle, traffic, etc.) effects on safety. No comprehensive model exists that takes into account the combined effect of multiple characteristics' types on safety as well as their effect on one another.

Research conducted in this study will develop a safety propensity index in a framework linking road infrastructure and weather conditions to observed crash and traffic data. This framework will allow for a better understanding of the safety implication of road infrastructure and weather features such as: pavement characteristics, number of lanes, lane width, curb width, curvature, grade, precipitation, visibility and roadway surface friction. Crash data as well as highway infrastructure/traffic characteristics of the collection sites (through the Virginia Department of Transportation (VDOT)) are used for verifying the suggested approaches with the structural equation method (SEM) technique. The different research findings will be used to develop surrogate safety measures on both interrupted and uninterrupted flow roadways and allow for comparison between the corresponding illustrated models: the commonalities and differences between the factors that influence safety under both scenarios will be presented.

The ultimate goals of the research are to (1) systematically identify the network characteristics that influence safety under different traffic situations; (2) study the response to changes in network geometry as an evolving system with temporal and spatial elements with particular attention to the corresponding safety implications; (3) validate the formulated behavioral traffic models against statistical models estimated using existing national incident data (NHTSA, 2010); (4) develop and compare these models for both interrupted and uninterrupted flow scenarios; and (5) observe the models to gain a deeper understanding of how better transportation system performance can be achieved and strategies can be proposed to improve traffic safety and operations.

2. Conceptual framework and background

Creating a safer driving environment is a main objective for transportation researchers in the United States, and worldwide. On roadways in the United States, specifically, there were over

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33,000 fatalities in 2009 and although this is a decrease in both total fatalities and fatalities per vehicle mile traveled (NHTSA, 2010), researchers are still seeking improvements to minimize this number. Before this marked decrease in fatalities (and in both fatal and total collisions) from 2008 to 2009, both the number of vehicle miles traveled and the number of total collisions had been following an ascending pattern for the previous 10 years (NHTSA, 2010). If vehicle miles traveled is considered a surrogate measure for congestion, and total collisions a measure for safety, there is a need to examine the different possible factors leading to the aforementioned patterns thus enabling a less congested transportation system and creating a safer driving experience. There are a variety of ways congestion can begin, even with freeway demand not at critical levels, including (but not limited to): shockwaves generated on uphill slopes due to trucks/trailers climbing at slower speeds; vision reduction for a few drivers by a rising sun in a straight highway segment; weaving near a freeway ramp; or exaggerated braking near an unconventional road design so that shockwaves propagate backwards and slow down or completely stop traffic down the road (Treiber et al., 2000). These examples illustrate complex interactions between roadway geometry, drivers' characteristics and environmental conditions that impact transportation efficiency and safety.

Previously conducted research in this area focuses on only one or two dimensions (such as geometry and traffic characteristics) (Karlaftis and Golias, 2002; Li et al., 1994) and mainly uses accident rates at the metric for evaluating safety (Joshua and Garber, 1990; Jones and Whitfield, 1988; Karlaftis and Golias, 2002; Li et al., 1994). In this paper, focusing on an empirical data-driven approach rather than on a simulation behavioral approach (Hamdar et al., 2008; Talebpour et al., 2012), through the FARS/GES crash libraries, different metrics (number of injuries, number of fatalities, etc.) are used to assess the safety of the roadway and multiple dimensions are considered in the analysis. Results from previous research can be used to develop an understanding of the effects that certain variables may have, but provide a weak basis for comparison of results as the type of analysis are fundamentally different. One such study (Lee et al., 2008) utilized a similar structural equation approach, but the dimensions selected (and the variables selected within those dimensions), the location of the study (Korean highways) and the flow conditions analyzed (only uninterrupted) all differed from the analysis conducted in this study.

Creating a safety propensity index (SPI) based on roadway geometry involves capturing the complex relationships outlined earlier. The interrelationships between latent and endogenous quantities on one hand and on the other, measured (observable) variables characterizing the environmental conditions, geometric features of the roadway, traffic situations, socio-demographics of the drivers, as well as instances of certain driving behaviors and collision scenarios. Fig. 1 presents an initial conceptual framework illustrating the main types of factors that enter into the formulations of the SPI, as well as its dependence on a set of complex relationships. This further illustrated in Fig. 2 through specific dimensions and example variables of measures that capture the dimension.

The complexities of the interrelationships followed by the dimensions and driving patterns mentioned above can be formulated us the structural equation modeling approach. Structural equation modeling (SEM) is a cause and effect approach to analyzing data where relationships between variables are postulated by the modeler based on theories and previous empirical results (Golob and Meurs, 1986a,b). The approach is "confirmatory rather than exploratory" (Golob, 2001), as the system of unidirectional effects of one variable on another is being constructed and then either accepted or rejected based on its validity (Golob, 2001). This approach is becoming increasingly popular in travel behavior research as user-friendly software becomes increasingly powerful and widely available (Golob, 2001).

Table 1
Uninterrupted flow data collection locations.

Segment number	Highway name	Mile markers
1	I-66 West	12–13
2	I-66 West	53–54
3	I-66 West	70–71
4	I-495 South	1.5–2.5
5	I-495 South	6–7
6	I-495 South	12–13
7	I-81 North	291–292
8	I-395 North	3–4
9	I-95 South	152–153

While safety can be derived from a number of different metrics, the manner and degree in which it is affected by the aforementioned observable variables if difficult to quantify. This propensity for safety is captured though a latent scale and index, and related to observable variables through the SEM formulation. This index allows for the identification of the major contributing factors for a certain flow scenario, the manner in which those factors vary with flow scenario, and assessment of the relative importance of different determinants.

3. Statistical model

The data used for analysis was provided in multiple databases by the Virginia Department of Transportation (VDOT). The three databases that were combined and edited contained data on collisions, traffic and pavement characteristics respectively. Both interrupted and uninterrupted flow conditions were considered. In the uninterrupted flow situation, nine highway segments were chosen for analysis and are displayed in Table 1.

In the interrupted flow situation, ten roadway segments – all of which are components of a network of signalized intersections – were chosen for analysis and are displayed in Table 2.

3.1. Available data and additional limitations

The major limitation of this study was the availability of data in the state of Virginia. Initial conceptual framework had to be adjusted as a variety of necessary data was either not available or incomplete. In response to these major obstacles the following was implemented:

1. A friction variable was developed. In order to compute the friction values for the specific segments of roadway at the time of each individual collision, the weather conditions at time of collision, the pavement type, the vehicle speed and the time since last roadway rehabilitation were employed in unison. Cross referencing these values with a table of accepted friction values (Baker and Fricke, 1990; Table 3)

Table 2
Interrupted flow data collection locations.

Segment number	Main/through	Minor/cross
1	State Route 7	State Route 193
2	State Route 7	US 29
3	State Route 123	State Route243
4	US 50	Old Ox Road
5	State Route 28	Liberia Drive
6	US 29	US 15
7	US 17	State Route 28
8	State Route 123	Burke Lake Road
9	State Route 234	Prince William Parkway
10	State Route 123	State Route 309