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Exploring the association between speed and safety: A path analysis approach

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ABSTRACT

Road safety is influenced by many factors; these factors include characteristics of the road, climate, traffic and, most importantly, vehicle speeds. Previous research shows that increases in speed are typically associated with an increased collision risk. Moreover, previous studies have also found relationships between road and traffic characteristics and collisions. In addition, these features have also been found to affect speeds. This paper aims to model all the aforementioned relationships simultaneously using a Structural Equation Modelling approach. More specifically, the paper attempts to model the relationship between average speed and collision frequency, while taking into account the effects of factors that confound the relationship. Moreover, the analysis attempts to assess the mediated effects that some variables have on collisions through their effects on speed. The data used in this study originated from 353 two-lane urban roads in the city of Edmonton, Canada. The average speeds were obtained from 35 million speed survey observations collected over a five-year period. The speed data are linked to the crash frequency at each location during the same time frame, along with the other factors (road, traffic and climate). The results show that, among others, average speed, volume, segment length, medians and horizontal curves all have statistically significant effects on collisions. On the other hand, shoulders, speed limits and vehicle-lengths are some variables that significantly influence speeds. The results also show that the effects of some variables on safety are indeed mediated through speeds (both partial and full mediation is observed). These findings provide valuable insight that may assist decision makers in choosing and developing alternative speed management strategies, which, in turn, could help improve safety.

1. Introduction

Speeding is an issue on roads worldwide, and its impacts on road safety are well documented in the safety literature (NHTSA, 2012). Speeding can be defined as simply exceeding posted speed limits or driving at speeds deemed too high for road or climate conditions during a certain period or at a certain location (e.g., foggy conditions or icy roads). In fact, the role that the road environment plays in a driver's decision to violate speed limits has been extensively researched in recent years (Oecd/Ecmt, 2006; Goldenbeld and Van Schagen, 2007; Yannis et al., 2013).

Whether it is driving at speeds higher than the speed limit or inappropriate for given conditions, speeding is a common factor contributing to collisions; in addition, speed-related collisions also represent a major share of severe collisions. Statistics show that, in 2012, 30% of all fatal collisions observed on roads in the U.S. were speed-related crashes (NHTSA, 2012); furthermore, statistics also show that, although the number of fatal collisions has dropped over the years, the portion attributed to speed-related collisions has not. Despite the statistics showing that speed is a common factor in collisions of all severity levels, the relationship remains one of the most debated topics in the field of traffic safety (Hauer, 2009).

Speeding is known to affect both the severity of a collision (Nilsson, 1982) and the likelihood of being involved in a collision (Aarts and Van Schagen, 2006). Although both relationships can be validated by means of basic laws of physics, research has shown that modelling the latter relationship is extremely complex. Common sense implies that the higher the speed, the less time (perception-reaction time) the driver has to react to an issue that could suddenly arise on the road and, thus, the higher the risk of not taking appropriate action. However, in reality, modelling the relationship is not as straightforward as it might seem (Elvik et al., 2004; Hauer, 2009).

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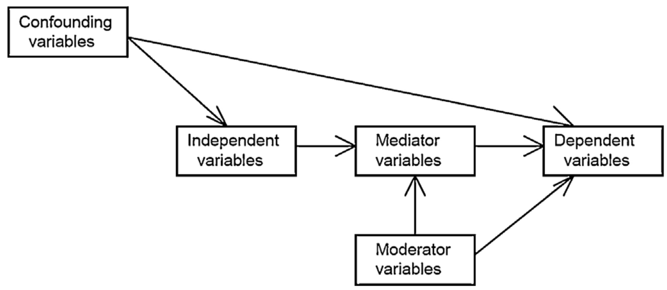

Fig. 1. Main Categories of Variables Influencing Road Accidents (Elvik et al., 2004).

Previous studies have attributed this complexity to the fact that collisions are random events that cannot be accredited to a single factor. This means that even though there is a possible high correlation between speed and collisions, it is impossible to ignore the other variables that affect collisions when modelling the relationship. Moreover, some of those variables could have masking effects, which conceal the relationship of interest (Elvik et al., 2004).

In an attempt to classify the different types of variables influencing road accidents, Elvik et al. (2004), developed the causal diagram shown in Fig. 1. As seen in the figure, the variables affecting collisions (i.e., the dependent variable) were divided into four different categories.

The dependent variable (DV) is the outcome variable to be predicted; in traffic safety, this is often the expected number of accidents. The mediator variable is a risk factor, which, if modified, can influence the dependent variable. It is also a variable through which other factors could impact the DV. The primary mediator when analyzing safety, according to Elvik et al. (2004), is changes in speeds. The independent variables (IV) are defined as the variables introduced to affect the DV through their influence on the mediator variable; examples of these variables include speed enforcement or other speed calming techniques. Moderating variables are seen as risk factors, which may include factors a safety measure does not intend to influence. One example is a road's surface condition (i.e., friction) moderating the effects of speed on collisions; the effects of speed on collisions could be greater on smooth surfaces than rough surfaces.

Confounding variables are the most challenging variables to account for; these variables, in addition to speed, have some influence on collision counts. Examples of these variables include different roadside features, elements of the road geometry, climate factors and temporal factors. Previous studies have found that these variables not only affect collision counts at a certain location but also the speeds (O'flaherty and Coombe, 1971; Giles, 2004). As a result, accounting for those factors is essential when assessing the speed-collision relationship.

The diagram in Fig. 1 helps create a rational framework for researchers attempting to model the relationship. Nevertheless, previous studies have assessed only individual paths of the diagram; thus, to the best of our knowledge, the diagram as a whole has not been validated using empirical data from any region. Therefore, the existence of those direct and indirect relationships illustrated in the path diagram remains entirely theoretical. This paper aims to address the aforementioned gap by performing a data analysis of two-lane urban roads in the city of Edmonton. Slight modifications to the diagram are applied and the path analysis is used to statistically test for the existence of the proposed relationships.

In addition to understanding the relationships among speed, safety and road environment, providing evidence of the existence of mediated effects between road geometry and collisions could also help authorities adopt a different approach when addressing speeding problems at collision hotspots. This matter is discussed in more detail in Section 5.

2. Previous work

Modelling the relationship between speed and the likelihood of a collision on a road section has often followed one of two approaches: cross-sectional analysis or longitudinal analysis. In cross-sectional analysis, data from several different locations are used to relate speed to collisions; whereas, in longitudinal analysis, time series collision data are analyzed. From a speed safety perspective, the majority of longitudinal studies involve before-after (BA) analysis of collision data where changes in speed are related to changes in collisions at specific locations.

Different statistical modelling techniques have also been considered in previous research; likewise, different measures of speed (e.g., average speed, speed variance) have all been modelled when analyzing the relationship. Despite the variation in techniques and analysis criteria, not all previous work has been able to reach perfectly consistent conclusions regarding the relationship between speed and safety. In studies where such a relationship was not concluded, researchers often cite confounding factors masking the relationship between speed and collisions as a possible reason; these factors are typically characteristics of the road that define its quality (Taylor et al., 2002). In the next few paragraphs, a review of relevant work is presented.

Taylor et al. (2002), developed a Poisson model to assess the effects of several variables, including speeds, on injury crashes observed at rural single carriage roads across the U.K. Data used in the study included traffic flows, spot speeds and information about road geometry and other features. Preliminary analysis of the data revealed that, for the compiled dataset, average speed was negatively related to accident frequency. The authors attributed this finding to the difference in road quality at the road segments sampled; therefore, they created homogenous groups through which the effects of road quality on the relationship between collisions and speed could be captured. Indeed, further analysis of the data, while including a group variable, revealed that average speed positively correlated with collisions.

The reasoning behind such a phenomenon, as expressed by Elvik et al. (2004), is that the "best roads tend to have the highest speed limits," with the best roads being those with the highest quality attributes. In fact, even in the study by Taylor et al. (2002), the variables on which the grouping was based were all attributes of road quality. In order to further elaborate on the concept, Elvik et al. (2004) used hypothetical data to compare the differences between running a bivariate analysis on all road groups (Fig. 2a) and running separate analyses for the different groups (Fig. 2b).

Despite the statistical validity in creating the homogenous groups, the models developed in (Taylor et al., 2002) were subject to some criticism. The reason was that the classification of the data into groups was based on variables that were also considered as explanatory variables in the model, which was seen as a limitation of the work by some researchers (Wang et al., 2013). For instance, traffic flow was a variable used to classify data into groups, but both flow and the grouping ID were used in the model, indicating a potential duplicate effect.

In an earlier study, Taylor et al. (2000) studied the effects of speed on urban classified roads. Data were collected from 300 different road sections and linked with 1590 injury crashes. In this case, statistical cluster analysis was used to classify sites based on their speed characteristics. The speed attributes used in the classification included average speed, variability in speeds and the proportion of slow vehicles. The findings of the analysis revealed that, among other variables, average speeds were strongly related