Accident Analysis and Prevention xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Structural equations modelling of drivers' speed selection using environmental, driver, and risk factors

Reut Sadia*, Shlomo Bekhor, Abishai Polus

Department of Civil and Environmental Engineering, Technion – Israel Institute of Technology, Haifa 32000, Israel

ARTICLE INFO

Key words:
Driving behaviour
Speed selection
Structural equations
Driving simulator

ABSTRACT

Drivers' speed has significant implications on road users' safety in general, and particularly so if a crash occurs. This paper explores the influence of environmental and road characteristics, situational factors, and individual characteristics on drivers' observed speed selection in a simulator experiment. The paper presents a theoretical framework for drivers' speed selection, and applies structural equation modeling for the various factors examined. The simulator experiments collected data of 111 drivers driving in 4 different scenarios composed of 22 segments for each scenario. The dataset was analyzed in several resolutions: Driver level, Trip level, and Segment level. The three models revealed that gender, age, and driving frequency are all significant in determining drivers' perceptions and attitudes, which in turn influence speed selection. Situational factors such as traffic speed, enforcement, and time-saving-benefits are also related to speed selection, as well as infrastructure characteristics. These findings demonstrate that structural equations provide a flexible modeling tool able to concurrently analyze the variety of factors that relate to speed selection. As a result, Structural Equations Modeling provides more accurate and refined explanations for the combined effects of various factors on drivers' speed selection than previous research so far. These tools can be useful in developing speed management strategies to improve road safety.

1. Introduction

The long-time research interest in drivers' speed has risen mainly from the effect of driving speed on road safety – the faster the speed, the harsher the resulting impact in case of a crash (Aarts and van Schagen, 2006). Speed dispersion and variations were also found in some studies to be related to crash risk (Aarts and van Schagen, 2006; Sadia et al., 2016). Thus, a great interest remains in understanding how drivers select their speeds, and how those speeds can be managed. A wide variety of factors has been studied in relations to drivers' speed selection, which can be generally divided into three categories: (i) Environmental Characteristics – such as infrastructure and traffic conditions, (ii) Driver Characteristics – such as personality traits and subjective perceptions, and (iii) Situational factors, defined here as Additional Risk/Benefit – such as being late to work or spotting a police car. All of these influence the driver's individually selected speed, which may change during a specific trip as a result of changes in these factors.

Research on Environmental Characteristics related to speed was mostly collected from aggregate on-road observations, field studies, and simulated driving conditions such as driving simulators and virtual reality (De Waard et al., 1997; Fildes et al., 1987; Polus et al., 2000; Stamatiadis et al., 2009; Tarko, 2009; Van der Horst and de Ridder, 2007). Design consistency studies also reveal how variations in road infrastructure relate to selection of operating speeds and crash risk (Mattar-Habib et al., 2008). Specific Environmental Characteristics that relate to infrastructure and influence selected speeds include horizontal curves and cross-section elements – such as road, lane, and shoulder width, the presence of a median, and barrier type (De Waard et al., 1997; Gitelman et al., 2014; Polus et al., 2000; Stamatiadis et al., 2009; Tarko, 2009; Van der Horst and de Ridder, 2007). Road-side elements and road classification also influence speed selection (De Waard et al., 1997; Fildes et al., 1987; Tarko, 2009; Van der Horst and de Ridder, 2007). In addition, Traffic characteristics may also be perceived as environmental characteristics related to speed selection; it was found that in free flow conditions, some driver explain exceeding the speed limit as an adaption to the speed of other surrounding vehicles (SWOV, 2012). Posted speed limits are assumed also to influence drivers' speed selection, but their interpretation varies greatly between drivers (Mannering, 2009).

Research on driver characteristics was conducted mostly by using questionnaires and interviews, especially research involving latent

* Corresponding author.
E-mail addresses: reut.sadia@gmail.com (R. Sadia), sbekhor@technion.ac.il (S. Bekhor), polus@technion.ac.il (A. Polus).

http://dx.doi.org/10.1016/j.aap.2017.08.034
Received 4 February 2017; Received in revised form 8 July 2017; Accepted 24 August 2017

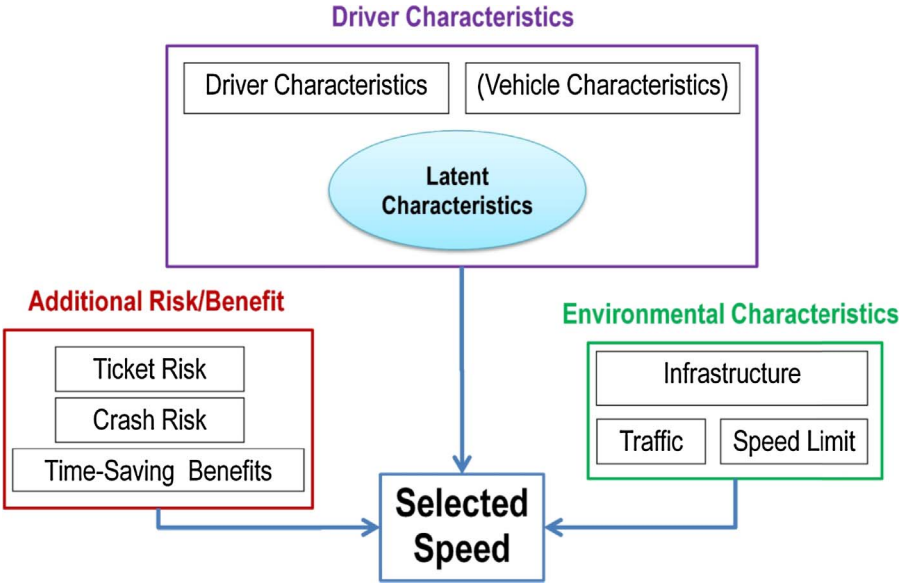

Fig. 1. Theoretical Framework for Speed Selection Research.

variables methodologies to reveal differences in drivers' norms, attitudes, and perceptions. Numerous studies have used questionnaires of Theory of Planned Behavior to examine these aspects in relations to drivers' intentions regarding their speed selection, with several studies also comparing their findings to the drivers' actual speeding behavior (Cestac et al., 2011; Cristea et al., 2013; Leandro, 2012; Paris and Van den Broucke, 2008; Warner and Aberg, 2006), with partially significant findings. Other latent variables of driver characteristics that have been measured include risk-taking propensity and sensation seeking (Cestac et al., 2011; Hatfield and Fernandes, 2009), as well as positive self-bias (Horswill et al., 2004; McKenna and Horswill, 2006; McKenna et al., 1991), which all had significant relations to speed selection, especially regarding young drivers' speeding behaviors.

Another aspect of drivers' speed selection incorporates the associated risks and benefits. Risks related to speed selection are most often crash risk and speeding-ticket risk, whereas the usual benefits are the time saved, as well as the secondary gain of thrill for some drivers (Tarko, 2009). Enforcement risk, for example, was studied for its duration and frequency, which determine its temporal and spatial effect on drivers' speeds. (Haglund, 2001; Hauer et al., 1982). Crash risk has been studied mostly as drivers' crash risk perception of a specific road segment driven (Haglund, 2001). Time is the benefit gained the most when drivers select higher speeds, although other benefits such as thrill and joy may as well influence higher speed selection. (Cristea et al., 2013; Richard et al., 2012; Tarko, 2009). These risks and benefits are evaluated either by driver questionnaires and interviews, or by assumptions made by the researchers, such as an elevated value of time during rush hour (Tarko, 2009).

One of the methods for estimating latent variables and their effects on observed variables is using structural equations (Bollen, 2002; Arbuckle, 2007; Washington et al., 2010). Structural Equations Modeling [SEM] allows a simultaneous estimation of several equations of independent and dependent variables, thus allowing a multi-layered model to be assessed. SEM is a technique that can handle a large number of endogenous and exogenous observed variables simultaneously. The term "simultaneous equations" means that a set of equations can be specified by direct links between variables. SEM is commonly used to model latent variables, generally specified as linear combinations of the observed variables. It has been used in several models, e.g. to analyze traffic accident size (Lee et al., 2008); sensation seeking and risky behavior (Scott-Parker et al., 2013); and driver distraction (Chen and Donmez, 2016).

According to Washington et al. (2010), SEMs have two components, a measurement model and a structural model. The measurement models within a SEM incorporate estimates of measurement errors of exogenous variables and their intended latent variable. The structural model is concerned with how the model variables are related to one another. The structural component of SEMs is similar to a system of simultaneous equations. Because of the ability of SEMs to specify complex underlying relationships, graphical representations have become the standard means for presenting information about SEMs.

From the literature review, it is apparent that speed selection is a complex phenomenon for which many models and explanations have been suggested. Studies on environmental characteristics and infrastructure have been conducted mostly using speed observations via field data and driving simulators, while studies on driver characteristics have used mostly questionnaires and interviews. Studies on speeding risks and benefits have used various methods, depending on the specific definition of the variables explored. However, there remains a lack in studies which have been able to utilize several methodologies such that several types of influences on speed selection can be obtained and assessed simultaneously.

In this study, a complex experimental design was constructed to capture several aspects of factors influencing drivers' speed selection – environmental characteristics, driver characteristics, and additional risk/benefit. This was achieved by using both a stated-preference survey and a driving simulator. The theoretical framework of the study is summarised in the next section.

2. Theoretical framework

The theoretical framework of this research suggests that the factors influencing speed selection may be divided into three main categories: Environmental Characteristics, Driver Characteristics, and Additional Risk/Benefit considerations. The components of these three categories can be seen in Fig. 1:

The category of Driver Characteristics refers to individual characteristics, which usually cannot be controlled in an experiment. Vehicle characteristics could be also included in this category, since different vehicles characteristics – such as engine displacement and horse power, vehicle size and weight, acceleration characteristics, etc – may lead to different selected speeds. However, the direction of causality is not clear; to what extent do driver characteristics influence vehicles choice and characteristics? And consequently, in what ways do vehicle characteristics influence speed selection? This part of the model appears in parenthesis since there is a lack of information in the