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What is the level of volatility in instantaneous driving decisions?

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ABSTRACT

Driving styles can be broadly characterized as calm or volatile, with significant implications for traffic safety, energy consumption and emissions. How to quantify the extent of calm or volatile driving and explore its correlates is a key research question investigated in the study. This study contributes by leveraging a large-scale behavioral database to analyze short-term driving decisions and develop a new driver volatility index to measure the extent of variations in driving. The index captures variation in driving behavior constrained by the performance of the vehicle from a decision-making perspective. Specifically, instantaneous driving decisions include maintaining speed, accelerating, decelerating, maintaining acceleration/deceleration, or jerks to vehicle, i.e., the decision to change marginal rate of acceleration or deceleration. A fundamental understanding of instantaneous driving behavior is developed by categorizing vehicular jerk reversals (acceleration followed by deceleration), jerk enhancements (increasing accelerations or decelerations), and jerk mitigations (decreasing accelerations or decelerations). Volatility in driving decisions, captured by jerky movements, is quantified using data collected in Atlanta, GA during 2011. The database contains 51,370 trips and their associated second-by-second speed data, totaling 36 million seconds. Rigorous statistical models explore correlates of volatility that include socioeconomic variables, travel context variables, and vehicle types. The study contributes by proposing a framework that is based on defining instantaneous driving decisions in a quantifiable way using big data generated by in-vehicle GPS devices and behavioral surveys.

1. Introduction

As the most dominant transportation mode in USA, automobile driving has significant impacts on traffic safety, energy, and emissions. With widespread deployment of emerging information and communication technologies, massive amounts of driving data in high resolution are becoming available, allowing researchers to scrutinize driving behavior in far more detail than was possible before. Insights can be obtained by studying instantaneous decisions made during driving in nearly real-time. Also, such "Big data" provides opportunities that support visualization, analysis, and modeling in new ways that could not be imagined before. The combination of data and tools can help create new visions that can potentially transform

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the way we monitor and evaluate transportation system performance and potential improvement actions. This study takes advantage of the big data collected by in-vehicle Global Positioning System (GPS) devices and survey data to define instantaneous driving decisions as drivers' choices of a set of options during driving. Such choices include maintaining speed, accelerating, decelerating, maintaining acceleration/deceleration, and vehicular jerk, i.e., the decision to change marginal rate of acceleration and deceleration. The sequential chaining of these short-term driving decisions can be volatile because they are intended to respond to the instantaneous changes in surrounding circumstances, such as approach of adjacent vehicles, pavement conditions, geometric transitions in the roadway, and weather conditions. Fluctuations in traffic flow can create challenges for safety, as well as challenges for energy consumption, tailpipe emissions and public health (Ji et al., 2011; Wang et al., 2013). Existing studies have shown that emissions and fuel usage vary significantly with different speed ranges (U.S. Environmental Protection Agency, 2010). Additionally larger deviations from mean speed can significantly increase crash risk (Transportation Research Board, 1998). Accordingly it is important to understand and quantify variability in drivers' instantaneous decisions and explore the associations with socioeconomic, vehicular, and contextual variables.

Volatility in instantaneous driving decisions can be quantified by variability in vehicular movement, and the variability can be represented by speed and its derivative (acceleration/deceleration) as well as its second derivative (vehicular jerk). Micro level GPS data along with behavioral survey data are used to answer the following fundamental questions:

(1) How to develop measures of driving volatility?
(2) What is the level of volatility in instantaneous driving decisions?
(3) What are the key correlates of driving volatility?

2. Literature review

Aggressive driving and its impacts on traffic safety has been a concern of the public and many other sectors, including public transportation agencies, policy agencies, insurance companies, various organizations such as American Automobile Association. No consensus exists regarding "aggressive driving" in the literature. Social psychology researchers define it from the perspective of intent (Miles and Johnson, 2003); for instance, "road rage" refers to more criminal-oriented offenses (Shinar, 1998), while NHTSA classify "aggressive driving" as "driving actions that markedly exceed the norms of safe driving behavior and that directly affect other road users by placing them in unnecessary danger" (National Highway Traffic Safety Administration, 2009). Other researchers had a list of "aggressive driving" (James and Nahl, 2000) including "weaving in and out of traffic", "driving at speeds far in excess of the norm which results in frequent tailgating, frequent and abrupt lane changes", "passing one or more vehicles by driving on the shoulder and then cutting in", or through certain syndrome of frustration-driven behaviors or negative cognitions such as annoyance, hostility, sustained horn-honking, glaring at others, yelling, gesturing, etc. (Shinar, 1998; Nesbit and Conger, 2012; Underwood et al., 1999; Tasca, 2000). These studies in driving psychology largely depend on self-reported surveys of the driving public (Miles and Johnson, 2003; Lajunen and Summala, 2003), or video recording which requires manual identifications (Shinar and Compton, 2004), with limitations on collecting data systematically and accurately. Critical research issues include: what are the so-called the norms of safe driving behavior; how to define a driver's extent of "aggressive driving" in a precise and quantifiable way.

While the research of "aggressive driving" in social psychology focuses more on peoples' intentions, the above driving behaviors and their cognitive processes in such driving situations are difficult to measure directly and continuously. Nevertheless, the speed profile as a common observable behavior is relatively easy to collect and has the potential of being utilized to characterize driving behavior. Measures used in the literature to identify aggressive or calm driving styles include the ratio of the standard deviation and the average acceleration within a specified time window (Langari and Jong, 2005), ratio of standard deviation and vehicular jerk of the normal driving style (Murphey, 2008).

Several critical cutoff points for aggressive behavior based on acceleration have been reported; 1.47 m/s^2 (4.82 ft/s^2) and 2.28 m/s^2 (7.47 ft/s^2) were reported as critical estimates of aggressive and extremely aggressive acceleration thresholds in urban driving environments (Kim et al., 2006; Kim and Choi, 2013). However, there is no consensus threshold, for instance, other researchers reported 0.45–0.65 m/s^2 (1.48–2.13 ft/s^2) as calm driving, 0.85–1.10 m/s^2 (2.79–3.61 $ft/^2$) as aggressive driving for urban journeys (De Vlieger et al., 2000).

The percentage of time acceleration exceeds 1.5 m/s^2 (4.92 ft/s^2) was reported as one of the most important parameters (out of 16 parameters) contributing to increases in emissions and fuel consumption (Ericsson, 2001). However, researchers argued that using acceleration alone may not represent the driving style accurately; therefore the coefficient of variance were also used as a complementary measurement in order to identify aggressive driving. Accordingly, accelerating at a relative regular rate, along with driving with medium acceleration but high standard deviation of acceleration are both flagged as aggressive driving (Langari and Jong, 2005).

Connections between aggressive driving and safety were found in existing studies (Renski et al., 1999; Paleti et al., 2010). Paleti et al. (2010) have explored aggressive pre-crash behaviors and defined aggressive driving to include "speeding, tailgating, changing lanes frequently, flashing lights, obstructing the path of others, making obscene gestures, ignoring traffic control devices, accelerating rapidly from stop, and stopping suddenly". Their results show a positive association between injury severity and aggressive driving (given a crash).

Regarding emissions and fuel consumption, studies have shown that emissions can vary according to the decisions including both strategic decisions (vehicle selection and maintenance tactical decisions (selection of routes, dealing with