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Modelling the effects of stress on gap-acceptance decisions combining data from driving simulator and physiological sensors

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ABSTRACT

Driving behaviour is an inherently complex process affected by various factors ranging from network topography, traffic conditions and vehicle features to driver characteristics like age, experience, aggressiveness and emotional state. Among these, the effects of emotional state and stress have received considerable attention in the context of crash analysis and safety research where driving behaviour has been found to be affected by drivers' mental state/stress, cognitive workload and distraction. However, these studies are mostly based on questionnaire surveys and self-reports which can be prone to response bias and reporting/measurement errors. The analyses are also often descriptive in nature. In a parallel stream of research, advances in sensor technologies have made it possible to observe drivers' stress through human physiological responses, e.g. heart rate, electrodermal activity etc. However, these studies have primarily focused on detecting stress rather than quantifying or modelling its effects on driving decisions. The present paper combines these two approaches in a single framework and investigates the gap-acceptance behaviour of drivers during an intersection crossing, using data collected using a driving simulator. The participants are deliberately subjected to stress induced by time pressure, and their stress levels are measured using two physiological indicators, namely Electrodermal Activity (skin conductance) and heart rate. In addition to statistical analyses, discrete choice models are developed to link the accept-reject choices of a driver with the driver demographics, traffic conditions and stress levels. The results of the models indicate that increased stress levels significantly increase the probabilities of accepting a gap. The improvement in model fit and safety implications derived from model estimates are also discussed. The insights from the results can be used for designing appropriate intervention strategies to improve safety.

1. Introduction

Road safety continues to be an important issue with road crashes among the leading causes of death - accounting for more than 1.2 million fatalities and 50 million injuries globally each year (World Health Organization, 2015). Driver behaviour is a factor in over 90% of crashes, with speeding as one of the major contributors (World Health Organization, 2015). Driving behaviour models, which provide mathematical representations of drivers' decisions involving

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acceleration-deceleration, lane-changing, overtaking, etc., are increasingly being used for evaluation and prediction of road safety parameters and formulating remedial measures (e.g. Farah, Bekhor, Polus, & Toledo, 2009; Barceló, 2010; Hoogendoorn, Hoogendoorn, Brookhuis, & Daamen, 2010; Farah & Koutsopoulos, 2014). Reliable driving behaviour models are also critical for accurate prediction of congestion levels in microscopic traffic simulation tools) and analyses of emissions.

Driving decisions are affected by various factors, including network topography, traffic conditions and driver characteristics – which include, among others, demographics, personality traits and emotional state. Existing driving behaviour models address many of these factors, either fully or partially, where the effects of surrounding traffic conditions have received considerable attention (Ossen and Hoogendoorn, 2005; Toledo, 2007; Choudhury, 2007; Marczak, Daamen, & Buisson, 2013 to name a few). However, in most cases, the models do not adequately capture the sophistication of driver behaviour and the causal mechanism behind their observed decisions. In particular, research in other realms, in the context of crash analysis and safety research, has confirmed that driving behaviour is significantly affected by drivers' mental state/mood (e.g. anger) (Garrity and Demick, 2001), cognitive workload (Hoogendoorn et al., 2010), distraction (Young, Regan, & Hammer, 2007) and fatigue (Thiffault and Bergeron, 2003). Existing work on drivers' stress has mainly focused on the investigation of the relationship between stress and aberrant behaviour and its impact on safety (Ge et al., 2014; Westerman and Haigney, 2000; Hill and Boyle, 2007). However, these studies primarily examined the effects of stress based on self-reported surveys which can be prone to response bias and reporting errors. Indeed, at best, a driver can report an indication of stress levels, but not an objective measure of a physiological state. In addition, many of these studies are largely descriptive rather than relying on detailed modelling work.

In a parallel stream of research, recent advances in sensor technologies have made it possible to measure drivers' stress levels through human physiological responses, e.g. changes in heart rate, electrodermal activity, etc. (Healey and Picard, 2005; Ahmed et al., 2015). However, these studies have primarily focused on detecting stress rather than quantifying or modelling its effects on driving decisions in detail.

This paper aims to fill in this research gap by developing gap acceptance models with explicit consideration of the effect of stress on driving behaviour. The gap-acceptance models developed in this research are based on an extensive experimental study in the University of Leeds Driving Simulator (UoLDS) where the drivers have been intentionally subjected to stressful driving conditions caused by time pressure and surrounding traffic conditions. Their choices of accepted gaps have been recorded alongside physiological measurements of stress indicators (Electrodermal Activity and heart rate) and socio-demographic characteristics (age, gender, experience). A series of gap acceptance models are developed and augmented by continuous physiological measurements.

The remainder of the paper is organised as follows. We first present a review of the literature, followed by the experimental setting and the data analyses. This is followed by a description of the methodological approach of the study. We then present estimation results followed by concluding remarks where insights from the models are discussed.

2. Literature review

2.1. Stress and driving context

'Driver stress' has been defined as a situation that challenges drivers' abilities, reduces their perceived control or threatens their mental/physical health (Gulian, Matthews, Glendon, Davies, & Debney, 1989). Driver stress can be a consequence of several factors including the direct demands of the driving task, the environmental conditions (e.g. foggy, icy, etc.), network characteristics (e.g. surface characteristics), junction frequency, speed and flow per lane and/or potential secondary tasks, such as use of navigation system, texting, etc. (Hill and Boyle, 2007). Moreover, time urgency and the level of congestion have been identified as two important factors influencing drivers' stress (Hennessy and Wiesenthal, 1999).

There is a substantial body of literature that investigates the effects of stress on driving behaviour. Drivers under stress may be overwhelmed by negative emotions and thus are more likely to get involved in hazardous situations (Ge et al., 2014). Self-reported stress has been linked to aberrant driving behaviour, namely errors and violations (Kontogiannis, 2006). These types of impaired behaviour are related to road crashes and incidents, therefore stress is considered as an issue related to traffic safety (Westerman and Haigney, 2000; Useche, Serge, & Alonso, 2015, Qu, Ge, Jiang, Du, & Zhang, 2014). Moreover, Ge et al. (2014) found that perceived stress is linked to aggressive and risky driving behaviour. Also, Clapp et al. (2011), grouped reactions under stressful situations in three main categories which are the extremely cautious driving behaviour, aberrant behaviour and aggressive (or hostile) behaviour. The aforementioned findings provide compelling evidence regarding the effects of stress on driving, however, they are based on self-reported survey results and therefore prone to response bias and reporting/measurement errors.

An alternative, and potentially more reliable, approach to detect drivers' level of stress and study its effects, is through its implications on human physiology. Recent advances in sensor technologies and affective computing have made it possible to measure drivers' stress levels through physiological responses, e.g. changes in heart rate, Electrodermal Activity (EDA), blood volume pulse, etc. There are several existing studies related to driving stress that use this type of data (some examples Healey and Picard, 2005; Singh and Queyam, 2013; Rigas, Goletsis, & Fotiadis, 2012). However, the aforementioned studies mostly focused on detecting stress rather than investigating its effects on observed driving behaviour.