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Longitudinal driving behavior in case of emergency situations: An empirically underpinned theoretical framework ☆

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ABSTRACT

Adverse conditions have been shown to have a substantial impact on traffic flow operations. It is however not yet clear to what extent emergency situations actually lead to adaptation effects in empirical longitudinal driving behavior, what the causes of these adaptation effects are and how these can best be modeled. In this paper we show using an elaborate driving simulator experiment that emergency situations lead to significant adaptation effects in longitudinal driving behavior. Furthermore we introduce a new theoretical framework. In this framework adaptation effects in longitudinal driving behavior are assumed to consist of compensation effects and performance effects. In order to empirically underpin this framework we show in this paper that compensation effects are reflected in parameter value changes in the Intelligent Driver Model, while performance effects are reflected in a reduction in model performance. Furthermore we show that compensation effects following an emergency situation are reflected in a change in the position of perceptual thresholds in a psycho-spacing model while performance effects are reflected in a reduced sensitivity of acceleration towards lead vehicle related stimuli at the action points. The paper concludes with a discussion as well as recommendations for future research.

1. Introduction

The ability of transport systems to deal with adverse conditions has become increasingly important. Adverse conditions, in this paper defined by conditions following an unplanned event with a high impact and a low probability of occurring, have been shown to have a considerable impact in terms of economic losses, casualties, medical costs, loss of production capabilities, material and immaterial costs. Examples of adverse conditions are emergency situations (e.g., due to man-made or naturally occurring disasters), adverse weather conditions (e.g., heavy rain, thick fog, snow, black ice, etc.) and freeway incidents (e.g., vehicle crashes).

Emergency situations have been shown to have considerable impacts on traffic flow operations. For example, in the US the events of the hurricanes Georges in 1998 and Floyd in 1999 precipitated the two largest evacuations and perhaps its two largest traffic jams (Urbina and Wolshon, 2003). Hurricane Rita created substantial problems as well, as massive traffic congestion as well as fuel supply problems occurred (Litman, 2006). This revealed the fact that emergency response agencies were not as prepared for such scenarios as had been previously assumed.

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However, since emergency situations have a low rate of occurring, little experience is available on how to cope with them. In order to investigate whether strategies are effective, simulation studies must be performed. For example, recently a large number of evacuation studies investigated the efficacy of evacuation strategies using well-established dynamic traffic simulation models developed for day-to-day traffic applications (Pel et al., 2012). Many of these studies make use of microscopic simulation models, such as PARAMICS (Cova and Johnson, 2003), CORSIM (Williams et al., 2007), VISSIM (Yuan and Han, 2009) and INTEGRATION (Mitchell and Radwan, 2006). In these microscopic simulation models mathematical models are used in order to approximate driving behavior. In order to adequately perform these studies, it is crucial that insight is available into the influence emergency situations have on empirical driving behavior as well as into the extent to which this influence is reflected in mathematical models of driving behavior.

However, insight into changes in driving behavior following an emergency situation does not inform us what the causes are of these so-called adaptation effects. Insight into the causes of these adaptation effects is crucial as this provides us with insight into how to best model the changes in driving behavior in relation to an emergency situation. To this end in this paper we introduce a new theoretical framework based on the Task-Capability-Interface model by Fuller (2005). In this theoretical framework it is assumed that emergency situations have an influence on the interaction between driver capabilities and task demands. This interaction is assumed to lead to conscious compensation effects in longitudinal driving behavior (e.g., changes in speed) and also to subconscious performance effects (e.g., reduction in the adequacy of the car-following task).

It is however not yet clear to what emergency situations actually lead to these changes in driving behavior. Furthermore, it is not yet clear to what extent compensation effects and performance effects in longitudinal driving behavior following an emergency situation are adequately represented in current car-following models.

In this paper, we therefore present extensive empirical analyses of driving behavior in case of an emergency situation using a driving simulator experiment with a multi-factorial design. We will show that emergency situations have a significant and substantial effect on empirical longitudinal driving behavior, reflected in changes in speed and distance to the lead vehicle.

In this context, in this paper we will show that emergency situations lead to substantial parameter value changes and model performance of an often used car-following model, i.e., the Intelligent Driver Model (Treiber et al., 2000). In the IDM (Treiber et al., 2000) acceleration is a continuous function of relative speed Δv (speed difference with the lead vehicle) and spacing s (following distance). In this paper we argue that parameter value changes in the IDM can be assumed be the result of the aforementioned compensation effects in longitudinal driving behavior following the emergency situation, while the change in model performance is argued to be an indicator for the presence of performance effects. We also argue that current continuous car-following models are less adequate in describing and predicting adaptation effects in longitudinal driving behavior due to the fact that human factors (i.e., changes in perception due to perceptual distortion, situational awareness, mental workload) are insufficiently incorporated in these models.

In order to correct for the fact that perception is not incorporated in these continuous models, psycho-spacing models were developed in the past. Basically in these models longitudinal driving behavior is controlled by perceptual thresholds. These thresholds serve to delineate a relative speed–spacing (Δv, s) plane in which the driver of a following vehicle does not respond to any change in his / her dynamic conditions and would seek to maintain a constant acceleration (Brackstone et al., 2002). On crossing one of these thresholds, a driver will perceive that an unacceptable situation has occurred and will adjust his longitudinal driving behavior through a change in the sign of his acceleration In the remainder of this paper these points in the relative speed–spacing (Δv, s) plane are referred to as ‘action points’.

It is however unclear to what extent compensation and performance effects in longitudinal driving behavior following an emergency situation are represented in changes in the position of the perceptual thresholds, reflected in the position of action points in the relative speed–spacing (Δv, s) plane, as well as to what extent the sensitivity of acceleration a towards relative speed Δv and spacing s at the action points is affected by this adverse condition. In this paper we show that compensation and performance effects following this adverse condition are substantially reflected in the position of the action points in the relative speed–spacing (Δv, s) plane and the sensitivity of acceleration towards lead vehicle related stimuli at these action points.

In sum, the objective of this paper is to empirically underpin the proposed theoretical framework through showing the effect emergency situations have on:

- empirical longitudinal driving behavior;
- parameter values and model performance of the IDM (Treiber et al., 2000);
- the position and shape of the perceptual thresholds and sensitivity of acceleration a towards relative speed Δv and spacing s in psycho-spacing models.

In the next section the state-of-the-art is presented. In this section we present an overview of performed research on the structure of the driving task and the influence of emergency situations on empirical longitudinal driving behavior. This subsection is followed by an overview of mathematical modeling of longitudinal driving behavior in relation to emergency situations. The section is concluded with an overview of the available theoretical frameworks of behavioral adaptation.

In the following section we present the theoretical framework based on the Task-Capability-Interface model (Fuller, 2005). The introduction of the theoretical framework is followed by a presentation of the research method. In this section