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Incorporating human-factors in car-following models: A review of recent developments and research needs

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A R T I C L E I N F O

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A B S T R A C T

Over the past decades there has been a considerable development in the modeling of car-following (CF) behavior as a result of research undertaken by both traffic engineers and traffic psychologists. While traffic engineers seek to understand the behavior of a traffic stream, traffic psychologists seek to describe the human abilities and errors involved in the driving process. This paper provides a comprehensive review of these two research streams.

It is necessary to consider human-factors in CF modeling for a more realistic representation of CF behavior in complex driving situations (for example, in traffic breakdowns, crash-prone situations, and adverse weather conditions) to improve traffic safety and to better understand widely-reported puzzling traffic flow phenomena, such as capacity drop, stop-and-go oscillations, and traffic hysteresis. While there are some excellent reviews of CF models available in the literature, none of these specifically focuses on the human factors in these models.

This paper addresses this gap by reviewing the available literature with a specific focus on the latest advances in car-following models from both the engineering and human behavior points of view. In so doing, it analyses the benefits and limitations of various models and highlights future research needs in the area.

1. Introduction

Car-following (CF) rules describe longitudinal interactions of vehicles on the road. The CF concept was first introduced by Pipes and Reuschel (Pipes, 1953; Reuschel, 1950). It can be defined as 'the decision of the driver to follow the preceding vehicle efficiently and safely'. Over the past decades, traffic engineers and traffic psychologists have contributed to the development of CF behavior modeling. Traffic engineers seek to understand characteristics of a traffic stream and apply Newtonian laws of motion to approximate CF behaviors in what this paper refers to (for the convenience of discussion) as 'Engineering CF models'. Traffic psychologists, on the other hand, are motivated to describe the human abilities and errors involved in CF, and their impact on traffic safety. Another mainstream driver behavior – lane-changing maneuvers – is reviewed in Zheng (2014) and is beyond the scope of this paper.

A large number of Engineering CF models have been developed in an attempt to describe CF behavior under a wide range of traffic conditions, ranging from free-flow to extreme situations. Some of these models have been used in commercial

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packages of microscopic traffic simulations (Barceló, 2010), and to guide the design of advanced vehicle control and safety systems (Yang and Peng, 2010). However, the limitations of Engineering CF models were the subject of spirited debate after the publication of Brackstone and McDonald's (1999) historical review of car-following models. In a commentary of this review, Hancock (1999) criticized the fact that the psychologically plausible characterization of how humans think about, and solve, the driving problem is not observed in these CF models.

Each driver is different so as their driving styles and risk-taking capabilities. Age and gender, for example, play an important role in the perception of risky driving situations. In addition, particular driving needs can influence aggressive driving, which is a potential source of driving error. While research shows that driver error contributes to up to 75% of all roadway crashes (Stanton and Salmon, 2009), few CF models can capture driver behavior in various driving conditions, especially in crash-prone conditions, such as traffic breakdowns, the undertaking of risk-taking behaviors, distraction, and adverse weather conditions.

To address this serious issue, a richer representation of the cognitive processes engaged during CF is required to describe driver responses, and the consequences of these responses, in adverse driving conditions. Moreover, CF models with the capability of mimicking a driver's mistakes and, consequently, with the ability to generate crash or near-crash scenarios can be important tools for evaluating safety-related technologies and policies. Unfortunately, most Engineering CF models do not include such scenarios.

Given the importance of the human factor in the driving process, it is necessary to integrate the latest CF modeling advances from both engineering and psychological perspectives, and to bridge any gaps or inconsistences in these perspectives. Such a union will be of great value in transportation research, especially in micro-simulation models for better prediction of driving behavior. This paper explores the existing CF models and their advances in describing human driving behavior.

Although some excellent reviews of CF models are available (Brackstone and McDonald, 1999; Hamdar, 2012; Olstam and Tapani, 2004; Panwai and Dia, 2005; Toledo, 2007), all have their limitations. For example, Brackstone and McDonald (1999) review CF models developed before 1999. Since then, however, there have been notable advancements in CF modeling. Furthermore, the Brackstone and McDonald review (1999) ignores cellular automation (CA)-based CF models, and their review is limited to Engineering CF models only. Similar conclusions can be drawn from the reviews by Olstam and Tapani (2004), Panwai and Dia (2005), and Toledo (2007). (Note, however, that Toledo (2007) does include CA-based CF models). In contrast, few efforts are observed on identifying human factors responsible for car-following with two exceptions. Hamdar (2012) summarized a list of human factors and situational environmental factors which may affect CF behavior. In a recent review, Treiber and Kesting (2013) described seven human factors (finite reaction time, estimation error, imperfect driving, spatial and temporal anticipation, context sensitivity and perceptual threshold) which could affect CF behavior, and applied them to a CF model using some hypothetical cases.

This paper provides a comprehensive review of the important recent developments in CF modeling from both engineering and human behavior perspectives. In particular, the paper focuses on notable efforts to integrate human behaviors into the traditional CF models, and on the future research that is needed to build on these efforts. For the sake of clarity and focus, the paper concentrates on representative CF models in the literature, rather than attempting to exhaustively cover all existing models.

To this end, the paper is organized as follows: Section 2 reviews notable traditional CF models and their extensions; Section 3 presents Engineering CF models that attempt to incorporate one or more human factors; and Section 4 discusses the major issues arising from these previous modeling attempts, determines what future research is needed in the area, and summarizes the conclusions arising from the review.

2. Car-following models: the engineering perspective

Numerous mathematical models have been developed to describe CF behavior under a wide range of conditions. In general, these models are based on the stimulus–response framework that was first developed at the General Motors research laboratories (Chandler et al., 1958; Gazis et al., 1961). The framework assumes that each driver responds to a given stimulus according to the following relationship:

$$response = sensitivity \times stimulus$$

Over the years, various researchers have used different factors as the stimuli to explain the response (acceleration) of the subject vehicle. While varying notations are used in the literature, for the sake of consistency and clarity, the same notations are used throughout this paper (These are listed in Appendix).

2.1. GHR model and its extensions

Gazis-Herman-Rothery (GHR) CF models is probably the most studied models in the area of CF modeling. The first version is the linear CF model developed by Chandler et al. (1958) and Herman et al. (1959), as shown in Eq. (1)

$$a_n(t) = \lambda . \Delta V_n(t - \tau_n) \tag{1}$$