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Heterogeneity in car-following behavior: Theory and empirics

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A B S T R A C T

The aim of this paper is to gain insights into the level of heterogeneity in car-following behavior in real traffic. We use a large sample of trajectory observations collected by means of a helicopter to identify differences between the car-following behaviors of: (1) passenger car drivers, (2) passenger car drivers and truck drivers and (3) passenger car drivers following a passenger car and passenger car drivers following a truck. We thereto calibrate eight car-following models making different assumptions about the way in which drivers follow their leader(s) on the same lane.

We show that considerable behavioral differences exist between passenger car drivers. Different passenger car drivers do not only consider different stimuli (like speed difference(s) with the leading car(s) and distance headway(s) to leading car(s)) but also the extents to which these stimuli influence their behavior differ. Truck drivers turn furthermore out to adopt in general a more robust car-following behavior than passenger car drivers. Their speeds show, for example, less variation over time. We also find indications that the desired headways of passenger car drivers are lower when following a truck than when following a passenger car.

1. Introduction

Heterogeneity is an important facet of human longitudinal driving behavior due to its large impact on traffic flow. Differences between the longitudinal driving behaviors of drivers determine to a large extent the flow dependent distribution of vehicles over lanes (Daganzo, 2002). Accordingly differences between the preferred longitudinal behaviors of drivers can induce lane changes leading to disturbances in traffic flow (Kerner and Klenov, 2004).

Also the propagation of a disturbance through a flow of vehicles driving on the same lane is expected to be influenced by the extent of heterogeneity (Hoogendoorn et al., 2007; Ossen and Hoogendoorn, 2007b). Others show furthermore that inter-driver differences in longitudinal driving behavior can partly explain the scatter in the congested branch of the fundamental diagram (Treiber and Helbing, 1999).

Despite this large influence of driver heterogeneity on flow characteristics only little information is available on the actual level of heterogeneity present in real-traffic. This is due to the fact that quantifying the level of heterogeneity in longitudinal driving behavior often requires detailed observations on the dynamics of individual vehicles. This holds especially for the car-following component of longitudinal driving behavior. Thus although it is well-known that heterogeneity is an important facet of longitudinal driving behavior, quantifying the extent of heterogeneity turns to be very difficult. An important example of a consequence of this is that the level of heterogeneity implemented in microscopic simulation tools can not be validated at the microscopic level. Another consequence of this is that the sample size required for performing a study

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on car-following behavior cannot be determined as this requires knowledge about the level of heterogeneity in the population.

To make a first attempt in quantifying the extent of heterogeneity in the car-following component of longitudinal driving behavior, we applied in (Ossen et al., 2006) a data collection method based on remote sensing to collect microscopic trajectory data for a large sample of vehicles driving under comparable heavily congested conditions. The results showed as expected that the level of heterogeneity in car-following behavior is substantial. That is, it turned out that different drivers do not only react to different stimuli (like speed difference(s) with the leading car(s) and distance headway(s) to leading car(s)) but also the extents to which these stimuli influence the behavior differ.

In performing this first analysis on heterogeneity we did not consider the causes for the established level of heterogeneity. For example, we did not consider whether we could identify differences between the car-following behaviors of truck drivers and passenger car drivers. This is a serious drawback as this information is needed, for example, for implementing our findings in a microscopic simulation tool.

In this contribution we therefore extent this work by identifying how the observed differences in the car-following dynamics of drivers can be related to different properties of the follower and different compositions of leader–follower pairs. We more specifically aim at answering the following three research questions:

1. How large is the extent of heterogeneity in car-following behavior within the group of passenger car drivers?
2. To which extent do the car-following behaviors of passenger car drivers and truck drivers differ?
3. Is there a correlation between the composition of the follower–leader pair (passenger car–truck, passenger car–passenger car) and the car-following behavior of the follower?

The answers to these questions do firstly significantly contribute to the knowledge on heterogeneity in longitudinal driving behavior. Secondly, by distinguishing between vehicle types it becomes possible to extrapolate our empirical findings on heterogeneity to traffic flows having different traffic compositions than the observed traffic flow, which enables implementation in microscopic simulation tools. Thirdly, the findings can be used in future researches to determine an appropriate sample size for performing a study on specific components of car-following behavior. By using the information about the causes for heterogeneity furthermore a more efficient sample design can be chosen (for example, stratified sampling).

The paper is structured as follows. We start by defining heterogeneity and distinguishing two types of heterogeneity. We then introduce the hypotheses used for answering the aforementioned research questions. After this the experimental design for testing these hypotheses is detailed and the trajectory observations to which the experimental design is applied are described. To be able to quantify our findings an experimental design is chosen in which eight car-following models making different assumptions about car-following behavior are calibrated for all observed drivers separately. After explaining the methodology, the research questions are answered in the order in which they are introduced.

It will be shown that there exist considerable differences between passenger car drivers. For example, clear differences are identified between the speed-dependent desired headways drivers want to keep. When comparing the behaviors of truck drivers and passenger car drivers it turns out that truck drivers drive in general with a more constant speed than passenger car drivers. Passenger car drivers appear furthermore to be more eager in restoring large deviations from their desired distance. Also an influence of the vehicle type of the leader on the car-following behavior of the follower is established. More specific, indications are found that the desired time headways of passenger car drivers are lower when following a truck than when following another passenger car.

2. Heterogeneity: definition, and types

In this section, it will be specified what we mean exactly by heterogeneity.

In this paper, *heterogeneity* will be defined as differences between the car-following behaviors of driver/vehicle combinations driving under comparable conditions, i.e. the same stretch of road, the same traffic conditions, similar weather conditions and so on. Changes in the behavior of a single driver over time are outside the scope of this paper.

Using this definition heterogeneity is a comprehensive term as it can be present in several ways. In this paper two types of heterogeneity will be discerned, namely, *driving style heterogeneity* and *heterogeneity within a driving style*. Driving style heterogeneity refers to heterogeneity in which the driving styles of drivers are inherently different. In this case different drivers have a different driving objective when following another car and react, for example, to different stimuli regarding their leader(s) or use a different driving rule for determining an appropriate control action. The second type of heterogeneity, i.e. heterogeneity within a driving style, is less strong and refers to differences in degree between the group of drivers reacting to the same stimuli and applying the same driving rule. This last type of heterogeneity is assumed in most microscopic simulation tools in which the same car-following model is used for all drivers while behavioral parameter values are varied.

In Ossen et al. (2006), both types of heterogeneity turned out to be clearly present in real-traffic. In this paper, therefore the same subdivision of heterogeneity is used as we want to establish in how far the observed large differences between driving behaviors of driver/vehicle combinations can be attributed to differences in the vehicle type of the follower and different leader–follower pair compositions.