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A generic multi-level framework for microscopic traffic simulation with automated vehicles in mixed traffic☆

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ABSTRACT

With an increasing number of automated vehicles (AV) appearing on roads and interacting with conventional traffic, there is a need for improved simulation approaches to replicate and forecast the resulting effects. Interactions between AVs and their drivers, and interaction with other human drivers involve new types of complex behavioural processes. There is an increasing necessity to explicitly incorporate these human factor processes in simulation, which cannot be properly accounted for with most current models. In this paper, we present an extended conceptual simulation framework based on human factors processes and applicable for automated driving that does this. The framework makes use of previously constructed constructs to include the effects of driver task demand, situation awareness and fundamental diagrams of task demand to extend to automated driving. This is especially considered for the case of transition of control (ToC), as an important aspect of vehicle-driver interaction. The framework is demonstrated in two experimental cases that consider different ToC situations and is found to be face valid within the applied assumptions. Challenges remain in regard to a lack of quantitative evidence from traffic psychology, automated vehicle dynamics & control and human-vehicle interaction. With increasing amounts of research on-going in these areas, the extended framework will act as a valuable approach to further study and quantify the effects of AVs in mixed traffic in the future.

1. Introduction

1.1. Research motivation

Accurate traffic models are of paramount importance for a wide range of purposes as national and local government, authorities and researchers attempt to understand the impacts of many future transport developments. A major current development in vehicle technology that will affect future traffic is vehicle automation. Many of the main effects of vehicle automation will occur in the interaction between human drivers and automated vehicle and the interaction between these vehicles with other road users. To be able to forecast and scale up the effects of vehicle automation, simulation is required that can reproduce these human driver interactions with the vehicles. This is the problem we aim to tackle in this paper, in presenting an extension for automated vehicles to a driver behaviour focussed microsimulation framework that will allow realistic human driving behaviour and automated vehicles to co-exist and interact in a valid manner.

Traffic flow modelling has existed for well over half a century, with many types of simulation models being proposed and

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Nomenclature

List of acronyms

AV	Automated Vehicle
ADCS	Automated driving control system
ADS	Automated Driving System
CF	Car Following
FDTD	Fundamental Diagram of Task Demand
FOT	Field Operatoinal Test
HAD	Highly Automated Driving
HDV	Human Driven Vehicle
HF	Human Factors
HMI	Human Machine Interface
IDM(+)	Intelligent Driver Model (plus)
RT	Reaction Time
SA	Situational Awareness
SAE	Society of Automotive Engineers
TC	Task Capacity
TCI	Task Capacity Interface
TD	Task Demand
ToC	Transition of Control
TOR	Take-over Request
TS	Task Saturation
TTC	Time to Collision
WL	Work Load

developed from stimulus-response, to safe-distance, and psychophysical type models to name just a few (van Wageningen-Kessels et al., 2015). Just about all these models have in common that there is some kind of control system; i.e. driver-vehicle units react to a certain stimulus from specifically annotated state variables. The control rules are different per model and represent the main phenomena caused by human drivers, such as congestion waves, capacity drop etc. Much of the implemented driving behaviour is implemented at a generic driver-vehicle level, rather than individual influences on driver performance from a more human factors perspective (Saifuzzaman et al., 2017). In practice, a driver interacts with their vehicle physically, such as pressing the brake and steering, but the driving task also includes a cognitive level, such as observing surroundings, processing information and making decisions (Endsley, 1999; Fuller, 2005). These aspects of human driving are generally not explicitly considered in most traffic simulation models, and to be honest it is normally not required. Proper calibration of a model with the generic behavioural patterns is often sufficient to perform simulation based forecasts. However, when considering intermediate levels of automation in which a human driver is partially in control, the aspect of real human driving behaviour plays a much greater role (Bellet et al., 2012; Gold et al., 2013; Hoogendoorn et al., 2014; Saffarian et al., 2012). The main reason for this relates to the increased and divergent interactions that drivers have with their partially automated vehicle and the demands that are put on driver's cognitive ability to remain in the loop (Saffarian et al., 2012). These cognitive processes do not have a generic description that can easily be included in a traditional simulation model. A good example of this is the case of transition of control between AV and driver, although many other situations and phenomena exist with vehicle automation (Casner et al., 2016; De Winter et al., 2014; Saffarian et al., 2012). There are many mechanisms that originate from a driver's cognitive processing of information that are too divergent and seemingly random, unless described in the context of the underlying mechanism in greater detail, to be captured in a single distribution of reaction time for example (Saffarian et al., 2012). By describing these processes explicitly by including a direct mechanism to human factors, the effects on driving can be replicated much more accurately and validly.

Driving behaviour research, and of human behaviour in a broader sense, has continued to develop in past decades (Fuller, 2005; Pipes, 1953; Teh et al., 2014). While there is a general understanding of various parts of human behaviour from a cognitive psychological viewpoint, much of it is still not well understood and certainly has little proven generic and generally accepted theory (Wickens et al., 2015). This adds a further difficulty when attempting to incorporate such a level of human (driving) behaviour in a 'quantitative' simulation model. Recent work by van Lint et al. (2018), and others such as Saifuzzaman et al. (2017), offer frameworks that attempt to explicitly and endogenously consider human behaviour from such an approach. They offer a good starting point for further development of traffic simulation that can consider human behaviour endogenously in a modelling environment with both AVs and Human Driven Vehicles (HDV), and interactions and transitions between automation. Also, further ongoing developments in understanding and gathering evidence on human behaviour in and with various types and levels of AVs from Field Operational Tests (FOT) and driving simulator experiments, offer opportunities to be able to calibrate and validate traffic simulation models that wish to include mixed AV-HDVs scenarios.

1.2. Objectives and constraints

We argue that it is imperative that simulation models that consider AVs in mixed automated-human traffic must also explicitly and endogenously consider real human driving behaviour. Therefore, following these recent developments in traffic flow modelling and the ongoing developments in driver psychology and human factors, we propose a novel extension to these models that allows both automated and conventionally driven vehicles to be collectively considered in mixed traffic, making use of explicit and endogenous human driving behaviour for driving and interaction with AVs. This contribution focusses on the interactions in mixed traffic and therefore explicitly considers one of the important aspect of initial automated driving, namely that of transition of control.

Throughout this paper, we will describe vehicle automation in two main categories: low and high automation. *Low automation* refers to level of automation in which the driver has an active role and aligns to Society of Automotive Engineers (SAE) levels 1–2 (SAE, 2018), while *high automation* refers to levels in which a vehicle can drive autonomously under certain conditions and aligns to SAE level 4–5. SAE 3 lies in between these two descriptions and can be considered as *partial automation*, as the driver has an active and continuous role of monitoring, while the vehicle does drive autonomously on the road and conditions that are permitted. Furthermore, we are well aware of the importance of vehicle cooperation as a necessary component to achieve many of the traffic