Modeling cooperative on-road systems

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***Abstract*— The extension of computer and communications systems in traffic from regulating roads and supporting individual drivers to enhancing cooperation between drivers raises new issues. In order to investigate the traffic flow and safety effects of such systems on the network level, we propose a holistic approach that parameterizes human-computer and human-human interactions in a driving simulator, and "scales up" the results using a traffic simulation.**

I. Introduction

High accident rates, congestion, and pollution have led to an array of innovative technologies in the fields of traffic management[1] and automotive design[2]. The latest systems use a host of information sensors and distributors allowing vehicles and infrastructure to communicate to achieve higher safety and efficiency (Car2X communication[1])[3]. Meanwhile, increased driving, congestion, and the faster pace of life appear to have given rise to a more stressful, aggressive and less cooperative traffic climate[4]. One future challenge for in- and ex-vehicle systems is to increase the level of coordination and cooperation between drivers, hence improving safety and efficiency still further[5]. Conventional modeling approaches are not well equipped to examine these systems in the detail required. We propose a holistic, bottom-up approach that can isolate and investigate specific local interactions with potential cooperation-enhancing systems in a driving simulator, and integrates the results into global investigations using a traffic simulation. The approach is cross-disciplinary, requiring techniques of psychology, transportation engineering and automotive technology, and is coordinated through the EU project SOCIONICAL, which aims to develop complexity science modeling methods for investigating exactly these kinds of relevant, socio-technical systems.

[1] The 'X' in Car2X represents infrastructure OR other vehicles

II. Background

A. Human Interaction and Conflict in Traffic

While the local and global influences of cutting-edge in- and ex-car systems on safety and efficiency have been, and continue to be researched (e.g. [6], [3], [7], [8], [9], [10]), factors such as trust (linked to the reliability or acceptability of the information), and driver state (e.g. cooperative, aggressive, selfish etc.), have received only limited attention (e.g. the likelihood of following route guidance information[7]). Yet, leaving technology aside, it has been shown that the state of the driver manifests itself in driving and interaction behavior[11], and is therefore communicated implicitly to other drivers, changing the system level driving conditions and the driving style of others[12]. The nature of these interactions between drivers can not only have catastrophic effects in the form of accidents, but also affects the traffic flow, particularly in the case of congested conditions[13], [14].

A classic hierarchical driver model[15] contains a strategical, tactical and operational level of action. The *strategic* level comprises trip decisions such as roads to take and the time to begin. Strategic decisions are made within a time frame of a few minutes. The spatial extent of these decisions comprises the known network. Decisions concerning *tactical* maneuvers, such as overtaking or cooperative braking, are made within shorter periods of time, typically within a few seconds. The basis for such decisions is the observable and anticipated part of the road network. The *operational* level (or control level) implies automated tasks like lane keeping, car following, or gear shifting. Vehicles in the direct neighborhood influence the behavior at this level.

While the need to accurately model drivers' interactions at the operational level in order to understand global traffic flow has been the subject of debate[16], transportation professionals have nevertheless turned to such models within large simulation packages in order to capture the heterogeneity of traffic (particularly in terms of desired speed, acceleration and braking capabilities through the use of different parameter sets), and to achieve finer representation of the road network (i.e. urban traffic structures and controls)[17]. The parameter sets are based on feasible data, assigned to drivers with stochastic variations, and a limited number are adjusted through calibration so that simulation results match accumulated car-based (e.g. following distance) or network-based (e.g. traffic flow rate, travel time) measurements[18]. The representation of traffic in this *microscopic* form allows the collection of 'driver-centric' quality measurements (such as number of stops), realistic emissions data and safety levels (through proxy measures such as Time-to-Collision[19]).

Such an approach can also permit the testing of potential systems where human-computer interaction, driver acceptance and driver state play a strong role. Driver state is a multidimensional construct, where relevant dimensions are attentiveness (e.g. vigilance, sleepy or awake), influence of psychoactive substances, and emotional state (e.g. anger, satisfaction). A dangerous emotional driver state in traffic is aggression. This can be the result of situational and/or personal factors[20]. In the freeway *situation* for example, the ability of drivers to communicate with each other is especially limited and the anonymity of drivers is increased, due to speed. However, drivers also have *personal* traits that define how likely they are to become annoyed with another's behavior. Once a driver is confronted with a frustrating situation (e.g. traffic jam, slow vehicle), situational (e.g. anonymity) and personal (e.g. driving anger trait) factors interact and define the current level of driving aggression. It is not only the behavior of the other drivers in itself that causes the frustration, but the evaluation of the situation and the attribution of causes (internal vs. external attribution)[21], [22].

Only through indirect signals, such as turn lights or headlights (that can be (mis)understood as aggressive) and through driving style (e.g. short following distance (headway), making a fast approach) can drivers communicate with others[12]. As direct communication is crucial in avoiding misunderstandings, conflicts between drivers are very likely[23]. Common interactions in traffic, especially merging operations (e.g. at on-ramps and in lane changes) are likely more complex than traditional models would suggest[24], featuring numerous small tactical and negotiatory maneuvers.

Understanding the details of these interactions is a crucial first step if we are to understand how technology may improve the situation.

B. Technology in Traffic

A variety of advanced driver assistance systems (ADAS)[9] and intelligent transportation systems (ITS)[1] have been employed to improve road safety and management. ADAS range from safety systems that support drivers in safety-critical situations and stabilize the car (e.g. anti-lock brake system and electronic stability control), through comfort systems that reduce the workload of the driver (e.g. adaptive cruise control (ACC)), to information systems (e.g. navigation system). ITS use sensors in the infrastructure to ascertain critical measures of road weather conditions and traffic flow. When a certain critical threshold is reached in the variable, the road regulations or warnings are altered via overhead signs (freeway traffic) or through traffic signals (urban traffic). This same information, especially concerning congestion, is communicated to the driver through radio announcements, a radio data channel for car radio or navigation device display and over the web to cell phones. Hence ITS supply an input to ADAS. The combination of GPS tracking devices in navigation systems and phones has led to a number of systems where car positions are regularly transmitted using the mobile phone network to a central traffic information repository (e.g. [25]). As vehicles become not just information receivers, but also information sensors and distributors, the driver is now assisting the infrastructure management, and hence other drivers, blurring the lines between ADAS and ITS, and between the drivers' levels of action they affect. These new feedback loops within both physical systems and driver levels of action have led to the term "cooperative systems" being frequently applied to new ITS technologies.

Clearly, the presence of ITS in traffic is serving to make the driver decisions along the journey more dynamic and complex[7]. In the case of ADAS, the role of the driver changes from acting to monitoring. This could lead to new problems such as reduced vigilance[26]. At the same time, assistance could help many drivers by compensating for individual limitations and by preventing misunderstandings. Indeed, these systems are trending towards greater amounts of cooperative behavior facilitation. ACC systems could improve their estimate/prediction of vehicle headway by exchanging data between vehicles concerning driving intention. Early attempts have already been made through trying to interpret vehicle control actions as early indicators of intention[27], but through the detection of anticipatory body movements[28] and navigation devices, there is the potential to extend this prediction even further into the future. Drivers can already use their GPS- and accelerometer-equipped phone to alert themselves to their own dangerous driving behavior[29]. In the SOCIONICAL project, situations where drivers are informed about other drivers' intentions and dangerous behavior will be investigated.

Much progress has been made in understanding system effects at the *strategic* level of action through the use of agent-based modeling to simulate complex evaluation decisions regarding routes[7], where the individual movements of vehicles are not of such concern.[2] Leaving new systems aside, the global effects of systems already on the road are not fully understood. As an example, ACC ought to create platoons of drivers, theoretically reducing the likelihood of traffic flow breakdowns, yet there is debate about the actual in-vehicle uses and hence the global effects[10] of such a system. This is largely because the local interactions are relevant, but have not been closely examined and the results integrated into larger traffic models.

III. Modeling Approach

A. Motivation

Driver 'personality' is represented in many traffic simulations in the form of assigned characteristics that are not altered by events along the journey or the results of small interactions with technology and other drivers (i.e. memory)[30]. When assistive systems have been introduced, drivers are typically simulated as equipped, or compliant, with a percentage that exhibits a different behavior but obeying or using the system under examination to its full degree (e.g. [13], [31]). Recent research[20], and everyday experience challenges such simplistic approaches. Many on-road interactions, such as slowing down to allow another vehicle on to the freeway, or failing to correctly interpret the intentions of others at intersections, require at least a real-time adjustment of these behavioral parameters or indeed even more detailed (i.e. human) modeling[19], [24]. As we strive to develop helpful and acceptable systems that interact with drivers directly and facilitate their communication, enhanced microscopic traffic simulation methods will be required to capture these kinds of interactions and their effects. In so doing we can investigate questions such as:

- Can problematic on-road interactions be improved through technology, or are they worsened?
- What are the effects of a particular system's outcome on driver style, attitude and future decisions?
- What spatial range should new driver assistance systems consider?
- How widely spread are the physical and psychological effects?

B. Approach

To understand how aggressive human-human interactions are responsible for global traffic situations, Maag et al. measured behavior functions of aggressive attitudes in drivers[11]. Measured behavioral outcomes included the average value and standard deviation of the headway kept to other vehicles while, for example, obstructed by a driver ahead. These behavior functions were then integrated into the car-following component of the traffic simulation PELOPS (University of Aachen, Aachen) so that the global traffic phenomena could be better explained by the inclusion of the aggression model.

This approach begins by isolating *prototypic situations* relevant to the potential application field of a new technology. Some general examples are approaching another vehicle on the left lane, following another vehicle on the left lane, or behavior at an on-ramp. By confronting drivers with these prototypic situations in a driving simulator and asking them to drive with different driving styles, the effect of driver state or intention on a particular aspect of the driving task can be studied. An approach with instructions is chosen, as it is very difficult to manipulate the drivers' emotional state directly. Additional situations can be defined to include different assistive devices so that the effect of the device interactions on driving behavior can be studied. These small scale ex-

[2] While the modeling itself can and often does still take place at the operational domain, the changes in behavior are above the car following and lane changing decisions, hence the *strategic* designation

periments must be used in order to yield understandable and statistically significant results. The output of the experiments is behavior functions that describe interaction parameters of driving behavior depending on driver state, driver intention or device functionality. Such functions link the objective characteristics of a small traffic situation to the behavior shown by drivers. The behavior can then be described in terms of the likelihood of showing a specific action, and the average value and standard deviation of specific driving parameters (e.g. headway to other vehicles). It is these behavior functions that can be added to existing models of vehicle action in driver and traffic modeling[11]. The complete investigational process is illustrated in Figure 1 and the list of steps summarized below:

1) Definition of prototypic situations
2) Description of driver behavior in these situations
3) Modeling of driver behavior in these situations
4) Integration of driver model into the traffic model
5) Validation of the enhanced traffic model
6) Usage of traffic modeling approach for further research questions

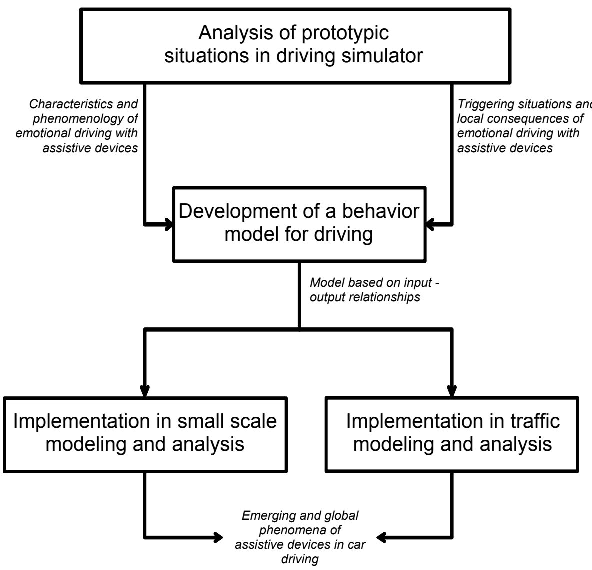

Fig. 1. Research Approach

In the following sections, we elaborate on these steps and the challenges of including assistive technology in the model, by way of a simple example.

C. *Prototypic situation and parameterization*

One example of a prototypic situation is the forced merging procedure of one driver from an on-ramp into a stream of slowly moving traffic on a freeway. The oncoming driver is (in this example) approaching at a higher speed than the traffic on the freeway and is confronted with gaps of many different sizes. The driver has to choose a gap and interact with other drivers. We can divide this situation into two separate experiments. In the first experiment, we would place the driver in the role of the oncoming driver, and measure the size of the gap they will choose in order to merge onto the freeway and the way they interact with other drivers. In the second, we place the driver in the right-most lane of freeway traffic, and confront them with an oncoming driver who wishes to merge. We can measure whether they adjust their following distance to create a sufficient gap. These experiments are a necessary first step in order to get reference values for a comparison with the technology-enhanced situation.

In the second step, we introduce an assistive device that allows an oncoming driver to signal their intention to merge at a particular point and allows a driver already on the freeway to signal their intention to slow down. We now repeat the first experiment with the device. Comparing both experimental conditions, we will learn whether merging drivers will change their choice concerning the time gaps due to the recommendations of the assistive system. Moreover, we will determine whether drivers will follow the suggestions of the assistive device and whether this leads to higher levels of cooperation.

Later experiments could complicate the situation by examining the case of uncooperative behavior (a driver who first agrees to create a gap but then fails to do so) and the situation of rewards (i.e. road tolling is reduced if the driver obeys external advice from a freeway operator).

D. *Development of a driver behavior model*

From these experiments, emerging phenomena of the device can be studied and a behavioral model using the principles of system theory[32] developed. In this way all relevant inputs, outputs and feedback loops can be captured, based on the results of the experiments. In a broader way, the development of the driver model itself can also feed back, eliciting new research questions for driving simulator experiments.

E. *Integration into traffic simulation*

The microscopic traffic simulation analyzes global traffic phenomena and the effects of the in-car technology with the altered driving and interaction behavior of the drivers, by integration of the determined behavior functions. Traffic simulation packages, including PELOPS, VISSIM (PTV AG, Karlsruhe) and AIMSUN (TSS, Barcelona) already allow the collection of measures concerning the riskiness of traffic and traffic flow. A number of packages allow access to the driver model itself (by parameter manipulation, editing of source code, or complete substitution).

Recently, with the interest in Car2X technologies, packages have been opened for extension in order to allow a vehicle's normal action to be supplemented with new information (e.g. [31]), such as changing the desired speed or route. By utilizing these new facilities and extending the driver model with the behavior functions gained from experiments, we can build the comprehensive simulation required to understand the direct and indirect effects of cooperative technology in traffic. While 'scaling up' the results from the traffic simulation experiments, new questions can also be investigated such as the effect of device penetration rate (proportion of equipped users) or of varying the distance that information is propogated throughout the road network.

The traffic simulation VISSIM is a suitable choice for this work. Its driver model is validated[33], it has been extended to include Car2X technologies[31] and it allows access to or replacement of its driver model[5]. Additionally, a number of authors have selected VISSIM as a particularly suitable basis for realistic examination of traffic safety[19], [34]. These aspects will be utilized to include the examined technologies and behavior functions.

F. Calibration and Validation

The traffic model, without the inclusion of assistive in-car devices, must be calibrated to existing road traffic field measurements as a first step[18]. In addition, the local interactions of the unequipped modeled drivers in the simulation will be measured and compared to the experimentally derived behavior functions in the first set of experiments. Test subjects will also give feedback about their impression of the simulated traffic. If this *face validity* is satisfying, the implemented driver model works well and results in traffic that is similar to real traffic. Finally, formal validation of the traffic simulation *without assistive devices* can be accomplished by supplying the input variables of a different data set (from a similar time of day/week), and measuring whether the output variables of the simulation match the corresponding traffic field measurements. If these two validation methods are successful, it allows us to have the maximum confidence in the results when device interaction behaviors are included. For many of the devices under consideration in SOCIONICAL, full validation to traffic data is difficult because these devices are not yet present in traffic. The goal is to make as reliable a prediction as possible of what the effects of these devices could be.

IV. Conclusions

As road traffic becomes more congested and more dangerous, drivers are becoming more aggressive. They are also bombarded with ever-increasing levels of in-car and ex-car technology that is becoming more interactive. While the aims of this technology are altruistic, we simply do not understand all the effects on either the driver or traffic in general (e.g. [10]). By pursuing a strategy of carefully planned driving simulator experiments, driver behavior modeling and integration into a traffic simulation package, we can begin to understand the nature of these effects. These tools will inform designers in both the driver-assistance technology and traffic management domains.

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