Enhancing the Validity of Traffic Flow Models with Emerging Data

Rita Excell, Jiaqi Ma, Steven Shladover, Daniel Work, Michael Levin, Samer H. Hamdar, Meng Wang, Stephen P. Mattingly and Alireza Talebpour

Abstract Modeling the impact of connected and automated vehicles (CAVs) on the environmental sustainability, mobility and safety of roadway traffic at the local link level or the regional network level requires a significant amount of currently non-available data. Multiple CAV test-beds and data collection efforts utilizing the latest sensing and communication technologies have been however publicized over the past few years. Such efforts have been led by the industry and public agencies in the US and abroad. Accordingly, (1) researchers and practitioners should be aware of the type and quantity of data needed to calibrate and validate traffic models while taking into account the impact of CAV technological specifications, the driver behavioral characteristics and the surrounding driving environments. (2) Moreover, the gap between such emerging data needs and the data made available to researchers or practitioners should be identified. This chapter summarizes the presentations of speakers that are investigating such gap during the Automated Vehicles Symposium 2017 (AVS17) held in San Francisco, California on July 11–13, 2017. These speakers participated in the break-out session titled "Enhancing the Validity of Traffic

R. Excell
Australia and New Zealand Driverless Vehicle Initiative, Adelaide, Australia
e-mail: rita.excell@advi.org.au

J. Ma
University of Cincinnati, 795 Rhodes Hall, Cincinnati, OH 45221, USA
e-mail: jiaqi.ma@uc.edu
URL: http://ceas.uc.edu/caecm/facultyandStaff/profiles/jiaqi_ma.html

S. Shladover
PATH, Institute of Transport Studies, University of California, Berkeley, CA, USA
e-mail: sess@berkeley.edu

D. Work
Vanderbilt University, 1025 16th Ave S, Suite 102, Nashville, TN 37212, USA
e-mail: dan.work@vanderbilt.edu
URL: https://my.vanderbilt.edu/danwork/

M. Levin
University of Minnesota, Minneapolis, MN, USA
e-mail: mlevin@umn.edu

G. Meyer and S. Beiker (eds.), *Road Vehicle Automation 5*, Lecture Notes in Mobility, https://doi.org/10.1007/978-3-319-94896-6_20

Flow Models with Emerging Data". The corresponding discussion and recommendations are presented in terms of the lessons learned and the future research direction to be adopted. This session was organized by the AHB45(3) Subcommittee on Traffic Flow Modeling for Connected and Automated Vehicles.

Keywords Traffic flow modeling · CAV/AV · Deployment · CACC Data · Test-beds · DSRCs · Platooning · Calibration/Validation

1 Introduction

Experts from the cyber-physical, communications, vehicle and traffic flow communities are needed to better understand the fundamental characteristics of traffic flow with varying levels of automation and to identify the research needs for developing models to assess real-world mobility and environmental sustainability implications of connected automated vehicles (CAVs). In particular, (1) there is a need for a discussion of innovative traffic flow modeling techniques and simulation tools to quantify the mobility and environment impacts of CAVs and their implications on highway capacity and freeway operations and designs [1]. (2) Special attention should be given to insights into behavioral differences in terms of lane-changing (lane choice, lane change execution) and car-following (following gap, reaction time, acceleration distribution) maneuvers and validation of existing and new CAV traffic flow models according to empirical data from CAV field tests.

Towards studying the CAV modeling efforts mentioned earlier and the gap between the available and the required data to support such efforts, the Transportation Research Board (TRB) AHB45(3) subcommittee on "Traffic Flow Modeling for Connected and Automated Vehicles" organized a breakout session at the Automated Vehicles Symposium 2017 (AVS17) held in San Francisco, California, on July 11–13, 2017. The breakout session titled "Enhancing the

S. H. Hamdar (✉)
George Washington University, 800 22nd Street NW, Washington, D.C. 20052, USA
e-mail: hamdar@gwu.edu

M. Wang
Delft University of Technology, Delft, The Netherlands
e-mail: M.Wang@tudelft.nl

S. P. Mattingly
University of Texas at Arlington, 425 Nedderman Hall, 416 Yates St., Box 19308, Arlington, TX 76019, USA
e-mail: mattingly@uta.edu

A. Talebpour
Texas A&M University, 3136 TAMU, College Station, TX 77845, USA
e-mail: atalebpour@tamu.edu

Validity of Traffic Flow Models with Emerging Data" brought together four scholars from academia and the industry. These scholars presented their latest work in CAV modeling and data collection efforts. Following the presentations, a panel consisting of the four invited speakers had extensive discussions with the audience. This chapter summarizes the four presentations made while identifying the data needs to model the impact of CAVs on the environmental sustainability, mobility and safety of roadway traffic at the local link level or the regional network levels.

The remaining sections of this chapter are organized as follows: Sect. 2 presents the summary of the four presentations and Sect. 3 introduces the key results from the panel discussion.

2 Data Needs and Modeling Methods

This section presents a summary of the four invited talks, which addressed the data collection efforts made and the challenges in utilizing such data to calibrate and validate traffic flow models that take into consideration the impact of CAVs on traffic mobility, safety and sustainability.

CAVs will have significant traffic impacts at different levels, from individual vehicle interactions, to system-wide aggregate effects. Impacts may take the form of strategic (trip, mode, and route choice), maneuvering (lane, speed, and gap choice), and control (steering, acceleration). The corresponding effects on traffic will depend on CAV technological specifications and the corresponding parameter choices. In view of such impacts, several major open questions remain to be answered by traffic flow researchers: (1) are existing traffic flow models good enough in describing driving behavior, and how it reacts to CAV related technological advances? (2) Do they differentiate the decision-making process for different levels of automation? (3) Do we, as practitioners and users, understand the corresponding differences? Answering such questions requires additional data collection efforts for traffic flow modeling, calibration and validation.

2.1 Using AV Pilots to Influence Public Opinions[1]

Governments (such as Australia) are providing opportunities for AV pilot programs. The main interest of such governments is related to influencing public opinions associated with CAVs while collecting data on the CAV user perception. For example, a demonstration in Adelaide on public roads reached 15 million viewers through Australia and New Zealand Driverless Vehicle Initiative (ADVI) media coverage. A public perception survey found widespread CAV acceptance, although

[1]By Rita Excell, Australia and New Zealand Driverless Vehicle Initiative.

the related levels of comfort and concern varied based on the technology presented and the suggested use [2]. For example, 46% of the survey respondents believe AVs will be safer, but 83% would like to drive manually from time to time. The comfort varied for different driving tasks, such as lane changing and route choice. 38% of the respondents were willing to pay more for automation. Given the answers received, it is crucial to have CAV testbeds that involve public roads. Cities are willing to open their roads for testing, but additional investment or further focus on specific spatial boundaries for testing could generate more usable data. At this stage, in Australia, data collection is qualitative in nature and less organized. The quantitative usable data mainly includes how CAVs respond to existing infrastructure, markings, and signage with a lesser amount of data on the interaction between CAVs and roadway users (i.e. drivers, cyclists, pedestrians and transit users).

2.2 Connected and Automated Vehicular Flows: Modeling Framework and Data Availability[2]

Advanced CAV technologies enable us to modify driving behavior and control vehicle trajectories, which have been greatly constrained by human limits in existing manually-driven highway traffic. Understanding and modeling automated vehicle "driving" behavior is critical to evaluating transportation system performance under different CAV deployment scenarios. There is a general CAV analysis, modeling and simulation (CAV AMS) framework currently under development by Federal Highway Administration (FHWA). The framework focuses on both the demand-side and supply-side impacts of AVs. The data needs and available datasets to calibrate the models resulting from such framework are identified. Some data collection efforts through field experiments using CAVs and connected infrastructure at the FHWA Saxton Transportation Operations Lab are made [3]. For example, the infrastructure to vehicle (I2V) communication data specified an eco-drive mode, optimizing fuel consumption by giving speed and powertrain commands to CAVs. Data collection efforts involved 5 vehicles with Cellular/LTE, corrected GPS, and using Dedicated Short Range Communication (DSRC) systems. Several sensors were used to estimate speeds, fuel consumption, and braking. Another field experiment was conducted on Interstate I-66, Virginia, USA. The goal was to create a rolling block of 3 AVs to smooth traffic behind. Indeed, the lead probe vehicle experienced much greater speed oscillations than probe vehicles behind the AV block. Other vehicle-to-vehicle (V2V) controls developed include a protocol for vehicles to merge into Cooperative Adaptive Cruise Control (CACC) strings. Some eco-approaches and departures at signalized intersections were found to reduce fuel consumption by slowing down or accelerating vehicles to avoid complete stops. Overall, a significant amount of data is

[2]By Jiaqi Ma, Leidos Inc.

being generated. However, more data is needed and limited numbers of AVs are available. Hardware-in-the-loop testing could be used to combine real data collection with simulation [4]. CAVs will need new types of tools and controls, and data is needed to calibrate key model components.

2.3 Recent Findings from Micro-simulation of Traffic Impacts of Cooperative Longitudinal Control Systems[3]

Some efforts have been made to simulate the microscopic interactions between manually driven vehicles and vehicles that use automatic longitudinal control systems, both autonomous (ACC) and cooperative (CACC) [5]. The models representing the automated car following behavior of the ACC and CACC systems are derived directly from the experimental responses of full-scale vehicles equipped with these systems, so they are much more realistic than previous theoretical models that have over-estimated traffic flow benefits of ACC. The models of manual driving include details of lane changing interactions on multi-lane highways and have been calibrated using field data from a complex freeway corridor. Results from the simulation performed by the PATH research group show the effects on highway throughput of various operational strategies including both continuous and limited access managed lanes for the equipped vehicles, limitations on discretionary lane changing, and limitations on the lengths of coordinated strings of vehicles, with varying levels of on-ramp and off-ramp traffic and for various market penetrations of equipped vehicles.

It should be noted that other microsimulation models used to analyze CAV or AV impacts on longitudinal traffic characteristics do not reflect actual ACC and CACC behavior. Drivers have several modes of manual driving with different combinations of lane changing and car following behaviors. To calibrate the models used in the PATH research presented in this section, 4 identical Nissan AVs were used to develop the microsimulation models of ACC and CACC. Extensive data were collected for the calibration task on the Sacramento SR-99 freeway. ACC and CACC modes were added to the manual driving modes. The ACC incorporation caused worse shockwaves than the manual driving. The shockwaves took approximately 5 s to propagate upstream through 4 vehicles. The reason behind such finding may be attributed to the fact that human drivers look more than one vehicle ahead (i.e. the look-ahead factor). With the incorporation of CACC, cars accelerate and decelerate together, which reduces the magnitude of oscillations when the shock-wave propagates backwards. In other words, communications play a key role in the AV efficiency.

A variety of additional experiments were performed on a highway network segment, with variables of on-ramp and off-ramp volume, CACC minimum gap,

[3]By Steven Shladover, PATH, UC Berkeley.

and AV market penetration. Overall, the roadway flow capacity increased with CACC market penetration. On-ramp volume decreased the downstream throughput. Off-ramp volume also reduced the main throughput with managed lanes due to vehicles weaving from the managed lanes to the exit ramps. The CACC reduced discretionary lane changing because it is often preferable to remain in a CACC string than change to a slightly faster lane.

In summary, the effects of ACC and CACC are noticeable but subtle. The modeling and simulation results may be feasible and interpretable; however, such results require careful calibration of microsimulation with real testing before being considered as definitive and suitable to design CAV related policies.

2.4 Control of Traffic with a Small Number of AVs[4]

Traffic control via mobile actuation is now viable thanks to recent and significant improvements in self-driving and connected vehicle technologies, and may offer new traffic management opportunities beyond today's fixed control systems such as variable speed limits. Traffic is already transitioning from fixed sensors and controls (e.g. loop detectors and traffic signals) to mobile sensors and controls (sensing through AVs, and using AVs to control traffic stream). Mobile sensing is already available through cell phones, and the next step is mobile control. In line of such developments, experimental evidence suggests that careful control of a small number of autonomous vehicles through mobile control in the traffic stream is sufficient to completely eliminate "phantom" traffic jams caused by human driving. Accordingly, a seminal demonstration was conducted by the Mathematical Society of Traffic Flow, in which 22 human-driven vehicles that initially drive smoothly around a circular track eventually degrade into substantial stop-and-go traffic [6]. These experiments resolved a long-standing discussion in transportation science, namely that traffic waves can in fact arise without any external causes, but did not offer a solution to prevent it. The 22 vehicle experiments were repeated with the modification that one intelligently controlled autonomous vehicle replaced a single human-piloted vehicle. A series of experiments in Tucson, Arizona were conducted to measure the influence of the carefully controlled AV on human-piloted vehicles. The main experimental result indicates that even when the penetration rate of autonomous vehicles is as low as 5%, stop and go traffic can be eliminated.

The AV speed control reduced braking events by 98.6%, the standard deviation of speed by 80.8%, and fuel consumption by 42.5%. The elimination of waves allows significant improvements in the total traffic fuel efficiency and safety, and is achievable long before the majority of vehicles are automated. It should be noted however that finding the optimal parameters for mobile control is still open—a parameter sweep was used for the results presented earlier. There is some

[4]By Daniel Work, University of Illinois at Urbana Champaign.

disconnect from the mathematics and *simulations* to the actual controllers due to the need for a safe gap to avoid real collisions. Moreover, in real life driving conditions, more than 5% AV market penetration may be needed to realize improvements in traffic flow mobility, safety and sustainability.

3 Discussion

The panel discussion (including audience interaction) identified the key challenges in traffic flow research in terms of data needs to calibrate and validate existing traffic flow models *involving* CAV/AV technologies:

1. *Data availability, cost and intellectual property*: Data collection for a variety of vehicles is needed. Each manufacturer will develop a separate ACC and CACC system, and even different vehicle models from the same manufacturer will behave differently. Researchers currently use simple models due to the difficulty and expense of obtaining real data. Companies are reluctant to make available their vehicles or even their ACC logic because they risk reverse engineering proprietary software through observation of powertrain commands.
2. *Human behavior*: Another research challenge is associated with human behavior; ironically, estimating the effects of AVs during the transitionary period of deploying AVs/CAVs requires more accurate modeling of human driving. Dr. Steve Shladover's study spent almost 75% of the effort calibrating the human driving model. As an illustration of such challenge along with the need to collect more data on human behavior, ACC minimum safe gaps for reverting to human control often seem quite low—for instance 0.6 s headways on free-ways. However, test subjects were generally comfortable with such gaps (although longer time headways would be needed on roads with lower speeds).
3. *Platooning logic versus automation*: Platooning plays a key role in the performance of AVs/CAVs but limited research has focused on this aspect of automation and communication between vehicles. For example, CACC systems differ from platooning systems in several ways. In platoons, the lead vehicle typically has a supervisory role for vehicles entering and leaving, whereas CACC string formation is more ad hoc. Also, current CACC systems often use constant time gap headways whereas platooning systems use constant clearance distances.
4. *Vehicle dynamics and communication specifications*: Models should include vehicle dynamics and receipt and response to communications. Including communications models of radio-wave propagation is not valuable—it is too dependent on the physical environment and not transferrable to other roads. Including message loss/delay functions without the under-lying causes is not sufficient.

In line of the above challenges and limitations, the panel suggests the following road map:

1. *Leveraging existing available data for CAV modeling and evaluation*: Existing, or currently available AV technologies, should be used for data collection. Although future opportunities may offer better data collection, current technologies supported by non-automotive companies allow avoiding extensive development costs. Moreover, standard fixed sensors and controls are better suited for some types of data collection and traffic control if compared to more "aggressive" new technologies.
2. *Further focus on freight transportation stakeholders*: Other types of AV applications, such as freight, are more economically driven. AVs are in consideration for railroads because of the associated reduction in operation cost. Part of the large infrastructure costs for freight transport should be directed towards modeling the freight traffic flow and the AV economic impacts.
3. *Guidance rather than prescriptive role-playing by the research community*: Research models are unlikely to be implemented or adopted directly by automative companies. However, CAV research can illustrate errors or issues for companies, such as the benefits of one type of longitudinal controller. Forums for technology transfer from researchers to industry should focus on the main ideas and lessons from experiments but not the details. Social scientist researchers may be more in tune with human factors than engineering models. For instance, a widely-cited model for ACC was ineffective when actually used on the road.
4. *Common research oriented test-bed and further coordination*: Development of common testbeds and data is a major issue that needs to be addressed by public agencies providing support to CAV research and by academicians. Sharing data with other researchers requires considerable expense for documentation and support. Data confidentiality becomes an issue as well. Such challenges may be overcome if a more elaborate partnership is established between the public and the academic sector in the United States (US) and abroad.

In conclusion, the panel along with the AHB45(3) Subcommittee recommends developing a partnerships with companies developing AVs to test and collect data. Further efforts are needed by the research community to educate the public on mobile control. For example, drivers may become angry or frustrated at vehicles implementing speed harmonization if they do not understand the benefits to congestion. Additional initiatives by the public agencies are needed with the aim of allocating funding in open AV tests for documenting and sharing data. The results may facilitate creating a forum for sharing main lessons and ideas with AV manufacturers without being involved in the corresponding administrative and legal details.

Acknowledgements The authors would like to acknowledge the breakout session organizers (the AHB45(3) committee members along with Robert Bertini from University of South Florida and Soyoung Ahn from University of Wisconsin, Madison) who made this book chapter possible.

Special thanks to Xiaopen Li from the University of South Florida, Danjue Chen from the University of Massachusetts Lowell, Steven Skabardonis from the University of California at Berkeley, Haizhong Wang from Oregon State University and Mark Brackstone from TSS-AIMSUM for their outreach efforts while coordinating the event details with the AVS2017 organizing committee.

References

1. Calvert S, Mahmassani HS, Meier J-N, Varaiya P, Hamdar SH, Chen D, Li X, Talebpour A, Mattingly SP (2007) Traffic flow of connected and automated vehicles: challenges and opportunities. In: Roadway vehicle automation, 4 edn. Springer, pp 235–245
2. Regan M, Cunningham M, Dixit V, Horberry T, Bender A, Weeratunga K, Cratchley S, Dalwood L, Muzorewa D, Hassan A (2017) Preliminary findings from the first Australian national survey of public opinion about automated and driverless vehicles, p 24. http://advi.org.au/wp-content/uploads/2017/08/ADVI-Public-Opinion-Survey_Final_ISBN.pdf
3. Learn S, Ma J, Raboy K, Zhou F (2017) A freeway speed harmonization experiment using connected and automated vehicles. IET Intell Transp Syst. https://doi.org/10.1049/iet-its.2017.0149
4. Ma J, Zhou F, Huang Z, Melson CL, James R, Zhang X (2018) Hardware-in-the-loop testing of connected and automated vehicle applications: a use case for queue-aware signalized intersection approach and departure. Transp Res Rec J Transp Res Board 18 (in-press: paper number 18-05431)
5. Liu H, Xiao L, Kan X, Shladover S, Lu XY, Men M, Shakel W, van Arem B (2018) Using cooperative adaptive cruise control (CACC) to form high-performance vehicle streams. PATH Final Report, Feb 2018
6. Stern RE, Cui S, Delle Monache ML, Bhadani R, Bunting M, Churchill M, Hamilton N, Haulcy R, Pohlmann H, Wu F, Piccoli B, Seibold B, Sprinkle J, Work DB (2018) Dissipation of stop-and-go waves via control of autonomous vehicles: field experiments. Transp Res Part C Emerg Technol 89:205–221