Computational Modeling of Driving Behaviors: Challenges and Approaches

Myounghoon Jeon
Virginia Polytechnic Institute and State University, Blacksburg, VA, United States
myounghoonjeon@vt.edu

Yiqi Zhang
Pennsylvania State University, State College, PA United States
yuz450@psu.edu

Heejin Jeong
University of Illinois at Chicago, Chicago, IL, United States
heejinj@uic.edu

Christian P. Janssen
Utrecht University, Utrecht, Netherlands
C.P.Janssen@uu.nl

Shan Bao
University of Michigan-Dearborn, Dearborn, MI, United States
shanbao@umich.edu

ABSTRACT

Computational modeling has great advantages in human behavior research, such as abstracting the problem space, simulating the situation by varying critical variables, and predicting future outcomes. Although much research has been conducted on driver behavior modeling, relatively little modeling research has appeared at the Auto-UI Conferences. If any, most work has focused on *qualitative* models about *manual* driving. In this workshop, we will first describe why computational driver behavior modeling is crucial for automotive research and then, introduce recent driver modeling research to researchers, practitioners, and students. By identifying research gaps and exploring solutions together, we expect to form the basis of a new modeling special interest group combining the Auto-UI community and the computational modeling community. The workshop will be closed with suggestions on the directions for future transdisciplinary work.

CCS CONCEPTS

• **Human-centered computing**; • **Human computer interaction (HCI)**; • **HCI theory, concepts and models**;

KEYWORDS

automated driving, computational modeling, driver behavior modeling

ACM Reference Format:
Myounghoon Jeon, Yiqi Zhang, Heejin Jeong, Christian P. Janssen, and Shan Bao. 2021. Computational Modeling of Driving Behaviors: Challenges and Approaches. In *13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '21 Adjunct), September 09–14, 2021, Leeds, United Kingdom.* ACM, New York, NY, USA, 4 pages. https://doi.org/10.1145/3473682.3477436

AutomotiveUI '21 Adjunct, September 09–14, 2021, Leeds, United Kingdom

ACM ISBN 978-1-4503-8641-8/21/09.
https://doi.org/10.1145/3473682.3477436

1 MOTIVATION AND GOALS

Computational modeling has been widely used in HCI to test if the prototype of a system works and to predict the outcomes in a safer and cheaper way than could be explored in the real world directly. It is a timely and relevant topic because more and more tools are available for multitasking support [1] with enhanced computational power [2]. From an Auto-UI perspective, developments within the field of automated driving involve many under-examined scenarios that are about the future, which cannot be tested on the road with people. Also, in-vehicle interfaces are developing so fast that user tests might not always be able to keep up. Instead, computational modeling allows exploration of more general principles and theories that can guide future interface design and testing. Also, models can help to expand the ideas from qualitative theories, by quantifying results to inform engineering more clearly (e.g., explicit discussion of "how much" and "why" people like/trust an interface, instead of just whether people like/trust it).

Even though Auto-UI is the premier conference in automotive user interfaces and driver distraction, little research on driver modeling has been presented at Auto-UI. There have been only a few explicit "modeling" sessions at Auto-UI (e.g., in 2011 & 2013). The keyword "modeling" first appeared in the list of topics at the 6th Auto-UI (2014), but it has been used as a generic term, rather than a technical term. Auto-UI has had a surprisingly small number of modeling papers and even fewer about "quantitative" modeling work as full papers (e.g., [3-4]). Based on this background, in the present workshop, we aim to build and nurture a new community that bridges the Auto-UI community with the modeling community, by (1) providing an overview of the state-of-the-art driver modeling work, (2) discussing challenges and exchanging solutions, (3) suggesting promising directions for future transdisciplinary work, and (4) yielding both immediate and long-term community-, research-, and design-guidance products. To this end, we will invite researchers, practitioners, and students interested in the domains of automotive user interfaces and computational modeling to the workshop. Achieving these goals will provide an opportunity to move this field forward and to build a solid community at Auto-UI, which can form the basis for further knowledge exchange and collaboration, including the basis of future Auto-UI submissions and creating a reviewer pool.

The field of computational modeling is broad in its approaches, goals and applications [38]. In science, models and simulations are used to represent complex and detailed reality in an abstract form and to test and plan future states [5]. Thus, models can serve as critical research tools and explanatory or pedagogical tools for students and domain novices. Models are developed and used to be more accessible, convenient, and economical to researchers and practitioners than reality. Computational models allow for integrating theories and ideas, that can then be tested on various domains [6-9]. Computational models can also aid in quantifying how human behavior is impacted in different scenarios and situations (e.g., different interfaces) [10]. This "model-based evaluation" (see [11]) is akin to engineering approaches that use models and simulations to quantify how variables (e.g., humidity) impact the physical worlds (e.g., weather).

There are different types of approaches in modeling. Qualitative models describe behavior in a general form without quantifying specific factors. In contrast, computational models can enable simulations with varying factors, providing quantitative explanations about the phenomena and predictions about future outcomes. Moreover, they can often be faster than real-time testing of huge numbers of potential real-world scenarios, which may influence to help identify situations where risks are high and system modifications may be needed [12]. Within our workshop, we want to identify current modeling efforts.

1.1 Qualitative modeling of driving behaviors

After Michon [13] introduced the hierarchical structure of driver behavior, a number of hierarchical driving models have adopted the three-level hierarchy structure to describe a driver's behavior. The Hierarchical Driver Model [14] is one of those examples, which consists of an operational, tactical, and strategic decision-maker in a bottom-up fashion. Later, more dynamic theories have been introduced to describe the relationship between a driver and tasks or contexts, going beyond the individual information processing level. For example, motivational models have considered risk [15] as a core role of the drivers' decision-making process to obtain driving safety. They include risk compensation models (e.g., risk homeostasis theory [16-18]), risk threshold models (e.g., zero risk theory [19]), and risk avoidance models (e.g., task-capability interface (TCI) model). In the TCI model, driving task difficulty is determined by comparing the demands of the driving task and the capability of the driver [20, 21]. There has also been an effort to make an overarching affect-integrated driving behavior model [22], but it is still a descriptive framework.

1.2 Computational modeling of driving behaviors

Quantitative models can be used for modeling human information processing and behavior processes. For example, researchers used statistical and machine learning models to formalize driver maneuvers. For example, Wu, Boyle, and Marshall [23] designed a logistic regression model to demonstrate that drivers' demographic information can predict their choice between steering and braking. Hu et al. [24] used a decision tree to predict driver maneuvers in a cut-in scenario. Researchers used cognitive architecture to model drivers' behavior. Salvucci [25-26] developed a computational driver model based on the Adaptive Control of Thought-Rational (ACT-R) to predict and test driver behavior. Zhang and colleagues [27-28] used the Queuing Network-Model Human Processor (QN-MHP) to model driver performance for speech warning systems in connected vehicles with different warning characteristics, such as warning timing, warning reliability, and warning style (i.e., notification and command warnings). Jeong and Liu [29] used the QN-MHP to predict drivers' eye glances and workload for four stimulus-response secondary tasks while driving. They also developed a computational model of driver behavior for in-vehicle remote-manual and voice interaction systems [30].

1.3 Modeling of driving behaviors in automated vehicles

To capture the potential confusion about the different automation modes of the semi-automated vehicle, Janssen et al. [31] introduced a Hidden Markov Model framework to formalize the beliefs that drivers may have about the mode. Gold, Happee, and Bengler [32] modeled driver takeover performance in level 3 semi-automated vehicles using a regression modeling approach, but they did not model the specific impact of auditory cues on takeover performance. Recent papers [33, 39] established new computational models using the QN-MHP framework to predict a driver's reaction time to auditory takeover displays, varying sound types and using drivers' subjective urgency level and acoustic characteristics of auditory displays.

2 TOPICS OF INTEREST

Despite the continuous efforts, more challenges remain unsolved in modeling driver behavior. The central objective of this workshop is to build and nurture a new community that bridges the Auto-UI community with the modeling community. As part of this effort, we will discuss various aspects of the intersection of these two fields. This may include, but is not limited to:

- Modeling techniques available (e.g., cognitive architecture vs. machine learning vs. hybrid models) and how these techniques can be made more relevant for the Auto-UI community;
- Grand challenges for computational modeling within the automotive UI field;
- The way modeling approaches can be aligned with other methodological approaches (e.g., experiments, designs, or prototyping) so that they can complement each other;
- The application of computational models in the advanced Auto-UI technology designs.

3 PLANS AND TENTATIVE SCHEDULES

Given that each workshop has only one and a half hours, the organizers will use time efficiently and effectively. Depending on the participants' regions, the organizers will host two separate workshop sessions of 90 minutes each to accommodate participants from different time zones (e.g., one for Europe + North America, another for North America + Asia) so that participants from different time zones could be accommodated. All organizers are flexible to make these two sessions happen and closely discuss the appropriate time slots with the workshop co-chairs. The organizers will send participants a short questionnaire in advance to survey their interest and to set up a discussion agenda. To engage more with the participants virtually, we have diverse strategies. The presentation from the organizers will be very brief (Pecha Kucha style). Speed dating will make participants get to know each other. Participants will actively interact using the online platform (e.g., Miro) so that they will be able to contribute to the discussions by writing, reading, speaking, or listening, depending on their preferred communication channels.

To increase community growth and public accessibility, we will provide information via multiple channels. We will set up a workshop website to publicize the workshop details. The call for participation will also be distributed electronically via the official channels of the Auto-UI, CHI, Human Factors communities, International Conference on Cognitive Modelling, ACT-R, and all scientific contacts of the organizers.

The tentative schedule (**90 mins. in total**) is as follows:

- **Introduction**: Opening and introduction (Organizers) & Setting up the agenda based on the survey results (Organizers) (10 mins.)
- **Session 1**: Pecha Kucha presentation of modeling practices (15 mins.)
- **Session 2**: Round table introduction or sub-group speed dating (depending on the number of participants) (10 mins.)
- **Bio Break** (5 mins.)
- **Session 3**: Discussing the topics and brainstorming ideas in breakout rooms (30 mins.)
- **Session 4**: Presentation of the discussion results (15 mins.)
- **Closing**: Wrapping up & future directions (5 mins.)

4 OUTCOMES

By highlighting challenges and opportunities of the field in discussion, this workshop will pave the road to:

- Forming a new modeling special interest group within the Auto-UI community
- Introducing the state-of-the-art modeling approaches from the Auto-UI community and beyond to students and novices
- Identifying research gaps and challenges
- Exploring ideas and solutions for research issues and future collaboration
- Co-writing a workshop report to present at the next year Auto-UI or other venues
- Guest-editing a journal special issue on "computational modeling of driver behaviors in automated vehicles"

As a first step in this direction, we will invite all workshop participants to write a short (150-250 words) summary of their perspective on the field. The combined perspective will be edited by the workshop organizers and published on the workshop website.

The proposers have successfully hosted multiple workshop series at Auto-UI (13 times collectively) and guest-edited journal special issues [34–36] in numerous journals by extending the topic of the workshops.

5 BIOGRAPHIES: ORGANIZER(S) AND PRESENTER(S)

Myounghoon Jeon is an Associate Professor of the Department of Industrial and Systems Engineering and the Department of Computer Science at Virginia Tech. His Mind Music Machine Lab tries to integrate different levels of research on human-automation (vehicles, robots, and agents) interaction, including neurological, psychological, and computational approaches.

Yiqi Zhang is an Assistant Professor of the Department of Industrial and Manufacturing Engineering at Pennsylvania State University. Her Human-Technology Interaction (HTI) Lab aims to understand human-vehicle interaction in ITS by adopting the behavioral approach and human performance modeling approach with the application of warning system design.

Heejin Jeong is an Assistant Professor of the Department of Mechanical and Industrial Engineering at the University of Illinois at Chicago and the director of the Human-in-Mind Engineering Research (HiMER) Lab. His lab develops human performance models based on eye and motion tracking data and cognitive processing theories.

Christian P. Janssen is an Assistant Professor of experimental psychology at Utrecht University. He leads Utrecht's research and teaching on Social and Cognitive Modeling. Chris' interests include human multitasking and human-automation interaction. He uses experiments and models to understand human behavior [37].

Shan Bao is an Associate Professor in the Department of Industrial and Manufacturing Systems Engineering at the University of Michigan-Dearborn and a human factors researcher with positions as an associate research scientist at University of Michigan Transportation Research Institute. Her areas of expertise include the statistical analysis of crash datasets and naturalistic data, vulnerable road user safety, experimental design, algorithm development to identify driver states and movement, evaluation of driving-safety technologies, measurement of driver performance, driver decision making, and statistical and stochastic modeling techniques.

REFERENCES

[1] D. P. Brumby, C. P. Janssen, T. Kujala, and D. D. Salvucci, "Computational models of user multitasking," Computational Interaction Design, pp. 341-362, 2018.
[2] A. Oulasvirta, "It's time to rediscover HCI models," Interactions, vol. 26, no. 4, pp. 52-56, 2019.
[3] S. Schneegaß, B. Pfleging, D. Kern, and A. Schmidt, "Support for modeling interaction with automotive user interfaces," In Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 71-78), 2011.
[4] K. R. May, B. E. Noah, and B. N. Walker, "Driving acceptance: Applying structural equation modeling to in-vehicle automation acceptance," In Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct (pp. 190-194), 2017.
[5] J. L. McClelland, "The place of modeling in cognitive science," Topics in Cognitive Science, vol. 1, no. 1, pp. 11-38, 2009.
[6] A. Newell, "Unified theories of cognition", Cambridge University Press, Cambridge, MA, 1990.
[7] J. R. Anderson, How can the human mind occur in the physical universe?: Oxford University Press, 2009.
[8] W. D. Gray, Integrated models of cognitive systems: Oxford University Press, 2007.
[9] D. Salvucci, and N. Taatgen, "Oxford series on cognitive models and architectures," The multitasking mind. New York, NY, US: Oxford University Press, 2011.
[10] S. K. Card, T. P. Moran, and A. Newell, "The psychology of human-computer interaction. 1983," Hillsdale, NJ: Lawrence Erlbaum Associates, 1983.
[11] D. Kieras, "Model-based Evaluation," In J. A. Jacko (Ed.). The Human-Computer Interaction Handbook (3rd ed., pp. 1299–1318). Boca Raton, FL: Taylor & Francis,

2012.
[12] A. D. McDonald, H. Alambeigi, J. Engström, G. Markkula, T. Vogelpohl, J. Dunne, and N. Yuma, "Toward computational simulations of behavior during automated driving takeovers: a review of the empirical and modeling literatures," Human Factors, vol. 61, no. 4, pp. 642-688, 2019.
[13] J. A. Michon, "A critical view of driver behavior models: what do we know, what should we do?," Human Behavior and Traffic Safety, pp. 485-524: Springer, 1985.
[14] E. Boer, "A driver model of attention management and task scheduling: Satisficing decision making with dynamic mental models."
[15] D. Taylor, "DRIVERS'GALVANIC SKIN RESPONSE AND THE RISK OF ACCIDENT," Ergonomics, vol. 7, no. 4, pp. 439-451, 1964.
[16] J. G. Adams, "Risk and freedom: the record of road safety regulation," 1985.
[17] R. Fuller, "A conceptualization of driving behaviour as threat avoidance," Ergonomics, vol. 27, no. 11, pp. 1139-1155, 1984.
[18] G. J. Wilde, "The theory of risk homeostasis: implications for safety and health," Risk analysis, vol. 2, no. 4, pp. 209-225, 1982.
[19] R. Näätänen, and H. Summala, "Road-user behaviour and traffic accidents," Publication of: North-Holland Publishing Company, 1976.
[20] R. Fuller, "Towards a general theory of driver behaviour," Accident Analysis & Prevention, vol. 37, no. 3, pp. 461-472, 2005.
[21] R. Fuller, "Psychology and the highway engineer," Fuller & Santos, 2002.
[22] M. Jeon, "Towards affect-integrated driving behaviour research," Theoretical Issues in Ergonomics Science, vol. 16, no. 6, pp. 553-585, 2015.
[23] X. Wu, L. N. Boyle, and D. Marshall, "Drivers' avoidance strategies when using a forward collision warning (FCW) system," In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 61, no. 1. Los Angeles, CA: SAGE Publications. (pp. 1939-1943), 2017.
[24] M. Hu, Y. Liao, W. Wang, G. Li, B. Cheng, and F. Chen, "Decision tree-based maneuver prediction for driver rear-end risk-avoidance behaviors in cut-in scenarios," Journal of advanced transportation, vol. 2017, 2017.
[25] D. D. Salvucci, "Modeling driver behavior in a cognitive architecture," Human Factors, vol. 48, no. 2, pp. 362-380, 2006.
[26] D. D. Salvucci, "Rapid prototyping and evaluation of in-vehicle interfaces," ACM Transactions on Computer-Human Interaction (TOCHI), vol. 16, no. 2, pp. 1-33, 2009.
[27] Y. Zhang, and C. Wu, "Modeling the Effects of Warning Lead Time, Warning Reliability and Warning Style on Human Performance Under Connected Vehicle Settings," In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, vol. 62. no. 1. Los Angeles, CA: SAGE Publications, (pp. 701-701), 2018.
[28] Y. Zhang, C. Wu, and J. Wan, "Mathematical modeling of the effects of speech warning characteristics on human performance and its application in transportation cyberphysical systems," IEEE Transactions on Intelligent Transportation Systems, vol. 17, no. 11, pp. 3062-3074, 2016.
[29] H. Jeong, and Y. Liu, "Modeling of stimulus-response secondary tasks with different modalities while driving in a computational cognitive architecture," In Proceedings of the 9th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design (pp. 58-64), 2017.
[30] H. Jeong, and Y. Liu, "Cognitive Modeling of Remote-manual and Voice Controls for In-vehicle Human-automation Systems," In Proceedings of the Companion of the 13th Annual ACM/IEEE International Conference on Human-Robot Interaction (pp.135-136), 2018.
[31] C. P. Janssen, L. N. Boyle, A. L. Kun, W. Ju, and L. L. Chuang, "A hidden markov framework to capture human–machine interaction in automated vehicles," International Journal of Human–Computer Interaction, vol. 35, no. 11, pp. 947-955, 2019.
[32] C. Gold, R. Happee, and K. Bengler, "Modeling take-over performance in level 3 conditionally automated vehicles," Accident Analysis & Prevention, vol. 116, pp. 3-13, 2018.
[33] S. Ko, Y. Zhang, and M. Jeon, "Modeling the effects of auditory display takeover requests on drivers' behavior in autonomous vehicles," In Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings (pp. 392-398), 2019.
[34] C. P. Janssen, S. J. Gould, S. Y. Li, D. P. Brumby, and A. L. Cox, "Integrating knowledge of multitasking and interruptions across different perspectives and research methods," International Journal of Human-Computer Studies, vol. 79, pp. 1-5, 2015.
[35] A. Riener, M. Jeon, and M. Reiner, "Theory and technological implications of subliminal perception research," Presence: Teleoperators and Virtual Environments, vol. 23, no. 1, pp. iii-vii, 2014.
[36] A. Riener, M. Jeon, I. Alvarez, and F. Zambonelli, "Special issue on "The social car: socially-inspired mechanisms for future mobility services," Pervasive and Mobile Computing, vol. 14, pp. 66, 2014.
[37] C. P. Janssen, S. T. Iqbal, A. L. Kun, and S. F. Donker, "Interrupted by my car? Implications of interruption and interleaving research for automated vehicles," International Journal of Human-Computer Studies, vol. 130, pp. 221-233, 2019.
[38] C. P. Janssen, L. N., Boyle, W. Ju, A. Riener, and I. Alvarez, "Agents, environments, scenarios: A framework for examining models and simulations of human-vehicle interaction," Transportation Research Interdisciplinary Perspectives, vol. 8, 100214, 2020.
[39] S. Ko, K. Kutchek, Y. Zhang, and M. Jeon, "Effects of non-speech auditory cues on control transition behaviors in semi-automated vehicles: Empirical study, modeling, and validation," International Journal of Human-Computer Interaction, Online First Version 2021.