ABSTRACT

Author: Wang, Jian, PhD.
Institution: Purdue University
Degree Received: December, 2018
Title: System modeling for connected and autonomous vehicles
Committee Chair: Srinivas Peeta

Connected and autonomous vehicle (CAV) technologies provide disruptive and transformational opportunities for innovations toward intelligent transportation systems. Compared with human driven vehicles (HDVs), the CAVs can reduce reaction time and human errors, increase traffic mobility and will be more knowledgeable due to vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. CAVs' potential to reduce traffic accidents, improve vehicular mobility and promote eco-driving is immense. However, the new characteristics and capabilities of CAVs will significantly transform the future of transportation, including the dissemination of traffic information, traffic flow dynamics and network equilibrium flow. This thesis seeks to realize and enhance the application of CAVs by specifically advancing the research in three connected topics: (1) modeling and controlling information flow propagation within a V2V communication environment, (2) designing a real-time deployable cooperative control mechanism for CAV platoons, and (3) modeling network equilibrium flow with a mix of CAVs and HDVs.

Vehicular traffic congestion in a V2V communication environment can lead to congestion effects for information flow propagation due to full occupation of the communication channel. Such congestion effects can impact not only whether a specific information packet of interest is able to reach a desired location, but also the timeliness needed to influence traffic system performance. This thesis begins with exploring spatiotemporal information flow propagation under information congestion effects, by introducing a two-layer macroscopic model and an information packet relay control strategy. The upper layer models the information dissemination in the information flow regime, and the lower layer model captures the impacts of traffic flow dynamics on information propagation. Analytical and numerical solutions of the information flow propagation wave (IFPW) speed are provided, and the density of informed vehicles is derived under different traffic conditions. Hence, the proposed model can be leveraged to

develop a new generation of information dissemination strategies focused on enabling specific V2V information to reach specific locations at specific points in time.

In a V2V-based system, multiclass information (e.g., safety information, routing information, work zone information) needs to be disseminated simultaneously. The application needs of different classes of information related to vehicular reception ratio, the time delay and spatial coverage (i.e., distance it can be propagated) are different. To meet the application needs of multiclass information under different traffic and communication environments, a queueing strategy is proposed for each equipped vehicle to disseminate the received information. It enables control of multiclass information flow propagation through two parameters: 1) the number of communication servers and 2) the communication service rate. A two-layer model is derived to characterize the IFPW under the designed queueing strategy. Analytical and numerical solutions are derived to investigate the effects of the two control parameters on information propagation performance in different information classes.

Third, this thesis also develops a real-time implementable cooperative control mechanism for CAV platoons. Recently, model predictive control (MPC)-based platooning strategies have been developed for CAVs to enhance traffic performance by enabling cooperation among vehicles in the platoon. However, they are not deployable in practice as they require anembedded optimal control problem to be solved instantaneously, with platoon size and prediction horizon duration compounding the intractability. Ignoring the computational requirements leads to control delays that can deteriorate platoon performance and cause collisions between vehicles. To address this critical gap, this thesis first proposes an idealized MPC-based cooperative control strategy for CAV platooning based on the strong assumption that the problem can be solved instantaneously. It then develops a deployable model predictive control with first-order approximation (DMPC-FOA) that can accurately estimate the optimal control decisions of the idealized MPC strategy without entailing control delay. Application of the DMPC-FOA approach for a CAV platoon using real-world leading vehicle trajectory data shows that it can dampen the traffic oscillation effectively, and can lead to smooth deceleration and acceleration behavior of all following vehicles.

Finally, this thesis also develops a multiclass traffic assignment model for mixed traffic flow of CAVs and HDVs. Due to the advantages of CAVs over HDVs, such as reduced value of time, enhanced quality of travel experience, and seamless situational awareness and connectivity, CAV users can differ in their route choice behavior compared to HDV users, leading to mixed traffic flows that can significantly deviate from the single-class HDV traffic pattern. However, due to a lack of quantitative models, there is limited knowledge on the evolution of mixed traffic flows in a traffic network. To partly bridge this gap, this thesis proposes a multiclass traffic assignment model. The multiclass model captures the effect of knowledge level of traffic conditions on route choice of both CAVs and HDVs. In addition, it captures the characteristics of mixed traffic flow such as the difference in value of time between HDVs and CAVs and the asymmetry in their driving interactions, thereby enhancing behavioral realism in the modeling. New solution algorithms will be developed to solve the multiclass traffic assignment model. The study results can assist transportation decision-makers to design effective planning and operational strategies to leverage the advantages of CAVs and manage traffic congestion under mixed traffic flows.

This thesis deepens our understanding of the characteristics and phenomena in domains of traffic information dissemination, traffic flow dynamics and network equilibrium flow in the age of connected and autonomous transportation. The findings of this thesis can assist transportation managers in designing effective traffic operation and planning strategies to fully exploit the potential of CAVs to improve system performance related to traffic safety, mobility and energy consumption.