100 YEARS TRB
MOVING IDEAS: ADVANCING SOCIETY

CENTENNIAL PAPERS

Standing Committee on Traffic Flow Theory and Characteristics (AHB45)
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Traffic Flow Theory and Characteristics

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The TRB Committee on Traffic Flow Theory and Characteristics (TFTC) is concerned with the development, validation, and dissemination of theoretical, experimental, methodological, and applied research on traffic flow theory (TFT) and traffic flow characteristics (TFC), and the determination of the relationship of TFT and TFC to the planning, design and operation of transportation systems. Such systems are undergoing rapid transformation due to the introduction of new technologies, mobility services and modeling paradigms. This provides new options for traffic monitoring and control that makes it possible to envision more safe, efficient and sustainable traffic operations. The TFTC committee research challenges are in line with this new era in transportation.

To mark the passage of the centennial, all TRB committees have mounted special efforts to capture the current state of the art and practice and their perspectives on future directions in their respective areas of focus. This paper begins with a review of the important evolutionary changes that have occurred in the field of TFT since the inception of the TFTC Committee in 1963. With the guideposts defined by this history, new paradigms of TFT and a vision of future directions are presented.

MILESTONES

The TRB Annual Meeting and associated TFTC committee meetings play a leading role in facilitating scientific exchange in the traffic flow theory community. Even as traffic processes and phenomena are better understood and more readily characterized through the availability of high resolution sensor data and advanced computing capabilities, the fundamentals are just as important today as in the early days. They form the foundation for all the theories, techniques, and procedures that are being applied in the design, operation, and development of advanced transportation systems. (*1*)

This section describes the principal milestones or accomplishments in the field of TFT that define the current state of the art. Historically, TFT has sought to describe the interactions among vehicles, drivers, and the infrastructure in a precise mathematical way (*1*). These descriptions have often been linked with empirical observations; however, some part of the literature pertains to models of system components that were not directly observable in order to improve our general understanding about their functioning. As generally conceived, the infrastructure consists of the surface transportation system, although communication layers are becoming increasingly integrated with the transportation system. These theories are an indispensable element of all traffic models and analysis tools that are being used in the design and operation of streets, highways, and urban systems.

The conceptualization of traffic as a science began in the 1930s with the first empirical data collection efforts and subsequent application of probability theory to the description of road traffic. This empirical thread has been woven through the developments in traffic science until today. The pioneering empirical studies conducted by Greenshields (*2*) led to a simple model relating vehicle flow and travel speeds, and the investigation of traffic performance at intersections. The expansion of the highway system and tremendous increase in automobile use after World War II led to a surge in the study of traffic phenomena, with notable empirical efforts led by Edie and others involving the Lincoln Tunnel in New York. (*3*, *4*) Along these lines, Wardrop also contributed to the scientific approach to transportation phenomena (*5*).

In 1959, Herman organized the International Symposium on the Theory of Traffic Flow (*6*). This was the first of what has become a series of symposia on the theory of traffic flow and transportation science (2019 will see the 23rd edition). Tracing the topics covered in the 22 proceedings of these symposia indicates the tremendous developments over the last 60 years in the understanding and the treatment of traffic flow processes. These proceedings also reflect exciting developments beyond the highway mode and involvement of researchers from many disciplines and countries around the world. (*6*)

In 1964, the Highway Research Board published the Monograph on Traffic Flow Theory as HRB Special Report 79 (*7*). Another version of the monograph was published in 1975 (*8*) and revised in 2001 (*9*). The latest monograph contains eleven chapters, the subjects of which are good indicators of the major progress in the understanding of TFT in the second half of the 1900s:

1. Introduction
2. Traffic Stream Characteristics
3. Human Factors
4. Car Following Models
5. Continuum Flow Models
6. Macroscopic Flow Models
7. Traffic Impact Models
8. Unsignalized Intersection Theory
9. Traffic Flow at Signalized Intersections
10. Traffic Simulation
11. Kinetic Theories

Review of several recent summaries of the development of the field of TFT (*10–12*) and leading scholars in TFT revealed that certain developments in the history of traffic theory stand out above the others.

Macroscopic Flow Models

Greenshields' pioneering work on empirical macroscopic flow relations (*2*) helped establish a scientific perspective toward traffic. The recognition of the similarity between traffic flow and compressible fluid, led to macroscopic traffic flow modeling based on application of hydrodynamics. In particular, the hydrodynamic models developed by Lighthill & Whitham (1955) and Richards (1956), referred to collectively as LWR models, and their enhancements serve as a guidepost in the history of traffic theory (*13*, *14*). Newell's simplified kinematic wave theory is also considered as a significant development of traffic theory (*15–17*). The monograph by (Nobel laureate Ilya) Prigogine and Herman (*18*) introduced gas-kinetic theories of traffic flow using approaches from statistical mechanics, providing the basis for more recent work including mesoscopic and cellular automata models. The discretization of the LWR formalized by Daganzo's cell transmission model (*19*, *20*) was incorporated in simplified dynamic traffic assignment and network models. The development of "higher order" flow models, starting with Payne (*21*), Daganzo's criticism (*22*), and subsequent rebuttal (*23*), further serve as milestones in traffic flow history. Extensions of this work more recently in the physics research community have included development of a three-phase hypothesis, including the consideration of a synchronized flow state (*24–26*). Daganzo (*27*, *28*) introduced a variational theory of traffic flow (also known as viability theory in other fields), which helped unify different traffic presentations (macroscopic, microscopic and mesoscopic) under the single umbrella of first-order conservative flow motion (*29*, *30*), revisit the numerical solution of the LWR model, and make connections between local and global traffic states using robust averaging methods.

Microscopic Flow Models

As a foundation for the more popular modeling approaches, the recognition of the similarity between traffic flow and moving particles led to the development of microscopic car following models (*31*) (*32*). This included the recognition of the importance of human factors in traffic flow modeling, which led to microscopic traffic flow modeling based on car-following, lane-changing, and gap acceptance behaviors. Notable families of subsequent car following models include: *Stimulus Response Models* (*33*, *34*), *Collision Avoidance Models* (*35–37*), *Psycho-Physical Models* (*38–49*), the *Optimal Velocity Model* (*50*), the *Intelligent Driver Model* (*34*, *51*), and *Cellular Automata Models* (*52*). Extensions to the macroscopic and microscopic perspectives have led to hybrid traffic flow models (*53*, *54*). With the development of autonomous vehicle technologies, car-following models have been extended for vehicle control, such as adaptive cruise control (ACC) (*55–58*) and cooperative adaptive cruise control (CACC) with the latter accounting for communication and cooperation among vehicles (*59–65*). Along with these technologies, platoon stability analysis rooted in car-following models has also gained new research interests (*56*, *60*, *62*, *63*, *66–70*).

Data and Simulation

The third set of accomplishments in the field of TFT are related to the advancements in sensing and computing that have led to improved empirical analyses and simulation techniques. These efforts have been inspired in part by the early empirical efforts of traffic science pioneers (e.g., (*71*)). The I-880 field experiment was one of the first studies to produce a comprehensive database of field data from multiple sensors and incident characteristics (*72*) and was among the earliest empirical traffic data sets made available online. The Berkeley Highway Laboratory (BHL) built off of the I-880 field experiment by combining per-vehicle loop detector data with video monitoring (*73*). In the subsequent years, many archival data management systems (ADMS) that provide conventional aggregated detector data along with data analysis and visualization for large highway networks have become available online (e.g., California Freeway Performance Measurement System (PeMS) (*74*)). ADMS are a common source for input, calibration, and validation of traffic models.

While the detector data from those efforts provide a wealth of macroscopic traffic data, a great need remains for additional microscopic traffic data to develop, validate and refine theories and simulations. Orthorectified imagery is the most direct means of collecting such data over many vehicles and large distances. An early example of such work is by Treiterer (*75*, *76*) which used airborne imagery to track 209 vehicle trajectories over 3 miles of freeway. Turner-Fairbank Highway Research Center used a similar technique to collect vehicle trajectory data in the 1980's (*77*). These needs were widely recognized and the FHWA-sponsored Next Generation Simulation (NGSIM) project collected such data from tall buildings adjacent to busy roadways, including the pre-existing camera deployment in the BHL (*78*). The NGSIM data is the largest set of empirical microscopic data set on vehicle movements and interactions that exists to date, and is considered as the best resource for simulation model developers, traffic flow theorists, and data analytics researchers. However, there is growing evidence of systematic errors in the NGSIM data sets, e.g., (*79–81*). Instrumented probe vehicles have been another source of microscopic traffic data and used to study aspects of microscopic traffic flow since the 1950's, e.g., (*31*, *82–85*). Regardless, the existing microscopic data sets combined only comprise a few hours of traffic and there is a greater need than ever for highly accurate empirical microscopic data.

Perhaps the most widely recognized and used products related to TFT by transportation system engineers and planners are different levels of simulation models (macroscopic, mesoscopic, and microscopic). Development of simulation models can be traced to the 1970s with increasing utilization in the 1980s. Commercially available products became available through the years, and most transportation system projects that involve traffic analysis are currently required to use simulation for analysis. As technology advances, traffic simulation is playing an increasing role as a problem-solving tool for transportation system analysis. Researchers and practitioners are realizing the urgent need for updating the underlining algorithms with emerging technologies, including connected and automated vehicles. This is reflected by the recent surge in research and development on this subject.

In 2008, the TFTC Committee began a series of biennial summer conferences. At a 2012 summer conference, held jointly between TFTC with the HCQS Committee, a major outcome was to move forward jointly to create a Transportation Simulation Manual (TSSM) to detail the state of the practice in transportation simulation. The first version of this manual has been developed and is expected to be released in 2019.

Traffic Phenomena: Capacity Drop and Stop-and-Go Traffic

Decades of research have been devoted to understanding two major freeway traffic phenomena: ‘capacity drop’ and stop-and-go oscillations. The capacity-drop phenomenon has been observed by many empirical studies, wherein bottleneck discharge rates diminish by 5-30% after the queue onset near merge bottlenecks (*86–91*), diverge bottlenecks (*92*, *93*), weave bottlenecks (*94*, *95*), uphills, or sags (*96*, *97*). Numerous theoretical and empirical studies suggest that capacity drop arises due to car-following behavior (*98–102*) and disruptive lane-changes (LCs) (*53*, *103–106*), including LCs downstream of the apparent bottleneck (*107*) and driver relaxation after LC maneuvers (*108–110*). Along with empirical observations, substantial modeling efforts have been made to obtain insights into and reproduce the capacity-drop phenomenon by identifying its causes, such as traffic voids caused by bounded acceleration or LC vehicles (*53*) or occupying multiple lanes simultaneously (*111*, *112*).

In stop-and-go traffic (often referred to as traffic oscillations), vehicles exhibit oscillatory trajectories with regular deceleration/acceleration cycles. These disturbances were typically found to form near active freeway bottlenecks (*113*), propagate against congested traffic flow at relatively constant speeds of 10-20 km/hr (*25*, *114–118*) and often grow in amplitude as they propagate (*114*), though depending on geometry, the disturbances may also attenuate (*119*). Stop-and-go traffic and capacity drop phenomena are closely linked as the latter is related to the generation of the former. This phenomenon was first reported in the late 1950s (*87*), but its mechanisms were not understood very well until high resolution data became available in the 2000's. Several later studies based on empirical microscopic data revealed that oscillations formation and growth are caused in part by LCs (*113*, *114*, *120–123*) and in part by driver characteristics (timid vs. aggressive) (*121*, *124*). An experiment on a test-track by Sugiyama et al. (*125*) showed that stop-and-go disturbances can emerge spontaneously due to instabilities in car-following, confirming the phenomenon referred to as "phantom bottlenecks". There have been extensive modeling efforts to describe oscillations in the form of car-following stability analysis (*126–129*), probabilistic driver behavior (*130*, *131*), introduction of new traffic regimes prone to disturbance generation (*132*, *133*), and time-varying driver characteristics (*124*, *134*).

Active Modes and Crowd Behavior

While walking is undoubtedly the oldest mode of travel, only in the second half of the previous century have its properties become the subject of scientific investigation. Most initial work has consisted of guidelines intended for the planning and design of sidewalks, stairways and terminals. Relations similar to the fundamental diagrams of vehicular traffic flow have been established for pedestrians along walkways and stairways. Just as vehicular traffic, pedestrian flows exhibit similar characteristics of decreasing average speed at higher densities, with decreasing throughput beyond a certain density level. However, pedestrian flows at higher densities differ markedly from vehicular traffic because of the multidirectional nature of the interactions, and the greater compressibility of human flows relative to vehicular flows. With the increase in size and occurrence of serious accidents in connection with large-scale gatherings (concerts, games, pilgrimage, political rallies, and so on), considerable attention turned to modeling crowd behavior and associated flow processes. Theoretical models have been coupled with observation, and a class of simulation tools have emerged to support the planning and design of pedestrian facilities and management of large-scale events, including emergency evacuation. Notable contributions include Helbing's social force model (*135*) and characterization of three phases of crowd behavior (*136*) (based on data collected at the Muslim pilgrimage in Makkah), Hoogendoorn and Bovy's gas-kinetic models (*137*), and Mahmassani and co-workers' Hajj simulation models (*138–140*). Many contributions based on experimental observation have also been developed, including the extensive work conducted at TU-Delft in Hoogendoorn's group (*141*, *142*) , and by Seyfried (*143*), and more recent analogies with ants and other animals (*144*). This interest has led to the establishment of a Crowd Dynamics and Modeling Subcommittee of the TFTC Committee, which has sponsored several sessions and workshops at the TRB Annual Meetings.

Along with greater interest in walking, urban dwellers are constantly encouraged to use active modes for local travel, particularly bicycles, but more recently also including electric scooters. Bicycle traffic science remains in its infancy, with scattered contributions over the past two decades (e.g. (*145*)). A more recent European effort at TU-Delft is helping address this gap (*146*).

With increasing heterogeneity amongst roadway users in urban environments, it is expected that the topic of mixed traffic flow will gain considerable attention in the coming decade.

Traffic Control

The primary form of traffic control applied by transportation agencies consists of traffic signals that allocate the shared right of way to alternating conflicting approach movements. Traffic theories for signalized intersections were derived from queueing models, and analytical expressions for delay at intersections sought to capture the effect of signal timing parameters on intersection delay. A good summary of this work is presented in a 1974 textbook by the late Gazis (*147*), as well as in a Chapter of the Traffic Flow Theory Monograph (*9*). Microscopic traffic simulation tools have gained wide acceptance in the evaluation of signalized intersections in the process of developing timing solutions.

For freeway traffic, early control attempts were all based on ramp metering under presumed steady state conditions. More realistic formulations were developed in a control theoretic framework, where the system model relating control variables to state variables is based on a higher-order continuum model of freeway traffic such as Payne's (*148*) and Papageorgiou's (*149*); Hadj-Salem and coworkers presented a comprehensive application of dynamic ramp metering using local feedback control (*150–152*) to the Boulevard Peripherique in Paris.

Mainline control attempts emerged primarily in Germany, with the main form of control consisting of dynamically displayed speed limits, intended to delay the onset of flow breakdown. The scientific underpinnings of these models were primarily due to Kühne (*153*) and his coworkers, who showed that adding a viscosity term to the dynamic speed density relation could produce stop-and-go waves, though these models were not essential to the implementation of the control strategy. More recent developments in flow breakdown control are also based on speed limitation, coupled with sophisticated sensing and control display technologies (*154–156*). Significant new opportunities for effective freeway control are possible with emerging new technologies such connected and automated vehicles (*157–159*).

At the network or system level, predictive management strategies have been proposed, using simulation-based traffic estimation and prediction systems that rely on mesoscopic flow models that integrate real-time sensor data with historical information (*160*, *161*). With additional deployment of connected and autonomous vehicles, the significance of these tools will increase, with additional improvement coming from selective application of machine learning techniques.

Human Factors

Incorporating human factors into traffic flow modeling has been challenging. However, limited studies have incorporated the following human dimensions in operational and tactical driving maneuvers: 1) risk-taking; 2) cooperation; 3) learning; 4) impatience; 5) aggressiveness; 6) distraction; 7) experience; 8) and uncertainty (*162*). Such human dimensions are essential as they are arguably the main contributors to collisions, and most traffic flow models are collision-free up to this day.

Van Lint and Calvert (*163*) offers a comprehensive framework on the different human cognitive processes (i.e., the "what") while classifying such processes into two key categories: the "Perception" and the "Response". Each of these process categories are translated to multiple traits, which researchers have attempted to incorporate into existing modeling framework with different levels of successes. In particular, within the perception category, the following traits were studied: the reaction time (*33*, *164*, *165*), the estimation errors (*164*, *166–170*), the perception thresholds (*171*, *172*), anticipation in space and time (*127*, *164*, *170*, *173*, *174*) and distractions (*175–184*). Within the response category, the following traits have been tackled: the sensitivity to the stimuli (*171*, *172*), the drivers' preferences (*80*, *173*), the context sensitivity (*124*, *173*, *185*), the insensitivity or inertia (*171*, *172*), and the risk-taking tendencies (*124*, *162*, *186–189*).

Next we will turn to a discussion of the recent shifts in paradigms of TFT.

NEW PARADIGMS OF TRAFFIC FLOW

Two major shifts in TFT research paradigms were made during the last few decades: one in the scale of traffic modelling and management and one considering emerging technologies (ITS, autonomous vehicles).

Network-wide Models of Urban Traffic

The first major paradigm shift in the TFT community was a change in the spatial scale at which surface transportation systems are modeled. Previously mentioned methods focused on behavior at specific locations, links or intersections, but recent work has modeled the collective behavior of vehicles over spatially compact urban regions and used this information to study aggregate traffic network dynamics. Initial efforts at this network-wide paradigm began in the 1960's and 1970's (*190–194*), but were limited by lack of available traffic data at the network-wide scale, which precluded the development of models that could model traffic network dynamics. One notable effort is Herman and Prigogine's two-fluid model, which related fraction of vehicles stopping with average vehicle speed and could be calibrated using data from a handful of probe vehicles traveling in the traffic stream (*18*, *195*, *196*). More recently, network-wide relationships between network production (measured in average vehicle flow or rate that trips could be completed) and network accumulation (number of vehicles traveling or average vehicle density) were examined using first simulation (*197*, *198*) and eventually, empirical data (*199*, *200*). These relationships are known as Network or Macroscopic Fundamental Diagrams (N/MFDs). Daganzo and Geroliminis (*201*) proposed the 'cuts method' based on the variational theory to analytically derive the MFD for an urban corridor, which was further improved in (*202*). Daganzo (*203*) showed how networks MFDs could be used to model traffic network evolution and identify basic control strategies to improve overall network efficiency. MFD-based regional modeling frameworks have been used to develop various large-scale control strategies to improve network efficiency by minimizing total vehicle travel time and mitigating congestion. These control strategies include: perimeter flow control (otherwise known as metering or gating), which identifies rates that vehicles should be allowed to move between regions of a network to improve network efficiency (*198*, *203–210*) (*209–216*); area-wide congestion pricing (*217–220*); allocation of space between various modes in a network (*221*, *222*); and, the use of one-way and two-way streets in urban regions (*223–226*). Other studies have focused on the properties of these network-wide relationships, including network instabilities, multivaluedness and hysteresis, and strategies to mitigate these to produce more reliable and well-defined relationships (*227–238*), and the development of new functional forms (*238–240*).

Some of the early studies on network-wide traffic also accounted for the interactions between cars and transit (*241*, *242*), evaluating not only the space consumed by each mode, but also their travel times. Smeed (*243*) estimated the average travel time for different cities depending on the modal split, showing that dependance on private cars was relatively fine for small towns, but could lead to significant delays for cities with 100,000 commuters or more. Owen (*244*) highlighted the need for better public transport solutions while simultaneously curbing the widespread use of the private car through some innovative traffic management strategies (e.g. car-free locations, congestion pricing). This idea was further reinforced with the Downs-Thomson paradox – the notion that to improve average travel speeds in cities it is imperative to improve the operations of public transport (*245*, *246*). Most recently, the MFD has been extended to capture the performance of multiple modes across the network (*247*) using a 3D-MFD version (*248*, *249*), and a number of efforts have been made to model multi-modal settings using either a similar concept (*250–253*) or higher order models (*254*).

Traffic Flow Modeling for Emerging Technologies

With the emergence of connected as well as connected and automated vehicle (CAV) technologies, a need to model such vehicles has arisen for simulation purposes. While connected vehicles convey information between vehicles, infrastructure, and road users using wireless technology, automated vehicles may operate without direct input from the driver (*255*). Although some automation technologies do not rely on connectivity, the higher levels of automation will likely require connectivity to reach the most ideal outcomes (*255*). Currently, two types of microscopic traffic modeling account for CAVs: logic-based models and vehicle dynamics/mechanistic models.

In theory, most existing car-following models could be considered logic-based traffic flow models with their generated traffic being considered automated. Several recent studies analyzed traffic flow properties using logic-based models with varying percentages of automated and/or connected vehicles (*256–260*). As highlighted in (*261*), most existing studies show that significant improvements can be achieved in most traffic flow performance measures as well as traffic string stability. Major drawbacks come from the use of simulation-based analyses and the lack of data needed to calibrate parameters for CAVs, as well as human driver behavior/attitudes toward the emerging. More recent work involves developing analytical frameworks to gain insight into the effects of CAVs on traffic flow (*262*, *263*).

Vehicle dynamics/mechanistic models focus on the vehicular aspects such as the steering, brake system and throttle, aerodynamics, rolling resistance, and even emissions and how they are modeled for connected and automated capabilities. Much of the focus of the latest research is on the control systems of the equipped vehicles in various platoon sizes (*69*, *264*, *265*). Traffic metrics of interest include not only string stability, but also internal stability for assessing controller design and effectiveness (*69*). An optimal control model for the mechanistic aspects of fuel consumption and emissions for CAVs has been developed for an intersection setting (*266*). Although these models capture detailed mechanistic features, they typically assume homogeneity in the type of CAV technology, and the human behavior/interaction with the systems is not prioritized.

FUTURE DIRECTIONS

There are many challenges for future developments in the field of TFT. The TFTC Committee should consider ways to become a clearinghouse for understanding traffic flow phenomena at multiple scales based on solid empirical studies, to be a forum for debate and discussions of conflicting evidence, and to serve as a repository for empirical data. In the last years, we observed an acceleration of the introduction of new technologies and services in transportation system. This is an invigorating stimulus for the TFTC committee towards revisiting the fundamentals of TFT and develop improved and further integrated simulation tools. Outlined below are four primary arenas where there are opportunities for major investments in research and improved systems.

Simulation

There are many challenges for improved simulation tools that should be addressed. There is a need for improved realism of driving behavior models—particularly in congested and oversaturated traffic conditions. There has been increased interest in the prediction of traffic safety and environmental impacts based on simulation models. There is also a need for the models and tools to encompass the full range of modes (including freight transit, bicycling and walking) and to account for the interaction of these modes. Multi-resolution modeling and real-time modeling of traffic flow are also important topics of research and development. The collection of trajectory data is becoming more feasible and methods for collecting this type of data and its use in the calibration and validation are needed.

Several efforts are underway to simulate the operation and analyze scenarios for emerging transportation systems and services. Most notably CAVs create many uncertainties that simulation tools need to model. Issues include modeling CAVs interactions with other vehicles (human-driven vehicles) and non-motorized modes (e.g., pedestrians and bicycles), measurement errors from the various sensors employed under different infrastructure conditions, the effect of false positives and false negatives of object detection and position have on these CAVs, and how temporal and spatial infrastructure changes influence the efficiency and effectiveness of these CAVs.

Utilizing simulation modeling as part of decision support systems to improve transportation system performance in real-time environment introduces additional challenges. Running simulation models should have low latency such that the prediction of the performance and impacts can be done in a timely manner. In addition, calibration of these models based on real-time data, possibly coming from CAVs in part, will improve the prediction capabilities of these models. Consideration should be given to the development of nanoscopic traffic flow models by incorporating engine performance, vehicle dynamics, intelligent drivers, and vehicle movement on a true two dimensional surface. Driving forces come from the need for more fidelity in safety, emissions, automatic cruise control, potential automated highway vehicle systems, etc.

Connectivity and Automation

Some of the most visible CAV leaders are currently private companies that have operated CAVs on public roads. While the feat is impressive, the implications for the TFT community are limited due to the private nature of the collected data. The USDOT Intelligent Transportation Systems (ITS) Joint Program Office (JPO) provides the opportunity to researchers to gain access to any of their seven test beds around the U.S. through a series of outlined steps (*267*). However, these testbeds are for connected vehicles and do not include any level of automation. Additionally, the USDOT ITS JPO created an online public database for researchers to upload and share ITS data and research findings (*268*). Even with these resources, there is still no standard for collecting data to be utilized by the traffic flow community.

Much work is being conducted to improve the traffic flow community's understanding of connected and automated vehicle impact on our roadways. Aspects of the logic-based and vehicle dynamics/mechanistic traffic flow models as well as models that attempt to capture human behavior in these changing roadway environments should be combined. Notably, although CAV models are mainly employed to remove human errors, their performance will depend on the way the humans/customers use the system. Thus, modeling the performance of CAVs will necessitate modeling the human factors interacting and operating such CAVs. Furthermore, with this integration comes the even greater need of data for both the driving logics as well as the mechanistic components. With this integration and access to data for calibration, the collective effects of emerging technologies on overall traffic could be analyzed.

Two data collection methods are the use of virtual environments or driving simulators and the use of instruments vehicles on testbeds/public roads. Driving simulators allow for a broad range of applications to be tested safely in a virtual environment (*269–272*). While much can be learned from driving simulator studies, the virtual aspect of driving simulators can be a downside. This leads to the implementation of instrumented vehicles, which are equipped with various sensors (e.g. LiDAR and RADAR), cameras, GPS, and control systems to obtain fine scope data regarding trajectories, headways, surrounding traffic, vehicle performance, subject reaction times, and subject attitudes. Some of these vehicles are used for data collection and automated vehicle research (*82*, *123*, *269*, *270*, *273–275*). Others are being used for connected and automated vehicle research (*269*, *270*, *276*).

Network-level or Regional Urban Traffic Control
The existence of well-defined network MFDs allows large-urban networks to be abstracted into a handful of regions and provides a computationally efficient way to model regional congestion dynamics. This paves the way to multiple applications. First, much work remains to improve large-scale MFD-based control strategies, such as perimeter control, optimal routing, pricing and others. In particular, how these regional control actions can be coordinated with local controllers (e.g. individual traffic signals) is very important to ensure the overall system efficiency. Second, field implementation for the control strategies and thorough validation for the models are crucial as a large body of the literature still resorts to idealized test cases and simulated networks. Third, the impacts of autonomous and/or connected vehicles and new mobility service on MFD properties and system dynamics are open areas of research. It would be interesting to investigate how MFD models can be used as a new tool for urban planning and land-use studies. Finally, network-wide traffic models are needed to estimate a variety of metrics, such as safety and environmental impacts. Preliminary work has been performed on the former (*277*).

Multi-modal Transportation Systems
The existence of clear macroscopic relations between buses and cars, is now prompting new research extending to other modes, including bicycles and pedestrians (*247*). These models not only lead to a better understanding of the interactions across modes, but can contribute to innovative strategies that look at the system holistically, and aim to improve overall people mobility. This is more relevant each day as the distinction between modes is slowly disappearing with the concept of shared economies (*278*, *279*); an idea that is expected to evolve much further with automated vehicle technologies (*280*). New technologies, in general, are contributing to more flexible transport services, including concepts such as mobility as a service (MaaS) and mobility on demand (MOD) (*281*). The goal of many of these new transport alternatives is to better tailor the provided solutions to the real time changes in demand.

ACCOMPLISHMENTS AND GOALS OF TFTC COMMITTEE

Over the years, the TFTC committee has authored two important documents, Monograph on Traffic Flow Theory and Transportation Systems Simulation Manual (TSSM), as described above. Since publication, the monograph has been used widely not only for research but also for education and a guide for young scholars. It is anticipated that the TSSM will have similar impacts but also reach out to practitioners that use simulations for their analyses and decision making. The TFTC committee has also authored "TRB E-Circular 197: Celebrating 50 Years of Traffic Flow Theory" involving the presentations at the TFTC summer meeting on August 11–13, 2014 in Portland, Oregon. The publication reflects on the traffic flow related research in the past 50 years and provides a glimpse of future research directions.

The TFTC committee has also formed three official subcommittees based on active research areas:

- AHB45(1) Joint Subcommittee on Simulation ("SimSub")
- AHB45(2) Crowd Flow Dynamics, Modeling and Management Subcommittee ("CrowdSub")
- AHB45(3) Traffic Flow Modeling for Connected and Automated Vehicles ("CATSub")

These subcommittees lead various important activities for the community including organizing workshops at TRB, issuing call for papers in strategic topics (for Annual meetings of TRB and other journals), representing the committee at various conferences, etc. AHB45(1) SimSub was created in 2005, in cooperation with seven other TRB committees: Transportation Network Modeling (ADB30), Freeway Operations (AHB20), Traffic Signal Systems (AHB25), Highway Capacity and Quality of Service (HCQS) (AHB40), Work Zone Traffic Control (AHB55), Managed Lanes Committee (AHB35), and Transportation and Air Quality (ADC20). SimSub coordinates the efforts of its eight parent committees to promote and endorse the use of simulation tools in transportation system analysis. SimSub is working closely with the TFTC committee and the TSSM development team to develop research problem statements and to support the provision of guidelines for the analysis, modeling, and simulation (AMS) of emerging technologies.

The Crowd Dynamic Subcommittee is part of TFTC committee and is supported by the Emergency Evacuation Committee (ANB80). The subcommittee promotes research in the area of empirical analyses, modeling, simulation, and management of crowds. Since established in 2014 the subcommittee organized two workshops and sponsored call for papers in every TRB annual meetings. The members of the subcommittee are involved in other well-known crowd dynamics international scientific committees including TFG and PED.

Anticipating transformative impacts of the CAV technology, the TFTC committee has formed AHB45(3) CATSub in 2014. Since its creation, the subcommittee has organized several workshops at TRB and sessions at the Autonomous Vehicles Symposiums (AVS). The summary of the presentations and the recommendations made by the organizers and panel members resulted in three book chapters (*282–284*).

The TFTC committee has also engaged in a variety of activities through unofficial subcommittees. After the successful Greenshields 75 Symposium in 2008, the TFTC committee established the Greenshields Prize, named in honor of Dr. Bruce D. Greenshields, a pioneer in our field. The Greenshields Prize recognizes annually a high-quality paper founded on real data analysis. A new award for the best theoretical contribution was established in 2018. The Awards subcommittee also provides nominations for other TRB awards including the Mickle and Burggraf awards (TRB-wide) and the Cunard award (Operations section-wide). The TFTC committee is proud to count two Mickle's awards (2016 and 2017), one Burggraf's award (2017) and six Cunard awards.

The Outreach and Diversity subcommittee has engaged in a variety of outreach activities through committee newsletters, website, Facebook, and Twiter. The subcommittee also hosted 68 webinars from 2010 to 2016. Through various subcommittee and outreach activities, the TFTC committee has engaged in young and diverse scholars. In recognition, the TFTC committee was awarded a Blue Ribbon Award in 2015 in the category of "Community Building & Mentoring: Committee on Traffic Flow Theory and Characteristics for engaging young diverse participants through innovative and inclusive outreach; and collaboration in research, education and training."

The TFTC committee has been a hub for traffic flow researchers to share knowledge, inspire new research directions, and welcome emerging scholars since its birth. The committee will continue this tradition and serve as a main venue for traffic flow researchers, where diverse ideas, approaches, members, and friends are welcome regardless of the school of thoughts, affiliation, race, gender, stage of career, etc. By nature, the TFTC committee is inclined for more fundamental research of traffic flow. However, the committee recognizes the importance of connection from research to practice and will continue to seek and engage government agencies as well as private industry. This is particularly important in the era of the fast-developing CAV technologies, where partnerships among different sectors are essential.

Historically, the TFTC committee has been close to several other committees and partnered with them for a variety of activities such as calls for papers, midyear meetings, workshops, etc. The committee will continue to partner with other committees, including:

- AHB15 Standing Committee on Intelligent Transportation Systems
- AHB20 Standing Committee on Freeway Operations
- AHB25 Standing Committee on Traffic Signal Systems
- AHB30 Standing Committee on Vehicle-Highway Automation
- AHB40 Standing Committee on Highway Capacity and Quality of Service
- ADB30 Standing Committee on Transportation Network Modeling

It is expected that as the field develops, the committee will adapt, lead new activities, and seek out new partnerships.

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REFERENCES

1. Lieu, H. Traffic Flow Theory. *Public Roads*, Vol. 62, No. 4, 1999, pp. 45–47.
2. Greenshields, B. D. A Study of Traffic Capacity. No. 1935, 1935, pp. 448–477.
3. Edie, L. C., and R. S. Foote. Traffic Flow in Tunnels. *Highway Research Board Proceedings*, Vol. 37, 1958, pp. 334–344.
4. Edie, L. C., and R. S. Foote. Experiments on Single Lane Flow in Tunnels. In *Theory of Traffic Flow, Proceedings of Symposium on the Theory of Traffic Flow* (R. Herman, ed.), Elsevier, New York, pp. 175–192.
5. Wardrop, J. G., and J. I. Whitehead. Some Theoretical Aspects of Road Traffic Research.

Proceedings of the Institution of Civil Engineers, Vol. 1, No. 5, 1952, pp. 767–768. https://doi.org/10.1680/ipeds.1952.11362.
6. Herman, R., Ed. *Theory of Traffic Flow, Proceedings of Symposium on the Theory of Traffic Flow*. Elsevier, New York, 1961.
7. *Monograph on Traffic Flow Theory*. 1964.
8. *Monograph on Traffic Flow Theory*. 1975.
9. Gartner, N. H., C. J. Messer, and A. Rathi, Eds. *Traffic Flow Theory-A State-of-the-Art Report: Revised Monograph on Traffic Flow Theory*. Turner-Fairbank Highway Research Center, 2002.
10. Hoogendoorn, S. P., and P. H. L. Bovy. State-of-the-Art of Vehicular Traffic Flow Modelling. *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, Vol. 215, No. 4, 2001, pp. 283–303. https://doi.org/10.1177/095965180121500402.
11. Gazis, D. C. The Origins of Traffic Theory. *Operations Research*, Vol. 50, No. 1, 2002, pp. 69–77. https://doi.org/10.1287/opre.50.1.69.17776.
12. Newell, G. F. Memoirs on Highway Traffic Flow Theory in the 1950s. *Operations Research*, Vol. 50, No. 1, 2002, pp. 173–178. https://doi.org/10.1287/opre.50.1.173.17802.
13. Lighthill, M. J., and G. B. Whitham. On Kinematic Waves II. A Theory of Traffic Flow on Long Crowded Roads. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, Vol. 229, No. 1178, 1955, pp. 317–345. https://doi.org/10.1098/rspa.1955.0089.
14. Richards, P. I. Shock Waves on the Highway. *Operations Research*, Vol. 4, No. 1, 1956, pp. 42–51. https://doi.org/10.1287/opre.4.1.42.
15. Newell, G. F. A Simplified Theory of Kinematic Waves in Highway Traffic, Part I: General Theory. *Transportation Research Part B*, Vol. 27, No. 4, 1993, pp. 281–287. https://doi.org/10.1016/0191-2615(93)90039-D.
16. Newell, G. F. A Simplified Theory of Kinematic Waves in Highway Traffic, Part II: Queueing at Freeway Bottlenecks. *Transportation Research Part B: Methodological*, Vol. 27, No. 4, 1993, pp. 289–303. https://doi.org/10.1016/0191-2615(93)90039-D.
17. Newell, G. F. A Simplified Theory of Kinematic Waves in Highway Traffic, Part III: Multi-Destination Flows. *Transportation Research Part B: Methodological*, Vol. 27, No. 4, 1993, pp. 305–313. https://doi.org/10.1016/0191-2615(93)90040-H.
18. Herman, R., and I. Prigogine. A Two-Fluid Approach to Town Traffic. *Science*, Vol. 204, No. 4389, 1979, pp. 148–151.
19. Daganzo, C. F. The Cell Transmission Model: A Dynamic Representation of Highway Traffic Consistent with the Hydrodynamic Theory. *Transportation Research Part B*, Vol. 28, No. 4, 1994, pp. 269–287. https://doi.org/10.1016/0191-2615(94)90002-7.
20. Daganzo, C. The Cell Transmission Model, Part II: Network Traffic. *Transportation Research Part B*, Vol. 29, No. 2, 1995, pp. 79–93.
21. Payne, H. Models of Freeway Traffic and Control. *Mathematical Models of Public Systems 1*, Vol. 1, No. 1, 1971, pp. 51–6.
22. Daganzo, C. F. Requiem for Second-Order Fluid Approximations of Traffic Flow. *Transportation Research Part B*, Vol. 29, No. 4, 1995, pp. 277–286. https://doi.org/10.1016/0191-2615(95)00007-Z.
23. Aw, A., and M. Rascle. Resurrection of “Second Order” Models of Traffic Flow. *SIAM Journal on Applied Mathematics*, Vol. 60, No. 3, 2000, pp. 916–938.

https://doi.org/10.1137/S0036139997332099.
24. Kerner, B. S. *The Physics of Traffic*. Springer Berlin Heidelberg, Berlin, Heidelberg, 2004.
25. Kerner, B. S., and H. Rehborn. Experimental Features and Characteristics of Traffic Jams. *Physical Review E*, Vol. 53, No. 2, 1996, pp. R1297--R1300.
26. Kerner, B. S. Congested Traffic Flow: Observations and Theory. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1678, No. 1, 2007, pp. 160–167. https://doi.org/10.3141/1678-20.
27. Daganzo, C. F. A Variational Formulation of Kinematic Waves: Basic Theory and Complex Boundary Conditions. *Transportation Research Part B: Methodological*, Vol. 39, No. 2, 2005, pp. 187–196. https://doi.org/10.1016/j.trb.2004.04.003.
28. Daganzo, C. F. A Variational Formulation of Kinematic Waves: Solution Methods. *Transportation Research Part B: Methodological*, Vol. 39, No. 10, 2005, pp. 934–950. https://doi.org/10.1016/j.trb.2004.05.003.
29. Daganzo, C. F. On the Variational Theory of Traffic Flow: Well-Posedness, Duality and Applications. *Networks and Heterogeneous Media*, Vol. 1, No. 4, 2006, pp. 601–619. https://doi.org/10.3934/nhm.2006.1.601.
30. Laval, J. A., and L. Leclercq. The Hamilton–Jacobi Partial Differential Equation and the Three Representations of Traffic Flow. *Transportation Research Part B: Methodological*, Vol. 52, 2013, pp. 17–30. https://doi.org/10.1016/j.trb.2013.02.008.
31. Chandler, R. E., R. Herman, and E. W. Montroll. Traffic Dynamics: Studies in Car Following. *Operations Research*, Vol. 6, No. 2, 1958, pp. 165–184. https://doi.org/10.1287/opre.6.2.165.
32. Herman, R., E. W. Montroll, R. B. Potts, and R. W. Rothery. Traffic Dynamics: Analysis of Stability in Car Following. *Operations Research*, Vol. 7, No. 1, 1959, pp. 86–106. https://doi.org/10.1287/opre.7.1.86.
33. Gazis, D. C., R. Herman, and R. W. Rothery. Nonlinear Follow-the-Leader Models of Traffic Flow. *Operations Research*, Vol. 9, No. 4, 1961, pp. 545–567. https://doi.org/10.1287/opre.9.4.545.
34. Treiber, M., A. Hennecke, and D. Helbing. Congested Traffic States in Empirical Observations and Microscopic Simulations. *Physical review E*, 2000.
35. Newell, G. F. Nonlinear Effects in the Dynamics of Car Following. *Operations Research*, Vol. 9, No. 2, 1961, pp. 209–229. https://doi.org/10.1287/opre.9.2.209.
36. Gipps, P. G. A Behavioural Car-Following Model for Computer Simulation. *Transportation Research Part B: Methodological*, Vol. 15, No. 2, 1981, pp. 105–111. https://doi.org/10.1016/0191-2615(81)90037-0.
37. Kometani, E., and T. Sasaki. On the Stability of Traffic Flow. *Journal of Operations Research Society Japan*, Vol. 2, No. 1, 1958, pp. 11–26.
38. Evans, L., and R. Rothery. Perceptual Thresholds in Car-Following—A Comparison of Recent Measurements with Earlier Results. *Transportation Science*, Vol. 11, No. 1, 1977, pp. 60–72. https://doi.org/10.1287/trsc.11.1.60.
39. Hoyer, R., and M. Fellendorf. Parametrization of Microscopic Traffic Flow Models Through Image Processing. *IFAC Proceedings Volumes*, Vol. 30, No. 8, 1997, pp. 889–894. https://doi.org/10.1016/S1474-6670(17)43934-6.
40. Sauer, C. W., G. J. Andersen, and A. Saidpour. Car Following by Optical Parameters. 2005.
41. Jin, S., D.-H. Wang, Z.-Y. Huang, and P.-F. Tao. Visual Angle Model for Car-Following Theory. *Physica A: Statistical Mechanics and its Applications*, Vol. 390, No. 11, 2011, pp.

1931–1940. https://doi.org/10.1016/j.physa.2011.01.012.
42. Montroll, E. . Acceleration and Clustering Tendency of Vehicular Traffic. 1959.
43. Michaels, R. M. Perceptual Factors in Car Following. 1963.
44. Lee, J. J., and J. Jones. Traffic Dynamics: Visual Angle Car Following Models. *Traffic Engineering and Control*, Vol. 8, No. 8, 1967, pp. 348–350.
45. Evans, L., and R. Rothery. Experimental Measurement of Perceptual Thresholds in Car Following. *Highway Research Record*, Vol. 464, 1973, pp. 13–29.
46. Lee, D. N. A Theory of Visual Control of Braking Based on Information about Time to Collision. *Perception*, Vol. 5, No. 4, 1976, pp. 437–459.
47. Leutzbach, W., and R. Wiedemann. Development and Applications of Traffic Simulation Models at the Karlsruhe Institut Fur Verkehrwesen. *Traffic engineering and control*, Vol. 27, No. 5, 1986, pp. 270–278.
48. Reiter, U. Empirical Studies as Basis for Traffic Flow Models. 1994.
49. Kumamoto, H., K. Nishi, K. Tenmoku, and H. Shimoura. Rule Based Cognitive Animation Simulator for Current Lane and Lane Change Drivers. 1995.
50. Bando, M., K. Hasebe, K. Nakanishi, A. Nakayama, A. Shibata, and Y. Sugiyama. Phenomenological Study of Dynamical Model of Traffic Flow. *de Physique I*, Vol. 5, No. 11, 1995, pp. 1389–1399. https://doi.org/10.1051/jp1:1995206.
51. Treiber, M., and A. Kesting. Modeling Lane-Changing Decisions with MOBIL. In *Traffic and Granular Flow '07*, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 211–221.
52. Nagel, K., and M. Schreckenberg. A Cellular Automaton Model for Freeway Traffic. *Journal de Physique I*, Vol. 2, No. 12, 1992, pp. 2221–2229. https://doi.org/10.1051/jp1:1992277.
53. Laval, J. A., and C. F. Daganzo. Lane-Changing in Traffic Streams. *Transportation Research Part B: Methodological*, Vol. 40, No. 3, 2006, pp. 251–264. https://doi.org/10.1016/j.trb.2005.04.003.
54. Leclercq, L. Hybrid Approaches to the Solutions of the "Lighthill-Whitham-Richards" model. *Transportation Research Part B: Methodological*, Vol. 41, No. 7, 2007, pp. 701–709. https://doi.org/10.1016/j.trb.2006.11.004.
55. Wang, M., W. Daamen, S. P. Hoogendoorn, and B. van Arem. Rolling Horizon Control Framework for Driver Assistance Systems. Part II: Cooperative Sensing and Cooperative Control. *Transportation Research Part C: Emerging Technologies*, Vol. 40, 2014, pp. 290–311. https://doi.org/10.1016/j.trc.2013.11.024.
56. Swaroop, D., and J. K. Hedrick. String Stability of Interconnected Systems. *IEEE Transactions on Automatic Control*, Vol. 41, No. 3, 1996, pp. 349–357. https://doi.org/10.1109/9.486636.
57. Zhou, Y., S. Ahn, M. Chitturi, and D. A. Noyce. Rolling Horizon Stochastic Optimal Control Strategy for ACC and CACC under Uncertainty. *Transportation Research Part C: Emerging Technologies*, Vol. 83, 2017, pp. 61–76. https://doi.org/10.1016/j.trc.2017.07.011.
58. Wang, M., M. Treiber, W. Daamen, S. P. Hoogendoorn, and B. van Arem. Modelling Supported Driving as an Optimal Control Cycle: Framework and Model Characteristics. *Transportation Research Part C: Emerging Technologies*, Vol. 36, 2013, pp. 563–574. https://doi.org/10.1016/j.trc.2013.06.012.
59. Gong, S., and L. Du. Optimal Location of Advance Warning for Mandatory Lane Change near a Two-Lane Highway off-Ramp. *Transportation Research Part B: Methodological*,

Vol. 84, 2016, pp. 1–30. https://doi.org/10.1016/j.trb.2015.12.001.
60. Li, S. E., X. Qin, Y. Zheng, J. Wang, K. Li, and H. Zhang. Distributed Platoon Control under Topologies with Complex Eigenvalues: Stability Analysis and Controller Synthesis. *IEEE Transactions on Control Systems Technology*, Vol. 27, No. 1, 2019, pp. 206–220. https://doi.org/10.1109/TCST.2017.2768041.
61. Qin, W. B., and G. Orosz. Scalable Stability Analysis on Large Connected Vehicle Systems Subject to Stochastic Communication Delays. *Transportation Research Part C: Emerging Technologies*, Vol. 83, 2017, pp. 39–60. https://doi.org/10.1016/j.trc.2017.07.005.
62. Ploeg, J., R. Vugts, R. van de Molengraft, M. Steinbuch, and G. Naus. Cooperative Adaptive Cruise Control, Design and Experiments. No. 1, 2014, pp. 6145–6150. https://doi.org/10.1109/acc.2010.5531596.
63. Naus, G. J. L., R. P. A. Vugts, J. Ploeg, M. J. G. Van De Molengraft, and M. Steinbuch. String-Stable CACC Design and Experimental Validation: A Frequency-Domain Approach. *IEEE Transactions on Vehicular Technology*, Vol. 59, No. 9, 2010, pp. 4268–4279. https://doi.org/10.1109/TVT.2010.2076320.
64. Talebpour, A., and H. S. Mahmassani. Influence of Connected and Autonomous Vehicles on Traffic Flow Stability and Throughput. *Transportation Research Part C: Emerging Technologies*, Vol. 71, 2016, pp. 143–163.
65. Zhang, L., J. Sun, and G. Orosz. Hierarchical Design of Connected Cruise Control in the Presence of Information Delays and Uncertain Vehicle Dynamics. *IEEE Transactions on Control Systems Technology*, Vol. 26, No. 1, 2018, pp. 139–150. https://doi.org/10.1109/TCST.2017.2664721.
66. Wang, M. Infrastructure Assisted Adaptive Driving to Stabilise Heterogeneous Vehicle Strings. *Transportation Research Part C: Emerging Technologies*, Vol. 91, 2018, pp. 276–295. https://doi.org/10.1016/j.trc.2018.04.010.
67. Talebpour, A., H. S. Mahmassani, and S. H. Hamdar. Effect of Information Availability on Stability of Traffic Flow: Percolation Theory Approach. *Transportation Research Part B: Methodological*, Vol. 117, 2018, pp. 624–638. https://doi.org/10.1016/j.trb.2017.09.005.
68. Ge, J. I., and G. Orosz. Dynamics of Connected Vehicle Systems with Delayed Acceleration Feedback. *Transportation Research Part C: Emerging Technologies*, Vol. 46, 2014, pp. 46–64. https://doi.org/10.1016/j.trc.2014.04.014.
69. Li, S. E., Y. Zheng, K. Li, Y. Wu, J. K. Hedrick, F. Gao, and H. Zhang. Dynamical Modeling and Distributed Control of Connected and Automated Vehicles: Challenges and Opportunities. *IEEE Intelligent Transportation Systems Magazine*, Vol. 9, No. 3, 2017, pp. 46–58. https://doi.org/10.1109/MITS.2017.2709781.
70. Knoop, V. L., M. Wang, I. Wilmink, D. M. Hoedemaeker, M. Maaskant, and E.-J. Van der Meer. Platoon of SAE Level-2 Automated Vehicles on Public Roads: Setup, Traffic Interactions, and Stability. *Transportation Research Record: Journal of the Transportation Research Board*, 2019, p. 36119811984588. https://doi.org/10.1177/0361198119845885.
71. Edie, L. C. Discussion on Traffic Stream Measurements and Definitions. 1963.
72. Petty, K. F., H. Noeimi, K. Sanwal, D. Rydzewski, A. Skabardonis, P. Varaiya, and H. Al-deek. The Freeway Service Patrol Evaluation Project: Database Support Programs, and Accessibility. *Transportation Research Part C: Emerging Technologies*, Vol. 4, No. 2, 1996, pp. 71–85. https://doi.org/10.1016/0968-090X(96)00001-0.
73. Coifman, B., D. Lyddy, and A. Skabardonis. The Berkeley Highway Laboratory-Building on the I-880 Field Experiment.

74. Choe, T., A. Skabardonis, and P. Varaiya. Freeway Performance Measurement System: Operational Analysis Tool. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1811, No. 1, 2002, pp. 67–75. https://doi.org/10.3141/1811-08.
75. Treiterer, J., and J. Myers. The Hysteresis Phenomenon in Traffic Flow. *Transportation and traffic theory*, Vol. 6, 1974, pp. 13–38. https://doi.org/10.1021/ac1009707.
76. Treiterer, J. Investigation of Traffic Dynamics by Arial Photogrammetry Techniques. *Interim Report 2, EEB 278-2*, Vol. Ohio State, 1969.
77. Smith, S. A. Creation of Data Sets to Study Microscopic Traffic Flow in Freeway Bottleneck Sections. *Transportation Research Record*, Vol. 1005, 1985, pp. 121–128.
78. Alexiadis, V., J. Colyar, J. Halkias, R. Hranac, and G. McHale. The Next Generation Simulation Program. *Institute of Transportation Engineers, ITE Journal*, Vol. 74, No. 8, 2004.
79. Punzo, V., M. T. Borzacchiello, and B. Ciuffo. On the Assessment of Vehicle Trajectory Data Accuracy and Application to the Next Generation SIMulation (NGSIM) Program Data. *Transportation Research Part C: Emerging Technologies*, Vol. 19, No. 6, 2011, pp. 1243–1262. https://doi.org/10.1016/j.trc.2010.12.007.
80. Montanino, M., and V. Punzo. Trajectory Data Reconstruction and Simulation-Based Validation against Macroscopic Traffic Patterns. *Transportation Research Part B: Methodological*, Vol. 80, 2015, pp. 82–106. https://doi.org/10.1016/j.trb.2015.06.010.
81. Coifman, B., and L. Li. A Critical Evaluation of the Next Generation Simulation (NGSIM) Vehicle Trajectory Dataset. *Transportation Research Part B: Methodological*, Vol. 105, 2017, pp. 362–377. https://doi.org/10.1016/j.trb.2017.09.018.
82. Coifman, B., M. Wu, K. Redmill, and D. A. Thornton. Collecting Ambient Vehicle Trajectories from an Instrumented Probe Vehicle. *Transportation Research Part C: Emerging Technologies*, Vol. 72, 2016, pp. 254–271. https://doi.org/10.1016/j.trc.2016.09.001.
83. Herman, R., and R. B. Potts. Single Lane Traffic Theory and Experiment. 1959.
84. Dingus, T. A., S. G. Klauer, V. L. Neale, A. Petersen, S. E. Lee, J. Sudweeks, M. A. Perez, J. Hankey, D. Ramsey, S. Gupta, C. Bucher, Z. Doerzaph, J. Jermeland, and R. Knipling. *The 100-Car Naturalistic Driving Study. Phase 2: Results of the 100-Car Field Experiment*. 2006.
85. Brackstone, M., B. Waterson, and M. McDonald. Determinants of Following Headway in Congested Traffic. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 12, No. 2, 2009, pp. 131–142. https://doi.org/10.1016/j.trf.2008.09.003.
86. Banks, J. Two-Capacity Phenomenon at Freeway Bottlenecks: A Basis for Ramp Metering? *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1320, 1991, pp. 83–90.
87. Edie, L. C., and E. Baverez. Generation and Propagation of Stop-Start Traffic Waves. 1958.
88. Hall, F., and K. Agyemang-Duah. Freeway Capacity Drop and the Definition of Capacity. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1320, 1991, pp. 91–98.
89. Cassidy, M. J., and R. L. Bertini. Some Traffic Features at Freeway Bottlenecks. *Transportation Research Part B: Methodological*, Vol. 33, No. 1, 1999, pp. 25–42. https://doi.org/10.1016/S0191-2615(98)00023-X.
90. Bertini, R. L., and M. T. Leal. Empirical Study of Traffic Features at a Freeway Lane Drop. *Journal of Transportation Engineering*, Vol. 131, No. 6, 2004, pp. 397–407.

91. Sarvi, M., M. Kuwahara, and A. Ceder. Observing Freeway Ramp Merging Phenomena in Congested Traffic. *Journal of Advanced Transportation*, Vol. 41, No. 2, 2007, pp. 145–170. https://doi.org/10.1002/atr.5670410203.
92. Muñoz, J. C., and C. F. Daganzo. The Bottleneck Mechanism of a Freeway Diverge. *Transportation Research Part A: Policy and Practice*, Vol. 36, No. 6, 2002, pp. 483–505. https://doi.org/10.1016/S0965-8564(01)00017-9.
93. Yeon, J., S. Hernandez, and L. Elefteriadou. Differences in Freeway Capacity by Day of the Week, Time of Day, and Segment Type. *Journal of Transportation Engineering*, Vol. 135, No. 7, 2009, pp. 416–426. https://doi.org/10.1061/(ASCE)0733-947X(2009)135:7(416).
94. Lee, J. H., and M. J. Cassidy. *An Empirical and Theoretical Study of Freeway Weave Bottlenecks*. 2009.
95. Marczak, F., W. Daamen, and C. Buisson. Empirical Analysis of Lane Changing Behavior at a Freeway Weaving Section. 2014.
96. Ros, B. G., V. L. Knoop, B. van Arem, and S. P. Hoogendoorn. Mainstream Traffic Flow Control at Sags. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2470, No. 1, 2014, pp. 57–64. https://doi.org/10.3141/2470-06.
97. Patire, A. D., and M. J. Cassidy. Lane Changing Patterns of Bane and Benefit: Observations of an Uphill Expressway. *Transportation Research Part B: Methodological*, Vol. 45, No. 4, 2011, pp. 656–666. https://doi.org/10.1016/j.trb.2011.01.003.
98. Chen, D., S. Ahn, J. Laval, and Z. Zheng. On the Periodicity of Traffic Oscillations and Capacity Drop: The Role of Driver Characteristics. *Transportation Research Part B: Methodological*, Vol. 59, No. 1, 2014, pp. 117–136. https://doi.org/10.1016/j.trb.2013.11.005.
99. Knoop, V. L., S. P. Hoogendoorn, and H. J. van Zuylen. Capacity Reduction at Incidents: Empirical Data Collected from a Helicopter. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2071, No. 1, 2008, pp. 19–25. https://doi.org/10.3141/2071-03.
100. Knoop, V., S. Hoogendoorn, and K. Adams. Capacity Reductions at Incidents Sites on Motorways. *European Journal of Transport and Infrastructure Research*, Vol. 9, No. 9, 2009, pp. 363–379.
101. Oh, S., and H. Yeo. Impact of Stop-and-Go Waves and Lane Changes on Discharge Rate in Recovery Flow. *Transportation Research Part B: Methodological*, Vol. 77, 2015, pp. 88–102. https://doi.org/http://dx.doi.org/10.1016/j.trb.2015.03.017.
102. Goñi-Ros, B., V. L. Knoop, T. Takahashi, I. Sakata, B. van Arem, and S. P. Hoogendoorn. Optimization of Traffic Flow at Freeway Sags by Controlling the Acceleration of Vehicles Equipped with in-Car Systems. *Transportation Research Part C: Emerging Technologies*, Vol. 71, 2016, pp. 1–18. https://doi.org/10.1016/j.trc.2016.06.022.
103. Elefteriadou, L., R. P. Roess, and W. R. McShane. Probabilistic Nature of Breakdown at Freeway Merge Junctions. *Transportation Research Recordsearch record*, No. 1484, 2005, pp. 80–89.
104. Chung, K., and M. Cassidy. Test of Theory of Driver Behavior on Homogeneous Freeways. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1883, 2004, pp. 14–20. https://doi.org/10.3141/1883-02.
105. Cassidy, M. J., and J. Rudjanakanoknad. Increasing the Capacity of an Isolated Merge by Metering Its on-Ramp. *Transportation Research Part B: Methodological*, Vol. 39, No. 10, 2005, pp. 896–913. https://doi.org/10.1016/j.trb.2004.12.001.

106. Chung, K., J. Rudjanakanoknad, and M. J. Cassidy. Relation between Traffic Density and Capacity Drop at Three Freeway Bottlenecks. *Transportation Research Part B: Methodological*, Vol. 41, No. 1, 2007, pp. 82–95. https://doi.org/10.1016/j.trb.2006.02.011.
107. Coifman, B., and S. Kim. Extended Bottlenecks, the Fundamental Relationship, and Capacity Drop on Freeways. *Transportation Research Part A: Policy and Practice*, Vol. 45, No. 9, 2011, pp. 980–991. https://doi.org/10.1016/j.tra.2011.04.003.
108. Cassidy, M. J., and J. R. Windover. Driver Memory: Motorist Selection and Retention of Individualized Headways in Highway Traffic. *Transportation Research Part A: Policy and Practice*, Vol. 32, No. 2, 1998, pp. 129–137. https://doi.org/10.1016/S0965-8564(97)00027-X.
109. Kim, S., and B. Coifman. Driver Relaxation Impacts on Bottleneck Activation, Capacity, and the Fundamental Relationship. *Transportation Research Part C: Emerging Technologies*, Vol. 36, 2013, pp. 564–580. https://doi.org/10.1016/j.trc.2013.06.016.
110. Leclercq, L., N. Chiabaut, J. Laval, and C. Buisson. Relaxation Phenomenon after Lane Changing Experimental Validation with NGSIM Data Set. *Transportation Research Record*, No. 1999, 2007, pp. 79–85. https://doi.org/10.3141/1999-09.
111. Coifman, B., S. Krishnamurthy, and X. Wang. Lane-Change Maneuvers Consuming Freeway Capacity. In *Traffic and Granular Flow '03*, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 3–14.
112. Jin, W.-L. A Kinematic Wave Theory of Lane-Changing Traffic Flow. *Transportation Research Part B: Methodological*, Vol. 44, No. 8, 2010, pp. 1001–1021. https://doi.org/http://dx.doi.org/10.1016/j.trb.2009.12.014.
113. Ahn, S., and M. J. Cassidy. Freeway Traffic Oscillations and Vehicle Lane-Change Maneuvers. 2007.
114. Mauch, M., and M. J. Cassidy. Freeway Traffic Oscillations: Observations and Predictions. 2002.
115. Coifman, B. A., and Y. Wang. Average Velocity of Waves Propagating through Congested Freeway Traffic. *16th International Symposium on Transportation and Traffic Theory*, 2005, pp. 165–179.
116. Yun Wang, D. Foster, and B. Coifman. Measuring Wave Velocities on Highways during Congestion Using Cross Spectral Analysis.
117. Lu, X., and A. Skabardonis. Freeway Traffic Shockwave Analysis: Exploring NGSIM Trajectory Data. *Transportation Research Board 86th Annual Meeting*, No. January 2007, 2007, p. 19.
118. Author, M., M. Schönhof, D. Helbing, and M. Schonhof. Empirical Features of Congested Traffic States and Their Implications for Traffic Empirical Features of Congested Traffic States and Their Implications for Traffic Modeling. *Source: Transportation Science*, Vol. 41, No. 2, 2007, pp. 135–166. https://doi.org/10.1287/trsc.l070.0192.
119. Ahn, S., J. Laval, and M. J. Cassidy. *Effects of Merging and Diverging on Freeway Traffic Oscillations*. 2010.
120. Zheng, Z., S. Ahn, D. Chen, and J. Laval. Applications of Wavelet Transform for Analysis of Freeway Traffic: Bottlenecks, Transient Traffic, and Traffic Oscillations. *Transportation Research Part B: Methodological*, Vol. 45, No. 2, 2011. https://doi.org/10.1016/j.trb.2010.08.002.
121. Zheng, Z., S. Ahn, D. Chen, and J. Laval. Freeway Traffic Oscillations: Microscopic Analysis of Formations and Propagations Using Wavelet Transform. *Transportation*

Research Part B: Methodological, Vol. 45, No. 9, 2011, pp. 1378–1388. https://doi.org/10.1016/j.trb.2011.05.012.

122. Chao Wang, and B. Coifman. The Effect of Lane-Change Maneuvers on a Simplified Car-Following Theory. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 9, No. 3, 2008, pp. 523–535. https://doi.org/10.1109/TITS.2008.928265.
123. Xuan, Y., and B. Coifman. Identifying Lane-Change Maneuvers with Probe Vehicle Data and an Observed Asymmetry in Driver Accommodation. *Journal of Transportation Engineering*, Vol. 138, No. 8, 2012, pp. 1051–1061. https://doi.org/10.1061/(ASCE)TE.1943-5436.0000401.
124. Laval, J. A., and L. Leclercq. A Mechanism to Describe the Formation and Propagation of Stop-and-Go Waves in Congested Freeway Traffic. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences*, Vol. 368, No. 1928, 2010, pp. 4519–4541. https://doi.org/10.1098/rsta.2010.0138.
125. Sugiyamal, Y., M. Fukui, M. Kikuchi, K. Hasebe, A. Nakayama, K. Nishinari, S. I. Tadaki, and S. Yukawa. Traffic Jams without Bottlenecks-Experimental Evidence for the Physical Mechanism of the Formation of a Jam. *New Journal of Physics*, Vol. 10, 2008. https://doi.org/10.1088/1367-2630/10/3/033001.
126. Ward, J. a., and R. E. Wilson. Criteria for Convective versus Absolute String Instability in Car-Following Models. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, Vol. 467, No. 2132, 2011, pp. 2185–2208. https://doi.org/10.1098/rspa.2010.0437.
127. Treiber, M., A. Kesting, and D. Helbing. Influence of Reaction Times and Anticipation on Stability of Vehicular Traffic Flow. *Transportation Research Record*, Vol. 1999, No. 1, 2007, pp. 23–29. https://doi.org/10.3141/1999-03.
128. Wilson, R. E., and J. A. Ward. Car-Following Models: Fifty Years of Linear Stability Analysis - a Mathematical Perspective. *Transportation Planning and Technology*, Vol. 34, No. 1, 2011, pp. 3–18. https://doi.org/10.1017/CBO9781107415324.004.
129. Wilson, R. E. Mechanisms for Spatio-Temporal Pattern Formation in Highway Traffic Models. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, Vol. 366, No. 1872, 2008, pp. 2017–2032. https://doi.org/10.1098/rsta.2008.0018.
130. Castillo, J. M. de. Propagation of Perturbations in Dense Traffic Flow: A Model and Its Implications. *Transportation Research Part B: Methodological*, Vol. 35, No. 4, 2001, pp. 367–389. https://doi.org/10.1016/S0191-2615(99)00055-7.
131. Kim, T., and H. M. Zhang. A Stochastic Wave Propagation Model. *Transportation Research Part B: Methodological*, Vol. 42, No. 7–8, 2008, pp. 619–634. https://doi.org/10.1016/j.trb.2007.12.002.
132. Orosz, G., R. Eddie Wilson, and G. Stefan. Traffic Jams: Dynamics and Control. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 1928. Volume 368, 4455–4479.
133. Yeo, H., and A. Skabardonis. Understanding Stop-and-Go Traffic in View of Asymmetric Traffic Theory. In *Transportation and Traffic Theory 2009: Golden Jubilee*, pp. 99–115.
134. Chen, D., J. Laval, Z. Zheng, and S. Ahn. A Behavioral Car-Following Model That Captures Traffic Oscillations. *Transportation Research Part B: Methodological*, Vol. 46, No. 6, 2012. https://doi.org/10.1016/j.trb.2012.01.009.
135. Helbing, D., and P. Molnár. Social Force Model for Pedestrian Dynamics. *Physical Review*

E, Vol. 51, No. 5, 1995, pp. 4282–4286. https://doi.org/10.1103/PhysRevE.51.4282.

136. AlGadhi, Saad AH and Mahmassani, H. Simulation of Crowd Behavior and Movement Fundamental Relations and Application.pdf. *Transportation Research Record*, Vol. 1320, 1991, pp. 260--268.
137. Hoogendoorn, S., and P. H. L. Bovy. Gas-Kinetic Modeling and Simulation of Pedestrian Flows. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1710, No. 1, 2007, pp. 28–36. https://doi.org/10.3141/1710-04.
138. Abdelghany, A., K. Abdelghany, H. Mahmassani, and S. Al-Gadhi. Microsimulation Assignment Model for Multidirectional Pedestrian Movement in Congested Facilities. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1939, 2007, pp. 123–132. https://doi.org/10.3141/1939-15.
139. Abdelghany, A., K. Abdelghany, and H. Mahmassani. A Hybrid Simulation-Assignment Modeling Framework for Crowd Dynamics in Large-Scale Pedestrian Facilities. *Transportation Research Part A: Policy and Practice*, Vol. 86, 2016, pp. 159–176. https://doi.org/10.1016/j.tra.2016.02.011.
140. Abdelghany, A., K. Abdelghany, H. Mahmassani, and W. Alhalabi. Modeling Framework for Optimal Evacuation of Large-Scale Crowded Pedestrian Facilities. *European Journal of Operational Research*, Vol. 237, No. 3, 2014, pp. 1105–1118. https://doi.org/10.1016/j.ejor.2014.02.054.
141. Hoogendoorn, S. P., and W. Daamen. Pedestrian Behavior at Bottlenecks. *Transportation Science*, Vol. 39, No. 2, 2005, pp. 147–159. https://doi.org/10.1287/trsc.1040.0102.
142. Daamen, W., and S. P. Hoogendoorn. Experimental Research of Pedestrian Walking Behavior. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1828, No. 1, 2007, pp. 20–30. https://doi.org/10.3141/1828-03.
143. Seyfried, A., B. Steffen, W. Klingsch, and M. Boltes. The Fundamental Diagram of Pedestrian Movement Revisited. *Journal of Statistical Mechanics: Theory and Experiment*, No. 10, 2005, pp. 41–53. https://doi.org/10.1088/1742-5468/2005/10/P10002.
144. Shiwakoti, N., M. Sarvi, G. Rose, and M. Burd. Animal Dynamics Based Approach for Modeling Pedestrian Crowd Egress under Panic Conditions. *Transportation Research Part B: Methodological*, Vol. 45 `, No. 9, 2011, pp. 1433–1449. https://doi.org/10.1016/j.trb.2011.05.016.
145. Taylor, D., and W. Jeffrey Davis. Review of Basic Research in Bicycle Traffic Science, Traffic Operations, and Facility Design. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1674, No. 1, 2007, pp. 102–110. https://doi.org/10.3141/1674-14.
146. Hoogendoorn, S., and W. Daamen. Bicycle Headway Modeling and Its Applications. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2587, No. 1, 2017, pp. 34–40. https://doi.org/10.3141/2587-05.
147. Gazis, D. C. *Traffic Science*. Wiley, New York, NY, USA, 1974.
148. Payne, H. Models of Freeway Traffic and Control. 1971.
149. Papageorgiou, M., J. M. Blosseville, and H. Hadj-Salem. Macroscopic Modelling of Traffic Flow on the Boulevard Périphérique in Paris. *Transportation Research Part B*, Vol. 23, No. 1, 1989, pp. 29–47. https://doi.org/10.1016/0191-2615(89)90021-0.
150. Papageorgiou, M., H. Hadj-salem, and J. Blosseville. *ALINEA: A Local Feedback Control Law for On-Ramp Metering*. 1991.
151. Papageorgiou, M., J. M. Blosseville, and H. Hadj-Salem. Modelling and Real-Time Control

of Traffic Flow on the Southern Part of Boulevard Peripherique in Paris: Part I: Modelling. *Transportation Research Part A: General*, Vol. 24, No. 5, 1990, pp. 345–359. https://doi.org/10.1016/0191-2607(90)90047-A.
152. Papageorgiou, M., J.-M. Blosseville, and H. Haj-Salem. Modelling and Real-Time Control of Traffic Flow on the Southern Part of Boulevard Peripherique in Paris: Part II: Coordinated on-Ramp Metering. *Transportation Research Part A: General*, Vol. 24, No. 5, 2002, pp. 361–370. https://doi.org/10.1016/0191-2607(90)90048-b.
153. Kühne, R. Freeway Speed Distribution and Acceleration Noise. 1987.
154. Hegyi, A., S. P. Hoogendoorn, M. Schreuder, H. Stoelhorst, and F. Viti. SPECIALIST: A Dynamic Speed Limit Control Algorithm Based on Shock Wave Theory. 2008.
155. Carlson, R. C., I. Papamichail, M. Papageorgiou, and A. Messmer. Optimal Motorway Traffic Flow Control Involving Variable Speed Limits and Ramp Metering. *Transportation Science*, Vol. 44, No. 2, 2010, pp. 238–253.
156. Carlson, R. C., I. Papamichail, M. Papageorgiou, and A. Messmer. Optimal Mainstream Traffic Flow Control of Large-Scale Motorway Networks. *Transportation Research Part C: Emerging Technologies*, Vol. 18, No. 2, 2010, pp. 193–212. https://doi.org/10.1016/j.trc.2009.05.014.
157. Letter, C., and L. Elefteriadou. Efficient Control of Fully Automated Connected Vehicles at Freeway Merge Segments. *Transportation Research Part C: Emerging Technologies*, Vol. 80, 2017, pp. 190–205. https://doi.org/http://dx.doi.org/10.1016/j.trc.2017.04.015.
158. Han, Y., and S. Ahn. Stochastic Modeling of Breakdown at Freeway Merge Bottleneck and Traffic Control Method Using Connected Automated Vehicle. *Transportation Research Part B: Methodological*, Vol. 107, 2018. https://doi.org/10.1016/j.trb.2017.11.007.
159. Han, Y., D. Chen, and S. Ahn. Variable Speed Limit Control at Fixed Freeway Bottlenecks Using Connected Vehicles. *Transportation Research Part B*, Vol. 98, 2017, pp. 113–134.
160. Ben-akiva, M., M. Bierlaire, H. Koutsopoulos, and R. Mishalani. DynaMIT: A Simulation-Based System for Traffic Prediction. *DACCORD Short Term Forecasting Workshop*, 1998, pp. 1–12.
161. Mahmassani, H. S., and K. F. Abdelghany. Dynasmart-IP: Dynamic Traffic Assignment Meso-Simulator for Intermodal Networks. In *Advanced Modeling for Transit Operations and Service Planning*, pp. 200–229.
162. Hamdar, S. H., H. S. Mahmassani, and M. Treiber. From Behavioral Psychology to Acceleration Modeling: Calibration, Validation, and Exploration of Drivers' Cognitive and Safety Parameters in a Risk-Taking Environment. *Transportation Research Part B: Methodological*, Vol. 78, 2015, pp. 32–53. https://doi.org/10.1016/j.trb.2015.03.011.
163. van Lint, J. W. C., and S. C. Calvert. A Generic Multi-Level Framework for Microscopic Traffic simulation—Theory and an Example Case in Modelling Driver Distraction. *Transportation Research Part B: Methodological*, Vol. 117, 2018, pp. 63–86. https://doi.org/10.1016/j.trb.2018.08.009.
164. Treiber, M., A. Kesting, and D. Helbing. Delays, Inaccuracies and Anticipation in Microscopic Traffic Models. *Physica A: Statistical Mechanics and its Applications*, Vol. 360, No. 1, 2006, pp. 71–88. https://doi.org/10.1016/j.physa.2005.05.001.
165. Davis, L. C. Modifications of the Optimal Velocity Traffic Model to Include Delay due to Driver Reaction Time. *Physica A: Statistical Mechanics and its Applications*, Vol. 319, 2003, pp. 557–567. https://doi.org/10.1016/S0378-4371(02)01457-7.
166. Castro, C., C. Martínez, F. J. Tornay, P. G. Fernández, and F. J. Martos. Vehicle Distance

Estimations in Nighttime Driving: A Real-Setting Study. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 8, No. 1, 2005, pp. 31–45. https://doi.org/10.1016/j.trf.2004.12.001.

167. Thiffault, P., and J. Bergeron. Monotony of Road Environment and Driver Fatigue: A Simulator Study. *Accident Analysis & Prevention*, Vol. 35, No. 3, 2003, pp. 381–391. https://doi.org/10.1016/S0001-4575(02)00014-3.
168. Nilsson, R. Drivers' Impressions of Front and Rear Gaps in Queues. *Ergonomics*, Vol. 43, No. 12, 2000, pp. 1985–2000. https://doi.org/10.1080/00140130050201436.
169. Hamdar, S. H., and H. S. Mahmassani. From Existing Accident-Free Car-Following Models to Colliding Vehicles. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2088, No. 1, 2008, pp. 45–56. https://doi.org/10.3141/2088-06.
170. van Lint, H., S. Calvert, W. Schakel, M. Wang, and A. Verbraeck. Exploring the Effects of Perception Errors and Anticipation Strategies on Traffic Accidents - A Simulation Study, pp. 249–261.
171. Wiedemann, R. Simulation Des Strassenverkehrsflusses. *Traffic Engineering*, 1974.
172. Fritzsche, H.-T. A Model for Traffic Simulation. *Traffic Engineering and Control*, Vol. 35, No. 5, 1994, pp. 317–321.
173. Ossen, S., and S. P. Hoogendoorn. Heterogeneity in Car-Following Behavior: Theory and Empirics. *Transportation Research Part C: Emerging Technologies*, Vol. 19, No. 2, 2011, pp. 182–195. https://doi.org/10.1016/j.trc.2010.05.006.
174. Hoogendoorn, S., S. Ossen, and M. Schreuder. Empirics of Multianticipative Car-Following Behavior. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 1965, 2006, pp. 112–120. https://doi.org/10.3141/1965-12.
175. Precht, L., A. Keinath, and J. F. Krems. Identifying Effects of Driving and Secondary Task Demands, Passenger Presence, and Driver Characteristics on Driving Errors and Traffic Violations – Using Naturalistic Driving Data Segments Preceding Both Safety Critical Events and Matched Baselines. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 51, 2017, pp. 103–144. https://doi.org/10.1016/j.trf.2017.09.003.
176. Precht, L., A. Keinath, and J. F. Krems. Identifying the Main Factors Contributing to Driving Errors and Traffic Violations – Results from Naturalistic Driving Data. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 49, 2017, pp. 49–92. https://doi.org/10.1016/j.trf.2017.06.002.
177. Grier, R., C. Wickens, D. Kaber, D. Strayer, D. Boehm-Davis, J. G. Trafton, and M. St. John. The Red-Line of Workload: Theory, Research, and Design. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 52, No. 18, 2008, pp. 1204–1208. https://doi.org/10.1177/154193120805201811.
178. Hansen, J. H. L., C. Busso, Y. Zheng, and A. Sathyanarayana. Driver Modeling for Detection and Assessment of Driver Distraction: Examples from the UTDrive Test Bed. *IEEE Signal Processing Magazine*, Vol. 34, No. 4, 2017, pp. 130–142. https://doi.org/10.1109/MSP.2017.2699039.
179. Saifuzzaman, M., Z. Zheng, M. Mazharul Haque, and S. Washington. Revisiting the Task-Capability Interface Model for Incorporating Human Factors into Car-Following Models. *Transportation Research Part B: Methodological*, Vol. 82, No. SEPTEMBER, 2015, pp. 1–19. https://doi.org/10.1016/j.trb.2015.09.011.
180. Chan, M., and A. Singhal. Emotion Matters: Implications for Distracted Driving. *Safety Science*, Vol. 72, 2015, pp. 302–309. https://doi.org/10.1016/j.ssci.2014.10.002.

181. Schömig, N., and B. Metz. Three Levels of Situation Awareness in Driving with Secondary Tasks. *Safety Science*, Vol. 56, 2013, pp. 44–51. https://doi.org/10.1016/j.ssci.2012.05.029.
182. Kaber, D. B., Y. Liang, Y. Zhang, M. L. Rogers, and S. Gangakhedkar. Driver Performance Effects of Simultaneous Visual and Cognitive Distraction and Adaptation Behavior. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 15, No. 5, 2012, pp. 491–501. https://doi.org/10.1016/j.trf.2012.05.004.
183. Hoogendoorn, R. G., S. P. Hoogendoorn, K. A. Brookhuis, and W. Daamen. Adaptation Longitudinal Driving Behavior, Mental Workload, and Psycho-Spacing Models in Fog. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2249, No. 1, 2011, pp. 20–28. https://doi.org/10.3141/2249-04.
184. Hoogendoorn, R., S. P. Hoogendoorn, K. Brookhuis, and W. Daamen. Mental Workload, Longitudinal Driving Behavior, and Adequacy of Car-Following Models for Incidents in Other Driving Lane. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2188, No. 1, 2010, pp. 64–73. https://doi.org/10.3141/2188-08.
185. Zheng, Z., S. Ahn, D. Chen, and J. Laval. The Effects of Lane-Changing on the Immediate Follower: Anticipation, Relaxation, and Change in Driver Characteristics. *Transportation Research Part C Emerging Technologies*, Vol. 26, 2013, pp. 367–379. https://doi.org/10.1016/j.trc.2012.10.007.
186. Michaels, J., R. Chaumillon, D. Nguyen-Tri, D. Watanabe, P. Hirsch, F. Bellavance, G. Giraudet, D. Bernardin, and J. Faubert. Driving Simulator Scenarios and Measures to Faithfully Evaluate Risky Driving Behavior: A Comparative Study of Different Driver Age Groups. *PLOS ONE*, Vol. 12, No. 10, 2017, p. e0185909. https://doi.org/10.1371/journal.pone.0185909.
187. Jamson, S., K. Chorlton, and O. Carsten. Could Intelligent Speed Adaptation Make Overtaking Unsafe? *Accident Analysis & Prevention*, Vol. 48, 2012, pp. 29–36. https://doi.org/10.1016/j.aap.2010.11.011.
188. Farah, H., E. Yechiam, S. Bekhor, T. Toledo, and A. Polus. Association of Risk Proneness in Overtaking Maneuvers with Impaired Decision Making. *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 11, No. 5, 2008, pp. 313–323. https://doi.org/10.1016/j.trf.2008.01.005.
189. Hamdar, S. H., M. Treiber, H. S. Mahmassani, and A. Kesting. Modeling Driver Behavior as Sequential Risk-Taking Task. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2088, No. 1, 2008, pp. 208–217. https://doi.org/10.3141/2088-22.
190. Smeed, R. J., and J. G. Wardrop. An Exploratory Comparison of the Advantages of Cars and Buses for Travel in Urban Areas. *Journal of the Institute of Transport*, Vol. 30, No. 9, 1964, pp. 301–315.
191. Smeed, R. J. The Road Capacity of City Centers. *Traffic Engineering & Control*, Vol. 9, No. 7, 1967, pp. 455–458.
192. Wardrop, J. G. Journey Speed and Flow in Central Urban Areas. *Traffic Engineering & Control*, Vol. 9, 1968, pp. 528–532, 539.
193. Zahavi, Y. Traffic Performance Evaluation of Road Networks by the α-Relationship. *Traffic Engineering & Control*, Vol. 14, No. 5–6, 1972, pp. 228-231-293.
194. Godfrey, J. W. The Mechanism of a Road Network. *Traffic Engineering & Control*, Vol. 11, No. 7, 1969, pp. 323–327.
195. Williams, J. C., H. S. Mahmassani, and R. Herman. Analysis of Traffic Network Flow

Relations and Two-Fluid Model Parameter Sensitivity. *Transportation Research Record*, Vol. 1005, 1985, pp. 95–106.
196. Ardekani, S., and R. Herman. Urban Network-Wide Traffic Variables and Their Relations. *Transportation Science*, Vol. 21, No. 1, 1987, pp. 1–16.
197. Mahmassani, H., J. Williams, and R. Herman. Performance of Urban Traffic Networks. 1987.
198. Geroliminis, N., and C. F. Daganzo. Macroscopic Modeling of Traffic in Cities. 2007.
199. Geroliminis, N., and C. F. Daganzo. Existence of Urban-Scale Macroscopic Fundamental Diagrams: Some Experimental Findings. *Transportation Research Part B: Methodological*, Vol. 42, No. 9, 2008, pp. 759–770. https://doi.org/10.1016/j.trb.2008.02.002.
200. Buisson, C., and C. Ladier. Exploring the Impact of Homogeneity of Traffic Measurements on the Existence of Macroscopic Fundamental Diagrams. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2124, 2009, pp. 127–136. https://doi.org/10.3141/2124-12.
201. Daganzo, C. F., and N. Geroliminis. An Analytical Approximation for the Macroscopic Fundamental Diagram of Urban Traffic. *Transportation Research Part B: Methodological*, Vol. 42, No. 9, 2008, pp. 771–781. https://doi.org/10.1016/j.trb.2008.06.008.
202. Leclercq, L., and N. Geroliminis. Estimating MFDs in Simple Networks with Route Choice. *Transportation Research Part B: Methodological*, Vol. 57, 2013, pp. 468–484. https://doi.org/10.1016/j.trb.2013.05.005.
203. Daganzo, C. F. Urban Gridlock: Macroscopic Modeling and Mitigation Approaches. *Transportation Research Part B: Methodological*, Vol. 41, No. 1, 2007, pp. 49–62. https://doi.org/10.1016/j.trb.2006.03.001.
204. Haddad, J., and N. Geroliminis. On the Stability of Traffic Perimeter Control in Two-Region Urban Cities. *Transportation Research Part B: Methodological*, Vol. 46, No. 9, 2012, pp. 1159–1176. https://doi.org/10.1016/j.trb.2012.04.004.
205. Haddad, J., M. Ramezani, and N. Geroliminis. Cooperative Traffic Control of a Mixed Network with Two Urban Regions and a Freeway. *Transportation Research Part B: Methodological*, Vol. 54, 2013, pp. 17–36. https://doi.org/10.1016/j.trb.2013.03.007.
206. Keyvan-Ekbatani, M., A. Kouvelas, I. Papamichail, and M. Papageorgiou. Exploiting the Fundamental Diagram of Urban Networks for Feedback-Based Gating. *Transportation Research Part B: Methodological*, Vol. 46, No. 10, 2012, pp. 1393–1403. https://doi.org/10.1016/j.trb.2012.06.008.
207. Keyvan-Ekbatani, M., M. Papageorgiou, and I. Papamichail. Perimeter Traffic Control via Remote Feedback Gating. *Procedia - Social and Behavioral Sciences*, Vol. 111, 2014, pp. 645–653. https://doi.org/10.1016/j.sbspro.2014.01.098.
208. Keyvan-Ekbatani, M., M. Yildirimoglu, N. Geroliminis, and M. Papageorgiou. Traffic Signal Perimeter Control with Multiple Boundaries for Large Urban Networks. 2013.
209. Ramezani, M., J. Haddad, and N. Geroliminis. Dynamics of Heterogeneity in Urban Networks: Aggregated Traffic Modeling and Hierarchical Control. *Transportation Research Part B: Methodological*, Vol. 74, 2015, pp. 1–19. https://doi.org/10.1016/j.trb.2014.12.010.
210. Geroliminis, N., J. Haddad, and M. Ramezani. Optimal Perimeter Control for Two Urban Regions with Macroscopic Fundamental Diagrams: A Model Predictive Approach. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 14, No. 1, 2013, pp. 348–359. https://doi.org/10.1109/TITS.2012.2216877.

211. Haddad, J. Optimal Perimeter Control Synthesis for Two Urban Regions with Aggregate Boundary Queue Dynamics. *Transportation Research Part B: Methodological*, Vol. 96, 2017, pp. 1–25. https://doi.org/10.1016/J.TRB.2016.10.016.
212. Aalipour, A., H. Kebriaei, and M. Ramezani. Analytical Optimal Solution of Perimeter Traffic Flow Control Based on MFD Dynamics: A Pontryagin's Maximum Principle Approach. *IEEE Transactions on Intelligent Transportation Systems*, , 2018. https://doi.org/10.1109/TITS.2018.2873104.
213. Csikós, A., T. Charalambous, H. Farhadi, B. Kulcsár, and H. Wymeersch. Network Traffic Flow Optimization under Performance Constraints. *Transportation Research Part C: Emerging Technologies*, Vol. 83, 2017, pp. 120–133. https://doi.org/10.1016/J.TRC.2017.08.002.
214. Keyvan-Ekbatani, M., M. Papageorgiou, and V. L. Knoop. Controller Design for Gating Traffic Control in Presence of Time-Delay in Urban Road Networks. *Transportation Research Procedia*, Vol. 7, 2015, pp. 651–668. https://doi.org/10.1016/J.TRPRO.2015.06.034.
215. Haddad, J., and Z. Zheng. Adaptive Perimeter Control for Multi-Region Accumulation-Based Models with State Delays. *Transportation Research Part B: Methodological*, 2018. https://doi.org/10.1016/J.TRB.2018.05.019.
216. Kouvelas, A., M. Saeedmanesh, and N. Geroliminis. Enhancing Model-Based Feedback Perimeter Control with Data-Driven Online Adaptive Optimization. *Transportation Research Part B: Methodological*, Vol. 96, 2017, pp. 26–45. https://doi.org/10.1016/J.TRB.2016.10.011.
217. Geroliminis, N., and D. M. Levinson. Cordon Pricing Consistent with the Physics of Overcrowding. In *Transportation and Traffic Theory 2009: Golden Jubilee*, Springer, pp. 219–240.
218. Gonzales, E. J., and C. F. Daganzo. Morning Commute with Competing Modes and Distributed Demand: User Equilibrium, System Optimum, and Pricing. *Transportation Research Part B: Methodological*, Vol. 46, No. 10, 2012, pp. 1519–1534. https://doi.org/10.1016/j.trb.2012.07.009.
219. Simoni, M. D., A. J. Pel, R. A. Waraich, and S. P. Hoogendoorn. Marginal Cost Congestion Pricing Based on the Network Fundamental Diagram. *Transportation Research Part C: Emerging Technologies*, Vol. 56, 2015, pp. 221–238. https://doi.org/10.1016/j.trc.2015.03.034.
220. Zheng, N., R. A. Waraich, K. W. Axhausen, and N. Geroliminis. A Dynamic Cordon Pricing Scheme Combining the Macroscopic Fundamental Diagram and an Agent-Based Traffic Model. *Transportation Research Part A: Policy and Practice*, Vol. 46, No. 8, 2012, pp. 1291–1303.
221. Daganzo, C. F., V. V. Gayah, and E. J. Gonzales. The Potential of Parsimonious Models for Understanding Large Scale Transportation Systems and Answering Big Picture Questions. *EURO Journal on Transportation and Logistics*, Vol. 1, No. 1–2, 2012, pp. 47–65. https://doi.org/10.1007/s13676-012-0003-z.
222. Zheng, N., and N. Geroliminis. On the Distribution of Urban Road Space for Multimodal Congested Networks. *Transportation Research Part B: Methodological*, Vol. 57, 2013, pp. 326–341. https://doi.org/10.1016/j.trb.2013.06.003.
223. Gayah, V., and C. Daganzo. Analytical Capacity Comparison of One-Way and Two-Way Signalized Street Networks. *Transportation Research Record: Journal of the*

Transportation Research Board, Vol. 2301, No. 2301, 2012, pp. 76–85. https://doi.org/10.3141/2301-09.

224. Ortigosa, J., V. V. Gayah, and M. Menendez. Analysis of One-Way and Two-Way Street Configurations on Urban Grid Networks. *Transportmetrica B*, 2017, pp. 1–21. https://doi.org/10.1080/21680566.2017.1337528.
225. Ortigosa, J., M. Menendez, and V. V. Gayah. Analysis of Network Exit Functions for Various Urban Grid Network Configurations. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2491, No. 2491, 2015, pp. 12–21. https://doi.org/10.3141/2491-02.
226. DePrator, A., O. Hitchcock, and V. V. Gayah. Improving Urban Street Network Efficiency by Prohibiting Left Turns at Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, No. in press, 2017.
227. Mazloumian, A., N. Geroliminis, and D. Helbing. The Spatial Variability of Vehicle Densities as Determinant of Urban Network Capacity. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, Vol. 368, No. 1928, 2010, pp. 4627–4647. https://doi.org/10.1098/rsta.2010.0099.
228. Gayah, V. V., and C. F. Daganzo. Effects of Turning Maneuvers and Route Choice on a Simple Network. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2249, No. 1, 2011, pp. 15–19. https://doi.org/10.3141/2249-03.
229. Daganzo, C. F., V. V. Gayah, and E. J. Gonzales. Macroscopic Relations of Urban Traffic Variables: Bifurcations, Multivaluedness and Instability. *Transportation Research Part B: Methodological*, Vol. 45, No. 1, 2011, pp. 278–288. https://doi.org/10.1016/j.trb.2010.06.006.
230. Gayah, V. V., and C. F. Daganzo. Clockwise Hysteresis Loops in the Macroscopic Fundamental Diagram: An Effect of Network Instability. *Transportation Research Part B: Methodological*, Vol. 45, No. 4, 2011, pp. 643–655.
231. Geroliminis, N., and J. Sun. Hysteresis Phenomena of a Macroscopic Fundamental Diagram in Freeway Networks. *Transportation Research Part A: Policy and Practice*, Vol. 45, No. 9, 2011, pp. 966–979. https://doi.org/10.1016/j.tra.2011.04.004.
232. Saberi, M., and H. Mahmassani. Hysteresis and Capacity Drop Phenomena in Freeway Networks: Empirical Characterization and Interpretation. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2391, No. 2391, 2013, pp. 44–55. https://doi.org/10.3141/2391-05.
233. Geroliminis, N., and J. Sun. Properties of a Well-Defined Macroscopic Fundamental Diagram for Urban Traffic. *Transportation Research Part B: Methodological*, Vol. 45, No. 3, 2011, pp. 605–617. https://doi.org/10.1016/j.trb.2010.11.004.
234. Gayah, V. V., X. Gao, and A. S. Nagle. On the Impacts of Locally Adaptive Signal Control on Urban Network Stability and the Macroscopic Fundamental Diagram. *Transportation Research Part B: Methodological*, Vol. 70, 2014, pp. 255–268. https://doi.org/10.1016/j.trb.2014.09.010.
235. Saberi, M., A. Zockaie, and H. Mahmassani. Network Capacity, Traffic Instability, and Adaptive Driving: Findings from Simulated Network Experiments. *EURO Journal on Transportation and Logistics*, Vol. 3, No. 3–4, 2014, pp. 289–308.
236. Mahmassani, H. S., M. Saberi, and A. Zockaie. Urban Network Gridlock: Theory, Characteristics, and Dynamics. *Transportation Research Part C: Emerging Technologies*, Vol. 36, 2013, pp. 480–497.

237. Mühlich, N., V. V Gayah, and M. Menendez. Use of Microsimulation for Examination of Macroscopic Fundamental Diagram Hysteresis Patterns for Hierarchical Urban Street Networks. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2491, No. 117–126, 2015.
238. Ambühl, L., A. Loder, M. C. J. Bliemer, M. Menendez, and K. W. Axhausen. Introducing a Re-Sampling Methodology for the Estimation of Empirical Macroscopic Fundamental Diagrams. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2672, No. 20, 2018, pp. 239–248. https://doi.org/10.1177/0361198118788181.
239. Mariotte, G., L. Leclercq, and J. A. Laval. Macroscopic Urban Dynamics: Analytical and Numerical Comparisons of Existing Models. *Transportation Research Part B: Methodological*, Vol. 101, 2017, pp. 245–267. https://doi.org/10.1016/j.trb.2017.04.002.
240. Knoop, V. L., P. B. C. Van Erp, L. Leclercq, and S. P. Hoogendoorn. Empirical MFDs Using Google Traffic Data. No. 2018–November, 2018, pp. 3832–3839.
241. Smeed, R. J. The Road Space Required for Traffic in Towns. *Town Planning Review*, Vol. 33, No. 4, 1963, p. 279. https://doi.org/10.3828/tpr.33.4.w4146r7656234837.
242. Sharp, C. The Choice between Cars and Buses on Urban Roads. *Journal of Transport Economics and Policy*, 1967, pp. 104--111.
243. Smeed, R. J. Traffic Studies and Urban Congestion. *Journal of Transport Economics and policy1*, 1968, pp. 33–70.
244. Owen, W. *Automobiles and Cities-Strategies for Developing Countries*. The World Bank, 1973.
245. Mogridge, M. J. H., D. Holden, J. Bird, and G. Terzis. The Downs/Thomson Paradox and the Transportation Planning Process. *International Journal of Transport Economics/Rivista internazionale di economia dei trasporti*, 1987, pp. 283--311.
246. Mogridge, M. J. The Self-Defeating Nature of Urban Road Capacity Policy. *Transport Policy*, Vol. 4, No. 1, 1997, pp. 5–23. https://doi.org/10.1016/S0967-070X(96)00030-3.
247. Daganzo, C. F., and V. L. Knoop. Traffic Flow on Pedestrianized Streets. *Transportation Research Part B: Methodological*, Vol. 86, 2016, pp. 211–222. https://doi.org/10.1016/j.trb.2015.12.017.
248. Geroliminis, N., N. Zheng, and K. Ampountolas. A Three-Dimensional Macroscopic Fundamental Diagram for Mixed Bi-Modal Urban Networks. *Transportation Research Part C: Emerging Technologies*, Vol. 42, 2014, pp. 168–181. https://doi.org/10.1016/j.trc.2014.03.004.
249. Loder, A., L. Ambühl, M. Menendez, and K. W. Axhausen. Empirics of Multi-Modal Traffic Networks – Using the 3D Macroscopic Fundamental Diagram. *Transportation Research Part C: Emerging Technologies*, Vol. 82, 2017, pp. 88–101. https://doi.org/10.1016/j.trc.2017.06.009.
250. Chiabaut, N., X. Xie, and L. Leclercq. Performance Analysis for Different Designs of a Multimodal Urban Arterial. *Transportmetrica B: Transport Dynamics*, Vol. 2, No. 3, 2014, pp. 229–245. https://doi.org/10.1080/21680566.2014.939245.
251. Chiabaut, N. Evaluation of a Multimodal Urban Arterial: The Passenger Macroscopic Fundamental Diagram. *Transportation Research Part B: Methodological*, Vol. 81, 2015, pp. 410–420. https://doi.org/10.1016/j.trb.2015.02.005.
252. Dakic, I., and M. Menendez. On the Use of Lagrangian Observations from Public Transport and Probe Vehicles to Estimate Car Space-Mean Speeds in Bi-Modal Urban Networks. *Transportation Research Part C: Emerging Technologies*, Vol. 91, 2018, pp. 317–334.

https://doi.org/10.1016/j.trc.2018.04.004.
253. Castrillon, F., and J. Laval. Impact of Buses on the Macroscopic Fundamental Diagram of Homogeneous Arterial Corridors. *Transportmetrica B: Transport Dynamics*, Vol. 6, No. 4, 2018, pp. 286–301. https://doi.org/10.1080/21680566.2017.1314203.
254. Lebacque, J.-P., and M. M. Khoshyaran. Multimodal Transportation Network Modeling Based on the Generic Second Order Modeling Approach. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2672, No. 48, 2018, pp. 93–103. https://doi.org/10.1177/0361198118797486.
255. Schrank, D., B. Eisele, and T. Lomax. *2012 Urban Mobility Report*. 2012.
256. Monteil, J. *Investigating the Effects of Cooperative Vehicles on Highway Traffic Flow Homogenization: Analytical and Simulation Studies*. Lyon, France, 2014.
257. Talebpour, A., H. S. Mahmassani, and F. E. Bustamante. Modeling Driver Behavior in a Connected Environment: Integrated Microscopic Simulation of Traffic and Mobile Wireless Telecommunication Systems. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2560, No. 1, 2016, pp. 75–86. https://doi.org/10.3141/2560-09.
258. Varotto, S. F., R. G. Hoogendoorn, B. van Arem, and S. P. Hoogendoorn. Empirical Longitudinal Driving Behavior in Authority Transitions Between Adaptive Cruise Control and Manual Driving. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2489, 2015, pp. 105–114. https://doi.org/10.3141/2489-12.
259. Talebpour, A., and H. S. Mahmassani. Modeling Acceleration Behavior in a Connected Environment. 2014.
260. Calvert, S., H. Mahmassani, J.-N. Meier, P. Varaiya, S. Hamdar, D. Chen, X. Li, A. Talebpour, and S. P. Mattingly. Traffic Flow of Connected and Automated Vehicles: Challenges and Opportunities, pp. 235–245.
261. Mahmassani, H. S. 50th Anniversary Invited Article—Autonomous Vehicles and Connected Vehicle Systems: Flow and Operations Considerations. *Transportation Science*, Vol. 50, No. 4, 2016, pp. 1140–1162. https://doi.org/10.1287/trsc.2016.0712.
262. Chen, D., S. Ahn, M. Chitturi, and D. A. Noyce. Towards Vehicle Automation: Roadway Capacity Formulation for Traffic Mixed with Regular and Automated Vehicles. *Transportation Research Part B: Methodological*, Vol. 100, 2017. https://doi.org/10.1016/j.trb.2017.01.017.
263. Ghiasi, A., O. Hussain, Z. (Sean) Qian, and X. Li. A Mixed Traffic Capacity Analysis and Lane Management Model for Connected Automated Vehicles: A Markov Chain Method. *Transportation Research Part B: Methodological*, Vol. 106, 2017, pp. 266–292. https://doi.org/10.1016/j.trb.2017.09.022.
264. Li, Y., L. Zhang, S. Peeta, X. He, T. Zheng, and Y. Li. A Car-Following Model Considering the Effect of Electronic Throttle Opening Angle under Connected Environment. *Nonlinear Dynamics*, Vol. 85, No. 4, 2016, pp. 2115–2125. https://doi.org/10.1007/s11071-016-2817-y.
265. Gong, S., A. Zhou, J. Wang, T. Li, and S. Peeta. Cooperative Adaptive Cruise Control for a Platoon of Connected and Autonomous Vehicles Considering Dynamic Information Flow Topology. (arXiv:1807.02224v2 [cs.SY] UPDATED). *arXiv preprint arXiv:1807.02224*, 2018.
266. Bichiou, Y., and H. A. Rakha. Developing an Optimal Intersection Control System for Automated Connected Vehicles. *IEEE Transactions on Intelligent Transportation Systems*,

2018. https://doi.org/10.1109/TITS.2018.2850335.
267. USDOT. Testing Connected Vehicle Technologies in a Real-World Environment. *Intelligent Transportation Systems - Connected Vehicle Test Bed*. https://www.its.dot.gov/research_archives/connected_vehicle/dot_cvbrochure.htm.
268. Intelligent Transportation Systems Joint Program Office. Explore Our Data Department of Transportation ITS JPO Data. *Intelligent Transportation Systems - Automation, U.S. Department of Transportation*.
269. Center for Intelligent Systems Research. GWU Driving Simulator. *George Washington University*.
270. Texas A&M Smart City Lab. Traffic Flow Theory Effects of Connectivity and Automation on Traffic Flow Dynamics.
271. Best, A., S. Narang, D. Barber, and D. Manocha. AutonoVi Autonomous Vehicles Planning with Dynamics Maneuvers and Traffic Constraints. *Gamma*.
272. The Ohio State University. Driving Simulation Laboratory. *DriveSim Ohio State University*.
273. University of Michigan M City. Mcity Driverless Shuttle.
274. Schorr, J., S. H. Hamdar, and C. Silverstein. Measuring the Safety Impact of Road Infrastructure Systems on Driver Behavior: Vehicle Instrumentation and Real World Driving Experiment. *Journal of Intelligent Transportation Systems*, Vol. 21, No. 5, 2017, pp. 364–374. https://doi.org/10.1080/15472450.2016.1198699.
275. Gao, B., and B. Coifman. A Vehicle Detection and Tracking Approach Using Probe Vehicle LIDAR Data. In *Traffic and Granular Flow'05*, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 675–685.
276. Virginia Tech Transportation Institute Center for Sustainable Mobility. Center For Sustainable Mobility. *Virginia Tech Transportation Institute*.
277. Alsalhi, R., V. V. Dixit, and V. V. Gayah. On the Existence of Network Macroscopic Safety Diagrams: Theory, Simulation and Empirical Evidence. *PLoS ONE*, Vol. 13, No. 8, 2018. https://doi.org/10.1371/journal.pone.0200541.
278. Furuhata, M., M. Dessouky, F. Ordóñez, M.-E. Brunet, X. Wang, and S. Koenig. Ridesharing: The State-of-the-Art and Future Directions. *Transportation Research Part B: Methodological*, Vol. 57, 2013, pp. 28–46. https://doi.org/10.1016/j.trb.2013.08.012.
279. Mourad, A., J. Puchinger, and C. Chu. A Survey of Models and Algorithms for Optimizing Shared Mobility. *Transportation Research Part B: Methodological*, 2019. https://doi.org/10.1016/j.trb.2019.02.003.
280. Fagnant, D. J., and K. M. Kockelman. The Travel and Environmental Implications of Shared Autonomous Vehicles, Using Agent-Based Model Scenarios. *Transportation Research Part C: Emerging Technologies*, Vol. 40, 2014, pp. 1–13. https://doi.org/10.1016/j.trc.2013.12.001.
281. Djavadian, S., and J. Y. J. Chow. An Agent-Based Day-to-Day Adjustment Process for Modeling "Mobility as a Service" with a Two-Sided Flexible Transport Market. *Transportation Research Part B: Methodological*, Vol. 104, 2017, pp. 36–57. https://doi.org/10.1016/j.trb.2017.06.015.
282. Calvert, S., H. Mahmassani, J.-N. Meier, P. Varaiya, S. Hamdar, D. Chen, X. Li, A. Talebpour, and S. P. Mattingly. Traffic Flow of Connected and Automated Vehicles: Challenges and Opportunities. In *Road {Vehicle} {Automation} 4*, Springer, pp. 235–245.
283. Excell, R., J. Ma, S. Shladover, D. Work, M. Levin, S. H. Hamdar, M. Wang, S. P. Mattingly, and A. Talebpour. Enhancing the Validity of Traffic Flow Models with Emerging Data.

2018.

284. Arem, B. Van, M. M. Abbas, X. Li, L. Head, X. Zhou, D. Chen, R. Bertini, and S. P. Mattingly. Integrated Traffic Flow Models and Analysis for Automated Vehicles. In *Road Vehicle Automation*, Springer, pp. 249–258.