Guest Editorial
Introduction of the Special Issue on Management of Future Motorway and Urban Traffic Systems

THE advent of vehicles' connectivity and automation opens up unprecedented opportunities to make road transport more efficient and sustainable going far beyond what can be achieved by the vehicle's intelligence alone, even in the presence of imperfect information of the surrounding traffic. Our community, which has been trying for decades to manage one of the most complex human dynamics based on limited, low-quality, and usually outdated information with only indirect tools (such as traffic lights and variable message signs), sees ahead the possibility to use rich, high-quality, and real-time data to provide personalized and targeted advice to each user of the transportation system.

While connectivity and automation are indisputable enablers for novel user- and vehicle-centered transport and mobility services, they can also help at distributing traffic and passengers in a better way according to the available infrastructure capacities, and in turn, the infrastructure can be adapted dynamically to achieve the important overall system's objectives of lower congestion levels, and contribute to achieve better air quality and to mitigate climate change effects. To pursue these objectives, a Copernican revolution is needed in the way we use and manage our roads. This will, however, require substantial efforts to upgrade all the methodologies and techniques used hitherto, and suggest and define new standards to plan, design, and implement smart infrastructures able to communicate and interact with the vehicles and the travelers.

In order to stimulate discussion on the most pressing issues that need to be tackled, a group of young European researchers has started a series of symposia held on a biannual basis to debate on the Management of Future Motorway and Urban Traffic Systems. This community has significantly expanded, since its first event organized in 2016, by including many representatives from all over the World. This series of symposia focus on future traffic management systems, covering the subjects of traffic control, estimation, and modeling of motorway and urban networks, with particular emphasis on the presence of advanced vehicle communication and automation technologies. In particular, a challenge addressed in this forum deals with the importance of understanding and managing the transition toward fully connected and automated mobility systems, and also look at this problem from a broader multimodal perspective, involving both passengers and freight. As we are facing an uncertain period until the moment when all actors in the system will reach full autonomy (level 5 in terms of automation according to the Society of Automotive Engineers [SAE]), and the infrastructures will be able to guide them according to some system's goal, it is paramount to propose solutions able to gently introduce the earlier automation and connectivity levels, while guaranteeing high levels of performance and safety.

The open call for papers of the present Special Issue has been launched during the 2018 Symposium (MFTS2018). A total of 35 submissions were received in response to it. These papers were rigorously evaluated according to the standard reviewing process of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS. The evaluation process took into consideration factors pertaining to originality, technical quality, presentational quality, and overall contribution.

In all, 13 papers were selected for inclusion in this Special Issue. They can be divided into three main categories.

The first category includes papers presenting innovative approaches for *advanced motorway and network-wide management*. In particular, novel traffic control strategies in the presence of connected vehicles were proposed. As vehicle connectivity allows (short-range) communication and cooperation, these strategies can rely on a decentralized approach and allow managing roads even in the case of heterogeneous traffic composition and variable or no lane discipline.

The second category concerns papers related to *advanced traffic monitoring and state estimation*, while the third category refers to papers dealing with *new subjects of investigation*. Connected vehicles can, in fact, augment traditional sensors such as loop detectors or floating cars, and through data fusion techniques, they can enrich information especially in the presence of limited or faulty measurements. Finally, some contributions focused on studying the trajectory of vehicles, particularly to understand the impact of automation on road capacity and on fuel consumption and emissions.

Looking at the ensemble of contributions in this Special Issue, emphasis is placed on connectivity and data exploitation for both monitoring and control applications. This could indicate that concepts like Cooperative Intelligent Transportation Systems (C-ITS) and Dynamic Traffic Management (Advanced Traffic Information Systems, Advanced Public Transport Management, etc.) are perceived as effective market-ready solutions even in the presence of partial or no vehicle automation.

In the remainder of the editorial, a brief introduction to each of the contributions is provided.

The paper titled "PC-SPSA: Employing dimensionality reduction to limit SPSA search noise in DTA model calibration" by Qurashi *et al.* deals with the problem of

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calibrating dynamic traffic models, which are essential to assess networks from a system level and incorporate the spatial and temporal dynamics of the demand. This problem is well known to be underdetermined, hence many solutions could equally fit the observed traffic and transport data. This problem will always be affecting our models, since trips are derived activities emerging from human mobility needs. To overcome the dimensionality problem, the authors further extend and improve a well-established algorithmic technique, the Simultaneous Perturbation Stochastic Approximation, by combining it with Principal Component Analysis. This allows one to solve large-scale instances and improves the results in terms of solution reliability.

The paper titled "Augmenting vehicle localization by cooperative sensing of the driving environment: insight on data association in urban traffic scenarios" by Brambilla *et al.* presents a distributed processing technique to augment the performance of conventional Global Navigation Satellite Systems (GNSS) exploiting vehicle-to-anything (V2X) communication systems. The proposed approach is tested via numerical simulation on both simplified and realistic traffic networks showing its superior performances with respect to the conventional GNSS. It therefore represents a promising solution to enhance both the accuracy and the robustness of positioning in urban scenarios also enabling new innovative C-ITS services especially in emerging automated driving scenarios, where the formation of tight convoys or platoons of vehicles facilitate the cooperation process.

The paper titled " Extended observer for urban traffic control based on limited measurements from connected vehicles" by Papapanagiotou and Busch presents a methodology that enables cycle-to-cycle traffic state estimation and prediction based on limited Connected Vehicles (CV) measurements. Current urban traffic control systems rely heavily on inductive loop detectors, whereas the emergence of CVs opens new possibilities for improving signal control; however, for low penetration rates, the CV measurements are sporadic and thus difficult to exploit by existing traffic control systems. The proposed observer does not require loop detectors and is independent of the type of signal control. The results show that, in particular, for oversaturation and low penetration rates, the proposed observer improves the CV measurement, resulting in lower errors in queue length estimation and a reduction in delays at the examined signal and the complete intersection.

The paper entitled "Response time and time headway of an adaptive cruise control. An empirical characterization and potential impacts on road capacity" by Makridis *et al.* deals with the impact of intermediate levels of automation to the overall road capacity. In particular, most of the current commercial car models in the market already offer Adaptive Cruise Control (ACC), which assists the driver in the longitudinal driving task by automatically adapting speed and distances from the preceding car. This system has been studied in the past, and its potential benefits in enhancing road capacity, increasing safety, and reducing emission have been reported both theoretically and with field operational tests. However, only a few studies have investigated in detail the properties of commercial ACC systems. By proposing a new methodology for the estimation of the controller's response time and the desired time-gap, the authors empirically showed that ACC-enabled vehicles may not necessarily improve the capacity of our motorways.

The paper titled "Motorway tidal flow lane control" by Ampountolas *et al.* deals with the particular traffic case when inbound and outbound traffic on a given facility is unbalanced throughout the day. This scenario may benefit from a lane management strategy called tidal flow (or reversible) lane control; in this case, the direction of one or more contraflow buffer lanes is reversed according to the needs of each direction. This paper proposes a simple and practical real-time strategy for efficient motorway tidal flow lane control, which consists of a state-feedback switching policy based on the triangular fundamental diagram, which requires only aggregated measurements of density. A theoretical analysis based on the kinematic wave theory shows that the strategy provides a Pareto-optimal solution. Microsimulations using empirical data from the A38(M) Aston Expressway in Birmingham, U.K., are used to demonstrate the operation of the proposed strategy. The robustness of the switching policy to parameter variations is demonstrated by parametric sensitivity analysis. The simulation results confirm an increase of motorway throughput and a smooth operation for the simulated scenarios.

The paper titled "Adaptive control strategies for urban network traffic via a decentralized approach with user-optimal routing" by Chow *et al.* presents an adaptive linear quadratic optimal traffic control system, solved via a decentralized approach and complemented with a user-optimal network traffic router. In particular, the user-optimal routing algorithm assists drivers' response to prevailing traffic state and control settings and seek the quickest route toward their destinations. The proposed control system is implemented and tested over different scenario settings including a real-life scenario in Central London, U.K. The study reveals that the proposed system could yield a performance similar to its centralized counterpart with the routing algorithm, even under congested conditions. This highlights the potential of decentralized control with effective travel guidance in cooperative traffic management.

The paper titled "A micro-simulation study of the generalized proportional allocation traffic signal control" by Nilsson and Como studies the problem of controlling phase activations for signalized junctions in an urban transportation network using local feedback information. The focus of the paper is on the validation and performance evaluation of the recently proposed Generalized Proportional Allocation (GPA) controller through microsimulations. Previous theoretical work has provided provable guarantees in terms of stability, and throughput optimality of the GPA controller in a continuous averaged dynamical queuing network model. In this paper, the authors provide and implement two discretized versions of the GPA controller in the SUMO micro simulator, comparing the performance of the GPA controller with that of the MaxPressure controller in an artificial Manhattan-like grid and a realistic Luxembourg scenario. The simulations show that the GPA controller outperforms both the fixed time and the cyclic MaxPressure controllers for the Luxembourg scenario, and behaves better than the MaxPressure pressure controller in the Manhattan-grid when the demands are low.

The paper titled "Minimization of fuel consumption for vehicle trajectories" by Typaldos *et al.* deals with eco-driving, by proposing a formulation of the eco-driving problem cast in an optimal control framework. State equations reflect the simple vehicle kinematics for position and speed, with the acceleration acting as a control input, whereas initial and final states (position and speed) are fixed. Smoothing procedures are then applied to enable the application of powerful numerical algorithms for the efficient solution of the resulting nonlinear optimal control problem. Furthermore, simpler quadratic approximations of the nonlinear formula are also considered, which enable analytical problem solutions. A comprehensive comparison based on various driving scenarios demonstrates that the often utilized, but sometimes strongly questioned, square-of-acceleration term delivers excellent approximations for fuel minimizing trajectories in the present setting. A GLOSA (Green Light Optimal Speed Advisory) approach, based on the analytical solution of an optimal control problem, is also presented.

The paper titled "Augmenting traffic signal control systems for urban road networks with connected vehicles" by Rafter *et al.* develops and tests a novel control algorithm, namely, Multi-mode Adaptive Traffic Signal (MATS), which exploits vehicle connectivity to identify the position of the vehicles in real time, and by adopting a decentralized approach, it adapts timing plans to maximize intersection throughput and reduce vehicle delays. The advantage of this approach is to be able to work with already low levels of connectivity, or for areas where connectivity will remain difficult due to communication issues. Comparison of the approach with the state-of-the-art methods shows significant gains, and with stronger and stronger improvements, a higher percentage of connected vehicles is introduced in the system.

The paper titled "A decentralized signal control for non-lane-based heterogeneous traffic under V2I Communication" by Kumaravel and Ayyagari proposes a novel decentralized, area occupancy-based back-pressure control for a nonlane-based heterogeneous traffic network under V2I communication. The paper aims at overcoming the limitation that queue- and delay-based back-pressure control algorithms are appropriate for homogeneous traffic with strict lane discipline, whereas, in nonlane-based traffic, every traffic movement does not form a separate queue and vehicular dimensions are highly varied. The authors propose a method considering the concept of spatial area occupancy and temporal area occupancy combined with back-pressure control and then conduct an extensive simulation study to illustrate the efficacy of the proposed algorithms using microscopic simulation tools. The results suggest that the proposed control algorithms significantly improve the performance of traffic network compared with vehicle actuated control and aggregated queue-based back-pressure control deployed on the same network.

The paper "Road data enrichment framework based on heterogeneous data fusion for ITS" by Rettore *et al.* proposes a data enrichment framework that fuses data from heterogeneous data sources to enhance Intelligent Transportation System (ITS) services such as vehicle routing and traffic event detection. Location-based social media data such as Twitter messages are used to enhance the two services. Results show that despite the limited amount and quality of the information used, the two services for which the framework is tested show comparable accuracy than existing commercial services, thus opening a new possibility of enhanced services in the future. The study also allowed to better understand the users' viewpoint about traffic events (such as road accidents and traffic jams) providing useful insights for future studies and applications.

The paper titled "Enhancing bus holding control using cooperative ITS" by Laskaris *et al.* develops a hybrid control strategy based on vehicle-to-infrastructure communication and real-time vehicle positioning technologies. The control strategy combines bus holding, driving assistance and transit signal priority (TSP) into a unified control framework, and allows seeking for service regularity while at the same time reducing the number of stops at traffic signals. Tests on a simulated busy line in Luxembourg show that the buses can be efficiently operated without necessarily providing additional priority to public transport via TSP, and hence, without negatively affecting the capacity of the private vehicles system.

The paper titled "Combined alternate-direction lane assignment and reservation-based intersection control" by Mitrovic *et al.* presents a concept for organizing directionally unrestricted traffic flows in automated vehicle environment. Different than in existing traffic, in the proposed concept, namely, Combined Alternate-Direction Lane Assignment and Reservation-Based Intersection Control (CADLARIC), vehicles can use lanes traditionally reserved for the opposite direction of travel. This allows left and right turning vehicles to align themselves in an appropriate lane before reaching the downstream intersection, so that they can smoothly go through the intersection without having any conflicts with vehicles from the other movements, whereas conflicts between through movements are handled by a reservation-based algorithm. To simulate and evaluate the proposed concept, a new microsimulation platform is developed, showing improvements in terms of traffic performance and reduction of conflicting situations with respect to conventional fixed-time signal control and fully reservation-based intersection control.

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