Guest Editorial Artificial Intelligence and Deep Learning for Intelligent and Sustainable Traffic and Vehicle Management (VANETs)

INTELLIGENCE and sustainability are two essential drivers for the development of current and future Intelligent Transportation Systems. On one hand, the complexity of vehicular ecosystems and the inherently risk-prone circumstances under which pedestrian and vehicles coexist call for the endowment of intelligent functionalities in almost all systems and processes participating in such ecosystems. On the other hand, risk may be the most important objective to be guaranteed by the provision of intelligence in ITS, but it is not certainly the only one: when safety is assured, sustainability comes into play, seeking to convey intelligence to the distinct parts composing the ITS landscape with efficiency, minimum carbon footprint, wastage of resources or any other factor affected by the technological empowerment itself.

To this end, today it is widely acknowledged that artificial intelligence (and particularly, deep learning) is arguably the main catalyst to provide ITS with the capability to undertake modeling tasks of unprecedented complexity. Vehicular perception, driver behavior characterization, traffic forecasting, or vehicular self-diagnostics are among the myriad of application scenarios in ITS embracing massively the adoption of deep-learning models for scene understanding, multimodal data fusion, federated learning, or reinforcement learning, among other tasks. Other learning paradigms such as the optimization of vehicular communications or the segmentation of multi-dimensional data have also benefited from the adoption of AI-based algorithms, including metaheuristic optimization or clustering algorithms. Whenever a machine is provided with the capability to learn by itself how to solve a complex task, AI brings in as an essential driver that today prevails in almost any research area related to ITS.

This Special Issue has intended to build on the upsurge of research around AI and deep learning for sustainable vehicle management to collect several high-quality works related to the use of these technologies for the management of vehicular ad-hoc networks (VANETs). Contributions summarized in what follows exemplify the enormous momentum of deep learning and other AI algorithms to support communications, coordination and autonomy in these networks, with an emphasis on problems that lie at their core: caching, path and route planning, communication quality assessment, decentralized learning, perception, resource allocation, autonomous driving, accident prevention, or location and tracking. The diversity of contributions received at the editorial office and finally included in the Special Issue exposes a future plenty of new applications in VANETs powered by AI-supported functionalities, allowing ITS to reach ever-growing levels of technological maturity.

Among the contributions published in this Special Issue, we pause first at those related to path and route planning. This is one of the core elements of vehicular ad-hoc networking, aimed at determining which paths/routes should be followed by vehicles under different criteria. As such, in [A1], Ma *et al.* proposed a collaborative metaheuristic algorithm to determine the paths of multiple unmanned surface mapping vehicles. The proposed approach produces routes with shorter path lengths, low number of turning points and units, and an improved coverage rate, showing that optimization algorithms capable of learning from their own experience are amenable to be utilized for collaborative path planning.

Another core functionality is the optimization of the information exchanged through the VANET, for which different routing and caching approaches have been devised. Among them, in [A2], Magaia *et al.* proposed Group'n Route, an information routing approach blending clustering and routing based on the concept of social strength, i.e., a measure of the relevance of a node (vehicle) within the VANET it belongs to. Information routing is also under the scope of [A3], in which Gao *et al.* proposed a vehicle-consensus routing management scheme (VCRMS) to support fair roadside assistance for driving users. The proposed scheme exploits the surrounding vehicle information for infrastructure selection and traffic management. The infrastructure and vehicle information are analyzed for their similarity using deep learning. Blockchain technology is also proven by Feng *et al.* in [A4] to be of utmost utility for storing and transmitting information through VANETs, supporting the development of AI-enhanced functionalities in VANETs with privacy and security guarantees. Focused on emergency messages, in the related work in [A5], Ahmed *et al.* elaborated on how to utilize Blockchain to effectively secure emergency-based message transmission. Security in communication protocols between drone VANETs is also examined in [A6], where Akram *et al.* designed a deep-learning-based key-exchange protocol to secure communications that are robust to different forms of attacks. In the interesting study in [A7], Xu *et al.* addressed the prediction of the communication quality in Internet of Vehicles Networks, which is addressed by means of an Elman model, a type of recurrent neural network suitable for problems formulated

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over sequential data with particularly low training complexity. Caching is another form of reducing the consumption of network resources in VANETs and to cope with intermittent connectivity resulting from high-mobility VANET scenarios. This is the rationale of the work in [A8], where Chen *et al.* proposed a caching protocol for vehicular named data networks by leveraging the spatial-temporal characteristics of safety-, traffic efficiency-, and service-related messages. Transmission control can also help to mitigate the effects of link data loss in heterogeneous VANETs, which is approached in [A9] by Zong *et al.* for hybrid multi-hop and satellite networks.

Following up the evolution of cellular communication networks, many researchers are starting to explore whether AI can help expedite the advent of the new releases of cellular networks (5G) to implement high-bandwidth, low-latency communications in VANETs. The portfolio of contributions in this Special Issue have also tackled this confluence of research areas. Among them, Khan *et al.* examine spectrum sharing using deep and reinforcement learning in [A10] for backscattered-aided vehicular networks, considering power allocation, user association, and spectrum sharing as variables to be optimized jointly toward maximizing the utility of the network service provider. Machine learning has been also investigated by Morgado *et al.* in [A11] for spectrum sharing in virtual 5G networks, considering a mixture of predictive, clustering, and reinforcement learning approaches for the purpose. The related study in [A12] joins this research path, in which Cao *et al.* address the use of the so-called B5G (Beyond 5G) networks for VANETs, casting a virtual resource allocation problem solved by an intelligent optimization algorithm. This subset of contributions ends with the work in [A13], tackling network resource control and allocation in VANETs using LTE-based long-range communications and IRS-aided dedicated short-range links. Deep reinforcement learning is used to learn an agent capable of managing such resources for the sake of the energy efficiency and latency of the overall network.

Besides challenges in communication and information sharing in VANETs, vehicles also resort to AI-assisted functionalities for different purposes. When it comes to self-diagnostics, in [A14], Rahman *et al.* propose a framework that encompasses machine learning techniques used for vehicular health monitoring. The framework can analyze vehicles' health conditions and notify stakeholders upon any detected problem. The capability of the vehicle to sense its surroundings, understand what occurs and react accordingly is also a major motivation for AI-based algorithms, including the monitoring of the drivers' cognitive status [A15], [A16], the detection of objects and pedestrians based on image data (vehicular perception) [A17], the detection of spatial relationships between observed objects to infer accident situations [A18], spatio-temporal traffic prediction for congestion avoidance [A19], or indoor localization for autonomous valet parking [A20]. All these functionalities rely on AI-based algorithms for the modeling tasks stemming from the practical problems they aim to solve. Of especially prevalence is the presence of neural networks for suitably modeling the complex multi-dimensional data handled in vehicular perception and driver characterization, including image and LIDAR data [A21].

Autonomous decision making in vehicles has been largely explored with reinforcement learning algorithms. Contributions in this Special Issue have not overlooked this promising path toward fully autonomous vehicular systems. This is the case of [A22], in which Anzalone *et al.* evaluated the performance of an approach combining curriculum learning and proximal policy optimization over the CARLA driving simulation. The results over different driving conditions and traffic scenarios are encouraging, suggesting that the proposed combination can be extrapolated to other value-based reinforcement learning algorithms. In this same research path, Raja *et al.* study pothole avoidance via reinforcement learning in [A23], using policy gradient algorithms to decide the time, speed, and angle of maneuver to avoid these obstacles on road surfaces. The comfort of the maneuver and the efficacy of the learned policy were tested, proving to outperform the state-of-the-art in this area.

Finally, we discuss two contributions accepted for its inclusion in the Special Issue because they reveal that the adoption of AI and deep learning for VANETs comes along with problems on their own: the privacy of vehicular data, calling for new methodologies to protect trajectory data [A24] and federate models and achieve synergistic knowledge exchange among them without compromising the privacy of data from where they were trained [A25], and the presence of class-imbalance in datasets used for learning models that detect infrequent circumstances, such as traffic collision [A26]. These problems, whose consequences can be catastrophic for the practical utility of AI-based models, require proper treatment when designing approaches for solving them effectively.

We hope that this Special Issue on AI- and deep-learning solutions for sustainable traffic and vehicle management in VANETs excels at its purpose targeted from the very beginning of its inception: to show the vigorous vitality of this area in the current ITS research landscape, and to stir up the community towards realizing the potential of AI for the sustainability and efficiency of autonomous vehicular networks.

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APPENDIX: RELATED ARTICLES

[A1] Y. Ma *et al.*, "CCIBA∗: An improved BA∗ based collaborative coverage path planning method for multiple unmanned surface mapping vehicles," *IEEE Trans. Intell. Transp. Syst.*, early access, May 13, 2022, doi: 10.1109/TITS.2022.3170322.

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