SUMMARY

The **e³CAV** workshop, on Connected and Autonomous Vehicles for Energy Efficiency and Environmental impact, held at IFPEN Rueil-Malmaison from 30th September to 1st October 2019, brought together 60 international participants. The workshop represented a rare opportunity to gather researchers from different fields of expertise (transportation engineering, operations research, control engineering, automotive engineering) and discuss the latest advancements in vehicles and traffic automation for a greener mobility.

The objective of this event was firstly to share and discuss the current research state-of-the-art on vehicles connectivity and automation and on how these new technologies can enable improved sustainability of transportation. The decision of having 21 invited speakers from the academic world, all with strong connections with public authorities and industry, was motivated by IFPEN's interest in consolidating the future mobility tendencies and anticipating the forthcoming industrial solutions, thus revealing key research directions to help them emerge. Secondly, the workshop was aimed at creating a brainstorming opportunity to foster discussion and understand how to overcome challenges and public skepticism as far as connected and automated vehicles (CAVs) are concerned.

The technical discussion that took place during the **e³CAV** workshop demonstrated how the goal of improving energy efficiency of transportation can be reached by means of several actions, of which CAVs definitely represent an important actuator. If one were to imagine mobility as composed by two main agents, the vehicle and the traffic network, which are controlled at two different levels, planning and operation, then research efforts to increase energy efficiency of mobility may be divided in four main categories, as described hereafter.

Program sessions

Vehicle planning

Predictive information provided by vehicles and infrastructure connectivity can be used to devise intelligent routing systems, which can reduce the trips energy footprint and improve local air-quality (eco-routing). The workshop witnessed contributions in this field by Bin Yang (Aalborg University), Kanok Boriboonsomsin (UC Riverside), Giovanni De Nunzio (IFPEN), and Hesham Rakha (Virginia Tech).

This session highlighted the importance of augmenting nowadays available data with accurate driver's and vehicles' models in order to correctly predict the environmental footprint of transportation. It seems desirable to model vehicles energy consumption and emissions by means of

stochastic models to capture the real variability of driving conditions. Finally, routing applications could be improved by integrating the concepts of cooperation among agents and feedback in order to better cope with disturbances and prediction inaccuracy.

Vehicle operation

Leveraging vehicles connectivity to optimize driving speed profiles in terms of energy consumption (eco-driving) both for a single vehicle and for a platoon of vehicles was the core topic of this second session. Contributions were given by Michail Makridis (European Union JRC), Martin Treiber (TU Dresden), Andrés Ladino (IFSTTAR), Giovanni De Nunzio (IFPEN), Hesham Rakha (Virginia Tech), Gabor Orosz (University of Michigan), Meng Wang (TU Delft), Karl Henrik Johansson (KTH Royal Institute of Technology), Lars Eriksson (Linköping University), Ardalan Vahidi (Clemson University), Tijs Donkers (TU Eindhoven), Dominik Karbowski (Argonne National Laboratory), M.A.S. Kamal (Gunma University), and Luigi Del Re (Johannes Kepler University Linz).

The research outcomes showed in this session demonstrated that the nowadays industrial implementation of Advanced Driver Assistance Systems (ADAS), such as the adaptive cruise control (ACC) may suffer from high response times which may lead to instability (i.e. increasing-magnitude oscillations) of the vehicle platoon and, in turn, cause a degradation of safety and energy performance. Thus, bringing together feedback control action, cooperation and prediction enabled by connectivity seems to be beneficial for several ADAS systems: vehicles and truck platooning with predictive cruise control (PCC) or cooperative adaptive cruise control (CACC), signalized intersections eco-approach, lane changing/merging, eco-driving, etc.

Network planning

The network planning topic consists in promoting modal shift towards “greener” means of transportation, in implementing energy-aware traffic assignment and enabling mobility-as-a-service (MaaS) in order to increase the chances of reducing congestion and emissions. Contributions in this session were given by Francesco Viti and Marco Rinaldi (University of Luxembourg), Javier Alonso-Mora (TU Delft), and Julien Monteil (IBM Research Ireland).

In the domain of public transportation, bus scheduling and fleet assignment applications seem to be very promising to optimize travelers waiting time while reducing energy consumption of the transportation fleet. In the case of electrified fleet, the problem can be made even more challenging by introducing constraints on charging duration and location. Furthermore, a new trend in mobility is emerging and showing significant benefits in terms of customers’ satisfaction and environmental impact. Mobility thus becomes a service for the community (MaaS). Ridesharing is probably one of the most successful applications of MaaS enabling higher occupancy of vehicles, reduction of vehicle density on the roads, and improved efficiency. The main strategies for achieving such benefits are predictive routing, fleet sizing, rebalancing, and cooperation among service providers.

Network operation

Network operation consists in enhancing communication between road infrastructure and vehicles (V2X) and controlling signalization (traffic lights, variable speed limits, etc.) in order to reduce congestion, increase network throughput, and more importantly reduce traffic energy consumption and emissions. Contributions in this session were given by Silvia Siri (University of Genova) and Maria Laura Delle Monache (INRIA).

The state-of-the-art in the field of energy and environment-aware traffic control seems to mostly utilize ramp metering for vehicular flow control on highways and traffic lights coordination in urban road networks. Nevertheless, coupling such well-established strategies with other actuators may prove beneficial in terms of system flexibility and performance improvement. In particular, variable speed limits could be used along with ramp metering to achieve increased density homogenization on highways or to more easily give rise to “green waves” in urban traffic. Furthermore, nowadays, thanks to the advent of CAVs, the vehicles themselves may be used as actuators and help improve traffic performance by dampening speed oscillation, shock waves, etc.

Participants consultation

The workshop was made interactive and animated by a set of activities on a dynamic presentation tool. A total of 15 activities were made available during the entire duration of the workshop and 52 attendees participated in such activities. The objective was to collect the opinions of all the workshop participants, even the ones who did not have the opportunity to present their work, on some key questions that we at IFPEN judged important and strategic.

The questions ranged from general-opinion topics on CAVs to more technical perspectives on research directions. It is known from the literature that there is still a high uncertainty on the impacts of CAVs on road traffic, and the community is torn between those who believe in a degradation and those who believe in an improvement of traffic performance. One of the questions showed the same trend with contradictory answers and visions on CAVs impact: 7 votes for ‘more congested traffic with the large diffusion of CAVs, 6 votes for ‘smoother’ traffic, 5 votes for ‘more energy-efficient’ traffic.

Furthermore, among the main positive-performance enablers, the attendees preferred eco-driving and MaaS, while the main negative-performance causes are to be found in an increased number of people having access to mobility and consequently in an increased traffic demand.

A majority of the participants believe that the first large application of CAVS in the next 10 years will be in public transportation, but they also believe that the main clients of the research advancements in the field are the vehicle manufacturers and tier-1 suppliers, as though the diffusion of CAVs were

expected to come mainly from the private sector. The role of policy and public authorities in diffusion and acceptance has been therefore discussed in the workshop concluding "think tank".

From a more technical perspective, we asked questions about 4 aspects considered critical for the large-scale research investigation and industrial deployment of CAVs: simulators, data, optimization approaches and sensors.

Final discussion

A "think tank" was conducted at the end of the workshop on 3 main topics that appeared to emerge quite consistently during the event and that seemed to be critical for the future of CAVs investigation and deployment: the need for common benchmark methodology and scenarios, the advantages of multi-layer vs. comprehensive optimization, the missing elements for a full scale deployment and acceptance of CAVs.