Kuru, K and Khan, W

A Framework for the Synergistic Integration of Fully Autonomous Ground Vehicles With Smart City

http://researchonline.ljmu.ac.uk/id/eprint/17623/

Article

Citation (please note it is advisable to refer to the publisher's version if you intend to cite from this work)

Kuru, K and Khan, W (2020) A Framework for the Synergistic Integration of Fully Autonomous Ground Vehicles With Smart City. IEEE Access, 9. pp. 923-948. ISSN 2169-3536

IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received November 17, 2020, accepted December 21, 2020, date of publication December 23, 2020,
date of current version January 5, 2021.

Digital Object Identifier 10.1109/ACCESS.2020.3046999

A Framework for the Synergistic Integration of Fully Autonomous Ground Vehicles With Smart City

KAYA KURU[1] **AND WASIQ KHAN**[2]
[1]School of Engineering, University of Central Lancashire, Preston PR1 2HE, U.K.
[2]Faculty of Engineering and Technology, Liverpool John Moores University, Liverpool L3 5UZ, U.K.

Corresponding author: Kaya Kuru (kkuru@uclan.ac.uk)

ABSTRACT Most of the vehicle manufacturers aim to deploy level-5 fully autonomous ground vehicles (FAGVs) on city roads in 2021 by leveraging extensive existing knowledge about sensors, actuators, telematics and Artificial Intelligence (AI) gained from the level-3 and level-4 autonomy. FAGVs by executing non-trivial sequences of events with decimetre-level accuracy live in Smart City (SC) and their integration with all the SC components and domains using real-time data analytics is urgent to establish better swarm intelligent systems and a safer and optimised harmonious smart environment enabling cooperative FAGVs-SC automation systems. The challenges of urbanisation, if unmet urgently, would entail severe economic and environmental impacts. The integration of FAGVs with SC helps improve the sustainability of a city and the functional and efficient deployment of hand over wheels on robotized city roads with behaviour coordination. SC can enable the exploitation of the full potential of FAGVs with embedded centralised systems within SC with highly distributed systems in a concept of Automation of Everything (AoE). This article proposes a synergistic integrated FAGV-SC holistic framework — FAGVinSCF in which all the components of SC and FAGVs involving recent and impending technological advancements are moulded to make the transformation from today's driving society to future's next-generation driverless society smoother and truly make self-driving technology a harmonious part of our cities with sustainable urban development. Based on FAGVinSCF, a simulation platform is built both to model the varying penetration levels of FAGV into mixed traffic and to perform the optimal self-driving behaviours of FAGV swarms. The results show that FAGVinSCF improves the urban traffic flow significantly without huge changes to the traffic infrastructure. With this framework, the concept of Cooperative Intelligent Transportation Systems (C-ITS) is transformed into the concept of Automated ITS (A-ITS). Cities currently designed for cars can turn into cities developed for citizens using FAGVinSCF enabling more sustainable cities.

INDEX TERMS Autonomous vehicles, driverless vehicles, smart city, crowdsourcing, cloud platform, fog platform, mobile-edge computing (MEC), Internet of Everything (IoE), automation of everything (AoE).

I. INTRODUCTION

Knight Rider, the television series (1982-1986), with Michael Knight and the intelligent fully autonomous science-fiction car named KITT is becoming a science-fact in our cities. The idea of driverless vehicles was introduced many years ago when autopilot systems were designed for airplanes [1]. Sixty-five years of automotive baby steps paving the way to the autonomous ground vehicles (AGVs) are summarised by Ross [2] starting with the invention of modern cruise control in 1948 to an envision that half of all new cars will be autonomous in 2030 against the common belief in several decades ago that computers would not be able to drive cars. How will AGVs, in other words, self-driving cars transform our cities? or How will Smart Cities (SCs) transform AGVs? We envision a future that both Level-5 fully AGVs (FAGVs) and SCs will transform one another drastically. Recent advances are urging both automobile manufacturers and city governors to change the way of doing business collaboratively and more intelligently. All the big players in the automotive industry envisage a future for driverless vehicles and they have already taken notable actions within their

The associate editor coordinating the review of this manuscript and approving it for publication was Rakesh Matam.

manufacturing phases massively supported by leading technology companies (e.g.,Samsung [3], Intel, Nvidia, Mobileye, Microsoft) (Table 1). Strictly speaking, those players are investing heavily in the technology and experimenting with autonomous technology and it's only a matter of time before someone releases the first commercially available driverless vehicle in the years to come [4] where FAGVs are evolving rapidly to adapt to their dynamic and unpredictable environment in a timely manner. Already autonomous car prototype models have covered millions of miles in test driving [5]. Are our cities ready for the effective and safe management of imminent exponential increase of FAGVs on urban roads? By taking the shortest and most convenient point-to-point (P2P) route to their destinations safely with no human intervention, FAGVs bring a lot of environmental and economic benefits to cities. To explicitly define, FAGVs equipped with high-performing computer systems, advanced sensors, actuators, analytics, Machine-to-Machine (M2M) communication technologies and effective human-machine interface (HMI) on the brink of revolutionary geometric and semantic understanding of the environment with proper sensing, detecting, classifying, reasoning and actuating are coming into our lives with great expectations. The developers of the FAGVs technology are claiming the safest driving on roads with the most experienced (self-) driver and promising a variety of benefits, particularly to 1) reduction of the number of accidents and traffic fatalities caused by human errors (e.g., driving fatigue, distraction), 2) reduction of health-care costs and other financial losses caused by traffic accidents, 3) ride-hail, delivery, logistics and transportation companies for reducing their driver costs, 4) disabled and old people in order to make them independent (e.g., blind), 5) reduction of traffic congestion, road stress, and parking space needs, 6) people who do not like driving, and 7) comfort of passengers with optimised and standardised movement of vehicles (e.g., most convenient turning, acceleration, deceleration).

Vehicles have a significant impact on the design of our cities in addition to the social impact on the community. The capacity of city roads are not increasing enough when compared to the increasing number of vehicles and vehicle-miles travelled (VMT) on roads. Total VMT by all vehicle types is projected to grow at an average rate of 1.1% annually over the 17 years through 2037 [6]. Citizens driving more-overall VMT are worsening the traffic, which is exacerbating the urbanisation concerns dramatically. The European Automobile Manufacturers' Association (ACEA) composed of 15 gigantic manufacturers has placed "connected and automated driving" at the top of their priority list [7] and they seem to have already made up their minds in putting FAGVs on city roads soon. The prospect of driverless cars wide-scale deployment is imminent owing to the advances in robotics, computational power, communication and sensor technologies [8]. Moreover, humans accept changes when there are benefits to the user [9]. US Secretary of Transportation stated at the Frankfurt Auto show that he expects driverless cars to be in use all over the world within the following years [10]. It is envisioned that FAGVs are expected to constitute around 50% of vehicle sales, 30% of vehicles, and 40% of all vehicle travel by 2040 [11] and in 2050 highly and fully automated vehicles with a market penetration of 75% mainly dominate the market [12]. According to European Commission, CO_2 emissions will no longer be an issue for means of transportation any longer in Europe by 2040 [13] with the massive use of electrification leading to the sustainability of cities. From ushering in an era of decreased car ownership, to narrowing streets and eliminating parking lots, FAGVs with their full potential promise to drastically reshape our cities [14].

The use of different types of autonomous vehicles (e.g., autonomous underwater vehicles (AUVs), autonomous unmanned aerial vehicles (UAVs)) have been analysed in various studies and we would like to emphasise that only fully autonomous road vehicles are focused in this study. The aim of this article is to establish a holistic framework — FAGVinSCF in which SC and FAGVs can be integrated one another on an orchestrated manner to transform today's driving society to future's next-generation driverless society and truly make self-driving technology a harmonious part of our cities. To the best of our knowledge, this is the first study that highlights a research gap in the field of the integration of FAGVs with SC, which leads us to analyse this integration from a philosophical point of view supported by sufficient knowledge involving societal impacts and ethical issues. Forging the abilities of FAGVs and SCs paves the way for the development of more synergistic ecosystems accommodating both high level of sustainability for cities and a high level of efficient mobility for FAGVs. To clarify the novelty of this article, particular contributions are outlined as follows.

1) The main components of FAGVs and their necessary integration requirements with SC domains are analysed to increase the efficacy of FAGVs in the SC ecosystem where both FAGVs and SCs can evolve within a new automated concept entitled Automated Intelligent Transportation Systems (A-ITS).
2) A synergistic holistic framework — FAGVinSCF in which all the components of SC and FAGVs involving recent and impending technological advancements are integrated is proposed to make FAGVs cooperate more safely and efficiently with one another and their environment using mission/service-oriented cooperation and swarm behaviour coordination to enable more sustainable and safer cities with optimised mobility.
3) Based on FAGVinSCF, a simulation platform is built to model the varying penetration levels of FAGVs into mixed traffic and to perform the optimal self-driving behaviours of FAGV swarms in tomorrow's SCs mobility.

The remainder of this article is organised as follows. The related works with the review of early concepts are explored in Section II. The methodology along with the proposed framework is explored in Section III.Results and discussion along with open issues and virtues of the proposed framework is provided in Section IV. Finally, Section V draws conclusions and unveils directions for potential future ideas.

II. RELATED WORKS

The idea of a self-driving vehicle isn't new; in the 1960s researchers at the Transport and Road Research Laboratory in Berkshire developed a "self-driving" Citroen DS car that was able to follow a series of magnetic cables embedded in the road [9]. Self-driving cars have come a long way since the first successful demonstrations in the 1980s [1], [9], [15]–[17]. AGVs have experienced a lot of upheavals since they were introduced in the real-world within 5 levels of autonomy, each of which is based on the gains in the previous levels. More specifically, vehicles are becoming increasingly automated by taking on more and more tasks under improving intelligent control systems based on enhancing sensor technologies and Artificial Intelligence (AI) techniques from the prior automation level to the next automation level. The first three levels of autonomy (i.e., 1: hands-on supported by driver assistance abilities such as lane-keep assist, auto cruise control, parking support, 2: hands-off supported by an autopilot requiring constant attention, 3: eyes-off still supported by a human under any emergency situations with communication by speech, gesture control, or via a touch-screen) have been achieved with very successful applications. Partially AGVs driven in the semi-autonomous modes — advanced driver assist system (ADAS) or Level 2 systems within J3O16 that many cars now offer, like Tesla's Autopilot [18], Cadillac's Super Cruise, Toyota Concept-I are requiring driver attention and more driver-assistance systems than true self-driving vehicles. In other words, autopilot is not a fully self-driving technology and drivers need to remain attentive at all times [19]. The safety driver or backup driver is meant to take control of the vehicle in the event of an emergency. Audi, BMW, Infiniti, Mercedes-Benz, and Volvo have similar autopilot systems to be taken over by human drivers under any sensory or technical difficulties. Those systems collecting a huge amount of data are perceived as the first phase of complete vehicle autonomy and paving the way to fully driverless vehicles on our city roads. There are very successful attempts for the last 2 levels (i.e., 4: no human intervention, mind-off mode 5: no human intervention, no steering wheel, no pedals, no breaks, even no windshield) equipped with a variety of advanced data acquisition modalities combined with a synergistic relationship, one is performed to complement the others' shortcomings/limitations (e.g., fuse of the data obtained from LIDAR and camera) that leads to invaluable insights about the current state of the vehicle along with the surroundings. Readers are referred to Table 1 for the real-world consumer-oriented AV examples ranging from level-3 to level-5 where the level-3 stage is a shift from human drivers to fully autonomous driving mode. We would like to note that level-4 AGVs and FAGVs represent similar technology, but with different concept. The aspects of Level-5 — FAGVs with no human input, no steering wheel, brakes, pedals as representing the next-generation autonomous cars put the manufacturer in a highly confident position compared to Level-4 AGVs. Readers are referred to [10] for the historical review of these levels.

TABLE 1. Autonomous models on level-3, level-4 and level-5.

Company	Model	Level	Complete
Lyft	AV HW and SW	3, 4, 5	✓
Goggle	AV SW	3, 4, 5	✓
Audio + NVIDIA	Audio A8 [1]	3	2021
Tesla	Tesla autopilot	3	✓
BMW + Intel + Mobileye	VISION iNEXT [20]	3	2021
Toyoto	Concept-i [2], Lexus [3]	3	✓
Toyoto + Microsoft	Toyoto Edge Cases	4	✓
Volkswagen + NVIDIA	ID Buzz [4]	4	2022
Yandex	Yandex taxi	4	✓
Renault	Renault Symbioz	4	✓
Renault	Trezor	4	✓
Rolls-Royce	103EX (customisable)	4	✓
Volvo + Microsoft	Volvo 360c	4	✓
Ford + Lyft	Ford Fusion	4	✓
Chrysler + Lyft	Chrysler Pacificas	4	✓
Alphabet + Lyft	Waymo (e.g., Koala)	4	✓
Aptiv + Lyft	Aptiv	4	✓
Google + Lyft	Aptiv	4	✓
Uber + NVIDIA	Aptiv	4	✓
Rinspeed	Rinspeed Oasis [5]	4, 5	✓
Rinspeed	Rinspeed Σtos [6]	4, 5	✓
Rinspeed	Rinspeed Snap [7]	5	✓
Rinspeed	Rinspeed MicroSnap [8]	5	✓
Mercedes-Benz	S-Class S 500 (no cockpit) [9]	5	✓
Mercedes-Benz	F 015 Luxury in Motion [10]	5	✓
Mercedes-Benz	Future Truck 2025 [11]	5	✓
Lyft	Lyft	5	2020
GM	GM	5	2021
Uber	Uber taxi	5	2021

Leading technological companies and car manufacturers have invested a staggering amount of resources in FAGVs, as they prepare for autonomous cars' full commercialisation in the coming years [5]. FAGVs such as Waymo, Lyft have fully self-driving capabilities, in other words, they are designed for riding not for driving. In 2017, Lyft's CEO predicted that within five years, all their vehicles will be autonomous [14]. In 2018, Waymo began conducting fully autonomous testing in Arizona without a human safety driver [14]. FAGVs without steering wheels, pedals are being produced to achieve a variety of tasks such as ride-sharing, delivery, individual and public transportation. Their cabin suiting individual needs becomes a place to socialise, conduct business or relax and multiple interactive screens could allow

[1] https://www.nvidia.com/en-gb/self-driving-cars/partners/audi/

[2] https://www.toyota.com/concept-i/

[3] https://global.toyota/en/newsroom/lexus/30279058.html

[4] https://www.designboom.com/technology/nvidia-drive-ix-buzz-electric-bus-volkswagen-self-driving-ai-01-08-2018/

[5] https://www.rinspeed.eu/en/Oasis_21_concept-car.html

[6] https://www.rinspeed.eu/en/Sigmatos_22_concept-car.html

[7] https://www.rinspeed.eu/en/Snap_48_concept-car.html

[8] https://www.rinspeed.eu/en/microSNAP_50_concept-car.html

[9] https://www.mercedes-benz.com/en/innovation/autonomous/

[10] https://www.mercedes-benz.com/en/innovation/autonomous/research-vehicle-f-015-luxury-in-motion/

[11] https://www.mercedes-benz.com/en/innovation/autonomous/the-long-haul-truck-of-the-future/

passengers to watch television, browse the internet, conduct face-to-face calls, or continue working while on their daily commute [4].

With a high density of travellers in urban areas, ride-sharing, shared self-driving vehicles, public autonomous transit fleet, and fully autonomous delivery are the emerging logistics and transportation options in SCs not only to alleviate the traffic congestion, but also to mitigate "first mile/last mile" (FMLM) problem. In 2017, National Association of City Transportation Officials (NACTO) created a Blueprint for Autonomous Urbanism, which encourages cities to deploy FAGVs that travel no faster than 25 mph as a tool for making streets safer, "with mandatory yielding to people outside of vehicles" [14]. Real-world trials of driverless vehicles are emerging all around the world. An autonomous campus mobility service using a driverless taxi on a 4.5-km campus road at Seoul National University started in November 2015 [21]. In SC — Milton Keynes, the RDM Group Driverless Pod is designed to transport people on the first and last leg of their journey [21]. RDM Group autonomous pods offer an FMLM solution for shoppers in busy city centres [4]. The Rinspeed Oasis can rotate on the spot which makes it perfect for inner city driving [4]. Trials of a four-passenger autonomous electrical shuttle — Harry over shared pedestrian and cycle pathways in London are exploring public reaction to vehicles for "last mile" transportation between transport hubs and residential areas and results of the trials will guide the wider rollout of automated vehicle technology in a complex urban environment [22]. In Shenzhen of south China, four self-driving buses began trial operations with a speed of 10 to 30 km/h and began running on a 1.2-km route in the bonded zone of Futian in November 2017 [23]. Several cities such as Austin, Detroit, Columbus and Ohio are currently testing FAGVs in slow-moving mode on city streets. In 2017, German lawmakers set the legal framework for allowing self-driving vehicles on public roads helping to realize this technology by providing clear legislation and legal responsibilities for its use [3]. The United Kingdom and France opened their streets to experimental FAGVs earlier this year, while the Chinese tech giant Baidu has been busy testing self-driving cars (developed with BMW) around Beijing and Shanghai [24]. Nissan conducted a series of tests for its driverless vehicles on The UK roads using a modified Leaf electric car [25]. The French PSA Group (Peugeot, Citroën and DS) also tested an eyes-off drive mode — i.e., 300 km in autonomous mode, from Paris to Amsterdam.[12] A Mercedes-Benz S-class vehicle called Bertha drove autonomously without human intervention for about 100 km from Mannheim to Pforzheim [26]. The company, PerceptIn, has FAGVs operating at tourist sites in Nara and Fukuoka, Japan and at an industrial park in Shenzhen, China; and it is just now arranging for its vehicles to shuttle people around Fishers, Ind., the location of the company's headquarters [27].

FAGVs with their strengths and limitations are practising a lot in very complex real and artificial environments to have the most experienced driver on roads. About half of U.S. states (e.g., Arizona, California, Georgia, Michigan, Nevada, Texas, Pennsylvania, and Washington) allow testing of FAGVs on public roads, with varying regulations [14]. The real-world tests of FAGVs even with backup drivers on the roads have come into question after several fatal accidents with AGVs. Nonetheless, FAGVs are being tested in real-time in a number of places without the necessity of a back-up driver such as Arizona, California, Michigan, and Ohio [13]. Effective testing and simulation environment is a vital part in the research of self-driving cars, which can test self-driving software and hardware quickly in different virtual environments at low cost [33]. Ten officially designated autonomous vehicle test sites designed and supported by the US Department of Transportation, one of which is GoMentum Station in California with 20 miles of paved roads and a cluster of barracks and buildings in an urban environment, provide grounds to help set the direction of policy-making and testing procedures for FAGVs [34]. The University of Michigan has developed an ecosystem of automated cars — Mcity, partnering with industry (Ford, Nissan, Toyota and General Motors) and government to test out fleets of connected vehicles and automated technology [35]. Several self-driving companies have also built their fake cities to put their vehicles through a series of structured tests without having to worry about unpredictable environments, specifically to test interactions with humans and provide privacy for their research. Examples of these fake cities with simulated city streets are Waymo — Castle [36], Toyota — 60-acre facility [34], Uber — Almono [37].

California almost certainly has more self-driving cars and operators on public roads than the rest of the world because it is home to Silicon Valley, where everything a prospective driverless car manufacturer needs software engineers, hardware geeks, roboticists, venture capital is available in a near-endless supply [24]. Virtually every large technology company — and most mainstream automakers — have offices in the Bay Area whose reliably mild, dry, and sunny climate is perfect for road testing of early generations of vehicles that still balk at the snow, fog, and heavy rain [24]. Google was the first to test experimental vehicles at scale, the first to move from relatively safe highways to unpredictable city streets, and the first to construct a purpose-built, steering-wheel-free, self-driving prototype [24]. Google has around twice as many AGVs and drivers on California's roads as everyone else combined [24]. Tests of 103 self-driving cars from nine manufacturers in 2017, driven over one million km on Californian roads, found Google's Waymo scored best with just one human intervention every 8,250 km [25].

---

[12] https://media.groupe-psa.com/en/psa-peugeot-citro%C3%ABn/press-releases/innovation-technology/autonomous-cars-paris-amsterdam

[13] https://www.abc15.com/news/region-southeast-valley/chandler/waymo-car-involved-in-chandler-arizona-crash

TABLE 2. Accidents caused by AGVs. AP stands for autopilot.

Application	Accident	Reason
2017 Volvo XC-90 SUV	An Uber-operated AV at 40 mph, for the first time, struck and killed 49-year-old Elaine Herzberg who was crossing the street with her bike in Tempe, Arizona on March 18, 2018 [28].	A human "safety driver" behind the wheel was not looking at the road as the videos acquired from the two cameras in the vehicle show. The environment is very dark and she was not using the crosswalk.
Google's AV Lexus SUV	A Waymo AV for the first time was involved in a crash at 2 mph bumped a bus that is at 15 mph in California toward the centre of the lane ahead of the bus in 2016 resulting no injuries [29].	Google says the car and the test driver assumed that the bus would yield when it attempted to merge back into traffic for a right turn. The bus didn't stop causing the accident with this misunderstanding.
Google's AV Van	A Waymo minivan with minor injuries in Chandler, Arizona while in autonomous mode in Chandler, Arizona on May 4, 2018, while in autonomous mode resulting in no injuries [13].	A driver ran a red light in Chandler and collided with the van as the video acquired from the cameras in the van and Police said Waymo's van was not the "violator vehicle".
Tesla AV Model S	The car on AP at 74 mph bumped a truck on a highway with a 65 mph speed limit and killed Joshua Brown driving the car in Florida on May 7, 2016 [19].	AP did not do an adequate job of detecting other traffic and did not inform the driver early enough to allow for sufficient reaction time.
Tesla AV Model X	The car on AP crashed headfirst into the safety barrier, the vehicle caught fire, and two other cars crashed into the rear end killing Wei Walter Huang in May, 2018 [30].	The driver had received several visual and one audible hands-on warning earlier and was not responding to warnings to re-take control.
GM Cruise	The car on AP in heavy traffic stroke a motorcyclist, Oscar Nilsson while changing the lane and knocked him to the ground with minor injuries in San Francisco in 2017 [31].	The car saw a space between two vehicles and began to merge, a vehicle decelerated and returned to the centre lane, which caused the accident. The AP is not successful in detecting motorcycles.
GM Cruise	GM Cruise vehicles were involved in 33 accidents in California [31].	None have been declared to be the fault of GM Cruise, California records show.
Uber	A self-driving car killed a woman in March, 2018 in Arizona [32].	The backup driver was watching a video on her phone at the time of the crash and AV apparently did not alert her to take over the vehicle during the incident.

While FAGVs are taking their places on city roads, today, and every day, worldwide, one million more people are born-into or move-into a city, and it is envisioned that this will continue for the next 30 years [38]. The global population is expected to double by 2050 [39] and more than 68% of the population will be living in an urban environment by 2050, most visibly in developing countries [40] with a population of 5 billion [41]. The pressure is growing on city governments to leverage every opportunity to improve the quality of life for inhabitants [42] due to the ever-growing demands of citizens, economic concerns, and imminent environmental risks. In this manner, to alleviate the problems of rapid urbanisation and to improve the liveability of citizens, there are many concerns to be taken into account in urban development and management [43], [44]. Recent advances in cyber-physical domains, cyber-physical-social systems, cloud platform, cloudlet, and edge/fog platforms along with the evolving Big Data (BD) analytics, Internet of Everything (IoE), Automation of Everything (AoE) [45], Advanced Insight Analytics (AIA) [45], ubiquitous sensing, location-independent real-time monitoring and control, dynamic vision analysis, heterogeneous network infrastructure, and cutting-edge wireless communication technologies (e.g., 5G and beyond) within the Industry 4.0 are providing many opportunities and urging city governors to pursue the ways that enable efficient and intelligent management of cities with effective public services [43] involving the effective use of FAGVs within SC contributing the sustainability and mobility of the city. To reduce the burden on cities and to make them smarter and sustainable, a novel framework entitled "TCitySmartF" was proposed in a recent study [43] that demonstrates a variety of insights and orchestrational directions for local governors and private sector about how to transform cities into automated and connected smarter cities from the technological, social, economic and environmental point of view, particularly by putting residents and urban dynamics at the forefront of the development with participatory planning for the robust community- and citizen-tailored services. Within this context, the safe use of FAGVs is the prime concern in SCs as accidents occur with FAGVs on city roads, examples of which are presented in Table 2.

Several approaches such as [46], [47] have been recently developed to make swarms of FAGVs safer and optimised in urban roads using the fusion of data from connected multiple AGVs, i.e., swarm intelligence using the understanding of connected and autonomous vehicles (CAVs) within the concept of Cooperative Intelligent Transportation System (C-ITS). Cui *et al.* [48] investigate the intelligent management of FAGVs within SC from the perspective of BD analytics that can process unstructured BD effectively where most of the BD is in unstructured format [49]. In a recent study, Minh *et al.* [50] emphasise the importance of using fog and cloud computing by supporting edge analytics for ITS services in using CAVs within SC effectively. Most of the recent studies analyse FAGVs from the perspective of CAVs within C-ITS using vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) without considering the recent developments in the SC initiatives. The literature review carried out by the authors of this article has shown that there is a big research gap in using FAGV in a highly automated SC environment effectively. This article highlighting this research gap and proposing a comprehensive holistic framework moulds the CAVs concept with the automated and connected SCs concept within A-ITS to exploit the full potential of FAGVs benefiting both concepts in an orchestrated and synergistic way. Within the vision of A-ITS, one of the major issues to be managed by the city governors is the effective and safe navigation of FAGVs on city roads based on the city autonomous swarm intelligence for making the urban traffic flow optimised and they do not seem to be empty-handed, full of ammunition, on the contrary, makes them exploit this forthcoming technology substantially — turning the challenges into advantageous tools. This article demonstrates that cooperation and coordination among the various SC components and traffic participants are an integral part of the optimisation of mobility in a city. With this in mind, a holistic framework — FAGVinSCF is developed in this article to incorporate FAGVs into SC effectively and efficiently. Different from the existing works, with this framework, FAGVs can use the swarm intelligence created by both all other FAGVs and SC leading to the observation of all city roads beyond the capabilities of their sensors and accordingly, leading to the optimisation of their actuation and routing and mobility of the city. The potential benefits of the framework are demonstrated with a modelling and simulation study in Section III-B7. More similar modelling and simulation studies can be executed to reveal the further virtues of the framework within various urban sceneries as indicated in Sections III-B7 and V as a future research.

III. METHODOLOGY

Before revealing our techniques and approaches proposed in this study, we would like to explore the main features and components of FAGVs and SCs briefly in Section III-A to make these techniques and approaches easier to understand with the agreed-upon terminology.

A. BACKGROUND OF THE METHODOLOGY

SCs and FAGVs have their particular components and these components need to be well integrated harmoniously to result in a synergistic environment benefiting both FAGVs and SC objectives. The main components of SC and FAGVs are presented in Fig. 1. These components which are the basis for integrating FAGVs with SC are revealed in the following two subsections to shed light on an effective way of smoother integration.

1) MAIN FEATURES AND COMPONENTS OF SC

A holistic SC framework is presented in [43] and the main objectives of establishing SCs are summarised as i) enabling the integration of the distributed services and resources in a combined synergistic fashion, ii) improving existing public services and providing new effective citizen-centric, user-driven, and demand-oriented services, iii) monitoring a city with easy-to-use visualisation tools, iv) enabling near-real-time services for end-users and/or further smart actuation, v) increasing the sustainability with optimised services, and vi) driving economic development, innovation, and global city investment competitiveness. The cloud platform (placed in the dedicated section titled ''A. Cloud platform smart domains'' in Fig. 1) with vertically expandable data storage and processing capabilities has the advantages for massive storage, heavy-duty computation, global coordination and wide-area connectivity [51], while edge, fog and Mobile-Edge Computing (MEC) platforms (placed in the dedicated section titled ''B. Smart City (SC) edge/fog/MEC smart domains'' in Fig. 1) are useful for real-time operations and responses, rapid innovation, user-centric services, and edge resource pooling [52]. Strictly speaking, edge, fog and most recent popular platform, so-called MEC are the emergent architectures for computing, storage, control, and networking that distributes these services closer to end-users [52] to enable a more independent processing and organisation, particularly for the applications requiring real-time decision-making, low-latency, ultralow-latency, high privacy and security with mobile services [43]. In order to enable low-latency and increase efficiency further, multiple edge/fog/MEC nodes may be needed to support highly distributed devices and systems over large geographic areas [43]. Data collected either from IoT devices or users is aggregated, sanitised, filtered, processed for insight generation and compressed in the edge/fog/MEC platforms to be sent to the cloud platform resulting in reduced network traffic, and reduced computation and storage costs in the cloud platform [43].

a: SENSING, ACTUATION, COMMUNICATION AND COOPERATION IN SC

The large deployment of IoT and AMSs is actually enabling SC initiatives all over the world using the sensing capabilities of everyday objects [53], [54]. With IoT and AMSs, physical objects are seamlessly integrated globally so that the physical objects can interact with each other and to cyber-agents in order to achieve mission-critical objectives [55]. IoT ecosystems play a vital role to gather rich sources of information and different cities have already deployed IoT infrastructures and a variety of sensory devices to collect continuous data [56]. Wireless sensor networks (WSN) enabling the collection of data from a countless number of widespread sensors is the main building block in establishing effective SC applications [45]. Most recent data analytic tools designed to work on the cloud platforms are analysed in [57]. The orchestration of resources and network traffic across geo-distributed nodes are provided using specialised interfaces such as OpenStack and OpenFlow enabling software-defined network (SDN) controller to manage distributed nodes effectively and efficiently. The evolution of SDN allows for a logically centralized but physically distributed control plane by eliminating vendor dependency and compatibility issues between different networking devices [58].

The connectivity of the SC objects relies on different types of networks and communication technologies to perform collaborative tasks for making the lives of the inhabitants more comfortable [59] in seamless communication ecosystem as shown in the dedicated section titled ''C. SC Communication infrastructure'' in Fig. 1. Heterogeneous networks integrating cellular networks, wireless local area

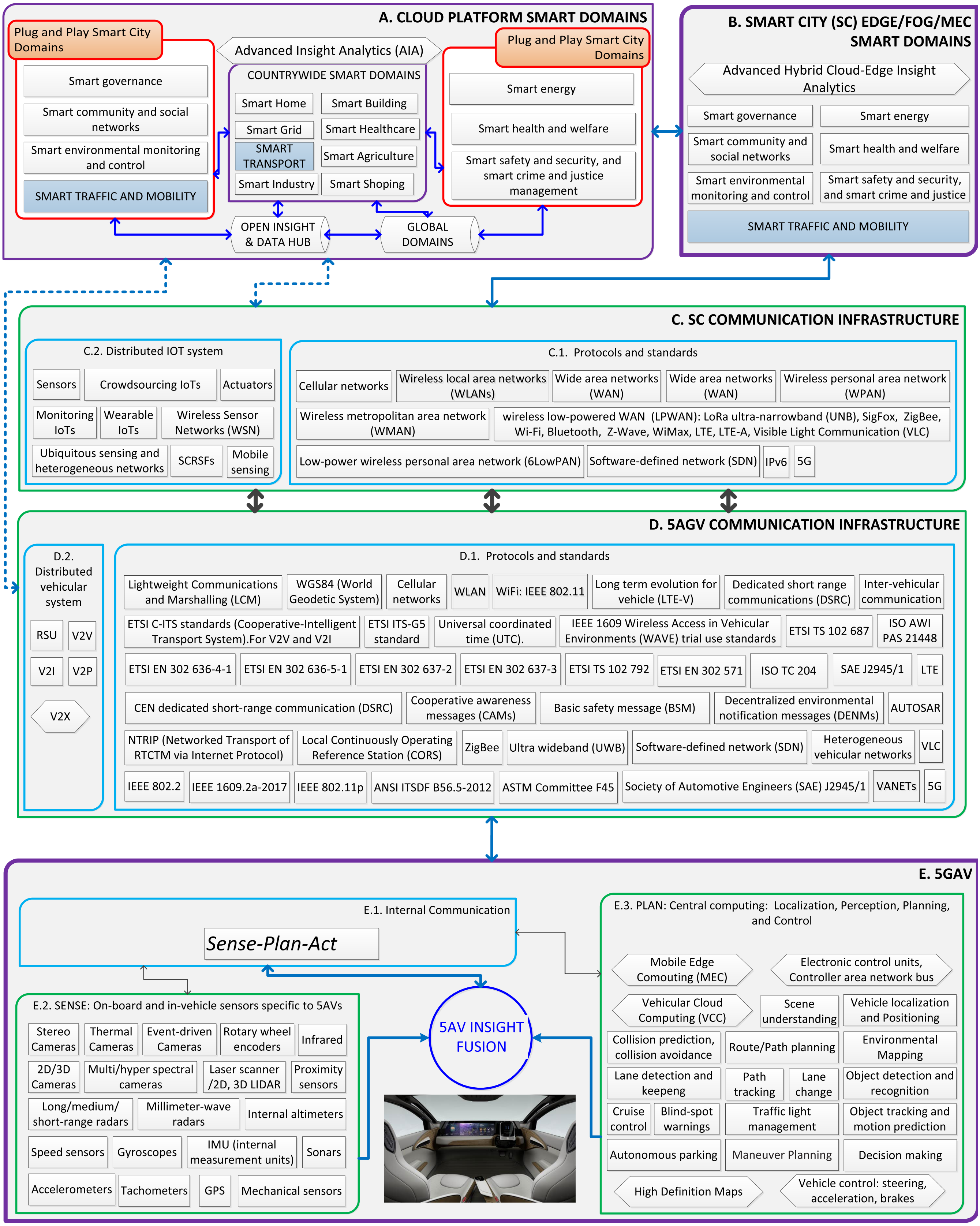

FIGURE 1. Main components of SC and FAGVs and their integration with one another using their current communication abilities.

networks (WLANs), wide area networks (WAN), wireless personal area network (WPAN), wireless metropolitan area network (WMAN) are the backbone of SC and aim to provide a wide variety of connectivity services with a seamless communication between the physical and cyber world in a highly interconnected smart public infrastructures and services [43]. The IoT devices spanning several kilometres are integrated using IPv6 addressing, particularly via low-power wireless personal area network — 6LowPAN. Several wireless low-powered WAN — LPWAN technologies such as LoRa ultra-narrowband (UNB) with an urban range of 2-5 km and SigFox with an urban range of 3-10 km support IoT deployments [53] along with 3G/4G, millimetre-wave communications, Zig-Bee (10-20 m), Wi-Fi (100 m) or Bluetooth (1-100 m), Z-Wave (100 m), WiMax (50 km), LTE (30 km), LTEA (30 km) using small cell technology and Visible Light Communication (VLC). Throughout these technologies, public Wi-Fi primarily supports the real-time SC applications in a crowdsourcing way, particularly, using location-aware services [43]. We envision that the use of fifth-generation (5G) with high capacity, high speed, high data transmission rates, high reliability, high availability and low-latency abilities will increase the efficacy of communication between FAGVs and SC substantially.

b: SC DOMAINS

The main smart domains within SC are smart government, smart environmental monitoring and control, smart energy, smart community and social networks, smart safety, security, crime and justice, and smart traffic and mobility.[14] These domains are not only strictly connected to each other, but also with the countrywide and global smart domains in the cloud platform to create a harmonious synergistic city environment coordinated globally as shown in the dedicated sections titled ‘‘B. SC edge/fog/MEC smart domains’’ and ‘A. The cloud platform smart domains’’ in Fig. 1. Management of FAGVs in SC domains essentially should be integrated with the SC domain, ‘‘Smart Traffic and Mobility’’ so-called sTrafficMobility.

The main goal of sTrafficMobility is to monitor city dynamics and direct these dynamics in order to make a city life smoother and easier (e.g., optimal mobility, less congested, less polluted environment) [43]. The intelligent mobility and traffic system could enable us to calculate the best route in real-time by connecting different transport modes to save time and reduce carbon emissions [53]. The essential elements of sTrafficMobility are i) smart traffic management (e.g. traffic monitoring, routing, prediction and directions, smart traffic signals/lights), ii) smart public transportation with public transport networks involving a shared ride (e.g., shared taxis, flexible car-sharing), iii) smart cycling (e.g., shared bikes), iv) intelligent parking, v) intelligent delivery (e.g., package delivery, fresh food delivery by trucks), vi) smart human mobility and commuting (e.g., elder, disabled people mobility) and pedestrian management (e.g., the flow of people), vii) smart autonomous driving supported by new hybrid and electric vehicles, and AGVs, viii) collision avoidance, ix) autonomous toll collection, and x) smart supply chain integrated with ‘‘smart industry’’ and ‘‘smart shopping’’ [53]. All these elements involving FAGVs should be orchestrated properly and appropriately to generate smooth mobility and traffic within SC.

2) MAIN FEATURES AND COMPONENTS OF FAGVs

FAGVs are equipped with up-to-date HD maps, sensors, high processing power, advanced AI tools, and actuators to safely interact with the environment, other vehicles, and pedestrians using advanced communication technologies. In this way, they avoid any accident and perform their tasks successfully. They can first, i) sense the environment, second, ii) interpret the sensed data, third, iii) plan proper action in regards with the main objectives and finally, iv) act appropriately using the robust combination of network, hardware (HW), and software (SW) components. The components of FAGVs are presented in Fig. 1 D and E.

a: SENSING AND ACTUATION IN FAGVs

Visual perception of the current state of their surroundings is obtained by FAGVs using a variety of sensor technology known as line-of-sight (LOS) sensors to perform their mission-critical tasks. Main sensors in FAGVs are displayed in Fig. 1 E2. Lateral control using the steering angle, longitudinal control using the acceleration level (i.e., acceleration torque) and the brakes status (i.e., braking torque) of the autonomous vehicle are three main actuators required to be coordinated harmoniously concerning the dynamically changing environment for performing all kinds of non-linear manoeuvrers within optimised actions. Interested readers are referred to the studies [27], [60] for more information about the AV sensor technologies, how they function and how data acquired from different combinations of these sensors is analysed and fused for decision-making.

b: FAGV SUBSYSTEMS, COMMUNICATION AND COOPERATION

FAGVs are designed to surpass the performance of expert human drivers in decision-making with both overall understanding of complex contextual relations and 3D environmental modelling using 360° of environmental observation supported by multiple sensors and Advanced Insight Analytics (AIA) — AI with Reinforcement Learning (DRL), Deep Learning (DL) with Neural Networks (NN), and Machine Learning with Ensemble Techniques (ET) without human input. The processing and fusion of data generated by various on-board sensors for real-time responses requires significant computing power. The main modules on FAGVs are designed based on four essential phases, namely, i) localisation (e.g., using global position system (GPS), internal measurement unit (IMU), ultra-wideband (UWB), simultaneous

---

[14] Interested readers are referred to the study [43] for detailed information about these SC domains.

localisation and mapping (SLAM), and offline map matching localisation [61]), ii) perception, iii) planning, and iv) control [62] with respect to the odometry data [63] through the instances — steering (changing lanes, turning), accelerating, and braking. Main subsystems and employed communication technologies and standards in FAGVs are shown in Fig. 1 E3 and D respectively.

FAGVs can visually map the streets of a city involving both static (e.g., road structures) and mobile objects (e.g., other vehicles, pedestrians) based on the data acquired from their sensors wherever they travel to achieve their tasks effectively. They employ HD maps on multiple layers to plan and perform their manoeuvrers properly. As explained in [27], the bottom layer of an HD map is a map with grid cells that are about 5 by 5 cm; it's generated from raw LIDAR data collected using special cars. This grid records elevation and reflection information about the objects in the environment. On top of that base grid, there are several layers of additional information. For instance, lane information is added to the grid map to allow FAGVs to determine whether they are in the correct lane. On top of the lane information, traffic-sign labels are added to notify FAGVs of the local speed limit, whether they are approaching traffic lights, and so forth. This helps in cases where cameras on the vehicle are unable to read the signs.

FAGVs can get connected to each other to respond cooperatively to a dynamic environment using agreed-upon communication technologies and standards (e.g., cellular networks, ad-hoc networks (VANETs)). Although cellular networks enable convenient voice communication and simple infotainment services to drivers and passengers, they are not well-suited for certain direct V2V or V2I communications [64]. Cellular network capacity can reach near-limits because of heavy traffic coming from cellular networks [65] and it might be costly for most people worldwide to access the Internet via cellular networks [66]. On the other hand, VANETs with a bandwidth ranging from 10 to 20 MHz comprise V2V and V2I communications based on wireless local area network (WLAN) and can send and receive hazard warnings or information on the current traffic situation with minimal latency [64]. According to the IEEE 802.11p standard that is used with VANETs, vehicles can share their location information such as position, speed, acceleration, and other control information with their neighbours [5]. Visible Light Communication (VLC) is also used in a connected car environment with a perfect line of sight where transmitters and receivers are installed in the headlights and taillights [67]. Interested readers are referred to the study [10] for more information about the subsystems, to the study [68] for communication technologies and standards, and to the study [69] for commonly employed security techniques in FAGVs.

ITS with vehicular networks incorporate tools as an example of CPS which integrates telecommunications, electronics and information technologies with transport/traffic engineering to improve transportation system efficiency [68], [70]–[73]. A new field titled C-ITS focusing on this particular area has emerged as a new research direction [74], mainly to coordinate FAGVs to pass through intersections points (e.g., Passing-Through Intersection (PTI) problem) [75]–[77] and FAGVs manoeuvrer in coordination with each other on roads [78] at a carrier frequency of 5.9 GHz [68]. C-ITS use the connectivity between vehicles, roadside infrastructure, and other road users (i.e., V2X) to enhance driving safety and comfort, and improve traffic management [73] and sustainability where the key enabling technology is V2X communication technology [71]. With V2I, sensors deployed along the road can monitor the movement of vehicles and if an emergency is required, it can be communicated to the approaching vehicles for actions to be taken in a time-efficient manner [79]. Vehicular Cloud Computing (VCC) was proposed to address the challenges and issues of vehicular networks, mainly traffic management, road safety-making [80] and route planning where users collaborate to share traffic images [81] by using vehicular resources integrated with internet. However, this approach still lacks in meeting the low-latency requirements of ITS and providing near-real-time dynamic traffic activities.

B. INTEGRATION OF FAGVs WITH SC AND FAGVinSCF

The concepts of IoE and AoE bring the people, organisations, lives, processes, data, and things into a concrete coherent structure - cyber-physical systems (CPSs) to develop a synergistic smarter connected globe [43]. Strictly speaking, we are on the verge of integrating everything location-independently within the concept of AoE with the help of CPSs connected to the edge/fog/MEC and cloud platforms. With this in mind, most of the current SC development and enhancement attempts are mainly focusing on urban mobility involving the flow of pedestrians within the domain of sTrafficMobility and a huge amount of investment has been underway in sensor-rich mobile devices, particularly in self-driving vehicles to support crowdsourcing applications to be able to observe the instant urban dynamics for near-real-time smarter decision-making [43]. An SC framework is presented in [43] and FAGVs within SC cannot be independent and should be integrated well with the SC framework both to realise their objectives swiftly and to be more functional with the other components of SC enabling smoothly working SC ecosystem. The automation of vehicles is one step forward toward the fully automated transportation networks as there will be still a need to automate other actors of the transport network such as traffic police agents, highway maintenance, and support teams [82]. FAGVs with the promising abilities of i) charging/fuelling and controlling itself with the power of being electrical, ii) sensing its environment using its sensors, iii) collecting BD via sensors and M2M communication to complete their mission by adapting the environmental dynamics, and iv) self-driving are expected to impact sTrafficMobility in SCs and countrywide and international smart transportation substantially by alleviating the problems of urbanisation. FAGVs collect very BD volumes during their missions within SC. The framework that aims to integrate the components and abilities of both SCs and FAGVs in a synergistic environment by taking the human behaviours and city dynamics into account with humanless technology - FAGVinSCF proposed in this study as a moderator is illustrated in Figs. 1, 2, 3 and 4 along with Algorithms 3 and 4 in a multi-dimensional and multi-functional manner. With FAGVinSCF, the communication and coordination between FAGVs and other SC components is provided with SC agents using Vehicle-to-Agents (V2A) to meet the urgent input requirements of low-latency real-time decision-making by mapping all concerning Region of Interest (ROI) beyond FAGVs' perception. First, we would like to explain the architecture of FAGVinSCF in Sections III-B1, III-B2, III-B3, III-B4 and III-B5 before exploring the merits of the automation within FAGVinSCF in Sections III-B6 and III-B7.

1) COMMUNICATION AND DATA SHARING APPROACHES BETWEEN FAGVs AND SC

Off-the-shelf communication technologies, standards and protocols used in both FAGVs and SCs are shown in Fig. 1 C and D. The study of the Internet of Vehicles (IoV) has sprung up, where vehicles perform as sensor hubs to capture information by in-vehicle or smartphone sensors, then publish it for consumers [83]. Delay-tolerant data can be offloaded and transmitted through connected vehicle networks without any extra infrastructure or hardware deployment on vehicle MEC platform equipped with on-board units (OBUs) connected to the SC facilities using VANETs [84]. However, effective and efficient implementation of A-ITS with high level of BD sharing abilities requires new communication approaches to establish a diligent integration and to meet the low-latency requirements of A-ITS between these two major developing fields. Moreover, there is no agreed-upon data sharing protocols and standards based on essential policies of synergistic moulding of these two developing fields. We can safely conclude that, the emerging communication infrastructure — 5G with high data transformation ability will be the key enabler to provide not only a seamless communication, but also low-latency abilities between SC and FAGVs. Continuous BD exchange in few seconds between the vehicle MEC and SC edge/fog/MEC platforms and cloud platform via cloudlets is highly important to establish the FAGVinSCF framework using advanced communication channels such as 5G via the SC infrastructure explored in Section III-B4 and components.

2) USE OF FAGVs MEC, SC EDGE/FOG/MEC AND CLOUD PLATFORMS

With efficient use of the MEC on board, SC edge/fog in SC and cloud platforms, FAGVs can plan and operate collaboratively not only locally, but also throughout the entire city based on the bigger observation of all current traffic activities and imminent traffic plans, which significantly enhances the efficiency of FAGV and SC mobility and sustainability of cities. More specifically, the current activities and future plans with imminent route planning involving the learned experiences such as information about the road, traffic conditions, and potential obstacles can be conveyed to other FAGVs with the automation of ITS within SC. The data traffic should be reduced as mush as possible using the local computing power to meet the low latency requirements. Supercomputers on-board within the vehicle MEC can process a huge amount of data rapidly and the sharing of processed data/insights rather than all acquired image/video or sensor data reduces this data traffic significantly. Furthermore, on the SC side, the processing of city-wise or street-wise acquired BD processed at the SC edge/fog/MEC platforms with high computing power for decision-making and generating insight for specific FAGVs diminishes this data traffic substantially. For instance, optimised routing schemes for FAGVs to reach their destination based on their current locations can be determined within the SC edge or fog rather than sending all required BD to FAGVs for their processing and route determination. Moreover, FAGVs and SCs can leverage the benefits of the cloud platform for the execution of resource-hungry requirements such as city-wise HD map generation, deep learning training, long-term-sensor data storage for further processing e.g., prognosis/diagnosis of any imminent failure or improvement of vehicle performance. In this respect, context-aware data sharing standards and protocols should be agreed-upon between the stakeholders as mentioned earlier in the previous section.

Optimisation of fuel cost and emissions locally was proposed by Alsabaan *et al.* [70] using first traffic-light-signal-to-vehicle (TLS2V) and then V2V communications by adjusting the speed of vehicles based on traffic signals. Within FAGVinSCF framework, orchestration of the SC and FAGV components are performed using the SC fog platform via SC facilities such as SC Road Side Facilities (scRSFs) that is explained in Section III-B4. Vehicles in Region of Interests (ROIs) of scRSFs or other SC facilities are not just informed about the imminent traffic light signals, but also, informed about the congestion, accident, road-closed cases in advance related to the routing of vehicles for better decision-making such as best routing, lane selection, speed, acceleration and deceleration, which is explained in Sections III-B6 in detail.

3) CROWDSOURCING USING FAGVs AND SC

The optimisation of mobility based on evolving mobility patterns (e.g., passenger volumes by various public services, taxi, bike; travel route, duration, intervals, displacement, distributions among services) within different days (e.g., public holidays), rush hours and peak times, or weather conditions is required to make the city dynamics flow seamlessly with effective decision-making abilities (e.g., congestion management, deploying new bus routes and stations, optimal use of the roads and parking spaces). Detecting and determining timely-manner mobility patterns requires the engagement with mobile crowdsourcing input and integration of all mobility services involving the information about private car use and driving habits, particularly to enable the optimisation of real-time mobility. The use of mobile crowdsourcing utilities and V2X collaboration in driving helps near-real-time monitoring of large urban regions efficiently. A huge amount of information are already being collected within SCs using highly distributed IoT and AMSs with WSNs and highly distributed heterogeneous communication nodes as detailed in Section III-A1. Vehicular crowdsourcing significantly reduces the financial and time costs needed for city governments to collect data and the trend is for FAGVs to replace humans to collect sensing data in cities [85]. Following the development of IoV and crowdsourcing techniques, Vehicular Social Networks (VSNs) as the emerging paradigm (i.e., the integration of IoV and social networks) are promising to solve the ever-increasing road accidents, traffic congestion, and other such issues that become obstacles to the realisation of the smart traffic in cities. VSNs are likely to pave the way for sustainable development by promoting mobility efficiency [83] and human factors that impact vehicular connectivity using the cloud platform and conventional V2X communication frameworks. In the project — scoop@F, carried out by the Ministry of Transport in France, vehicles in city roads will be connected to the smart route and interconnected via Wi-Fi, 4G or 5G technologies to share information about traffic, accident, presence of debris or an animal on the road [59].

Vehicle mobility information and the information acquired from the other SC mobility components (e.g., peoples‘ mobility) should be integrated to each other for more efficient mobility. The reasons for steering the crowd might be for emergency evacuation, guided tours, safe movement of people during large rallies and concerts, regulating the use of spaces or for commercial purposes (e.g., steer crowds to move through certain businesses areas) [86]. Car ownership poses a challenge in using crowdsourcing applications regarding the privacy and security concerns. In this sense, reducing car ownership using FAGVs with increasing ride-sharing without the costs and responsibilities of ownership will increase the crowdsourcing applications as a near-term reality. FAGVs equipped with onboard sensors (e.g., CO_2 emission measurement sensor) and wireless communication devices, integrated with SC may turn into eyes, ears and noses of the city. In turn, FAGVs can be supported by lots of real-time crowdsourcing data. Cooperative crowdsourcing enables cooperative crowdsensing, which increases the efficacy of decision-making. Dynamic road traffic monitoring, parking space detection, detection of road abnormalities with surface monitoring, air quality with a variety of sensors can be observed by FAGVs. With the help of the crowdsourcing applications using the FAGVs MEC, SC edge/fog/MEC and cloud platform, the realistic picture of the roads and traffic activities involving all the other vehicles not equipped with FAGVs technologies can be generated.

4) FAGV INFRASTRUCTURE DESIGN WITHIN SCs

The integration of FAGVs with SC will make the road design change significantly in which FAGVs can interact with their environments easier using digital information-sharing mechanisms such as digital traffic signs and scRSFs that can be communicated with via wireless channels. Stationary scRSFs as edge nodes with a full sensor suite of i) LIDAR with night-vision capabilities and a range of 150 meters observing the position and geometric structure of objects, ii) radar with a range of up to 200 meters, and iii) cameras supported by infrared with 60 frames per second and capable of producing high resolution images about 1 gigabyte of raw data per second, placed at appropriate locations over city roads can collect much useful instant information for specific ROIs. An effective placement of scRSFs along the city roads in which they overlap one another’ ROIs not leaving any dead-zone is illustrated in Fig. 2. They can be placed at high locations in order to both cover as much road section as possible and reduce end-to-end transmission delay. scRSFs interconnected to each other with high computing/processing powers for meeting low-latency requirements can process instant BD as edge nodes supported by SC fog for providing FAGVs with real-time insights for their instant decision-making requirements such as optimal route planning, lane-changing, acceleration/deceleration and collision avoidance. In particular, an optimal number of scRSFs can be deployed starting from the regions with high traffic density and equipped with most advanced sensors similar to the ones on-vehicle-board for 3D modelling of their ROIs, which allows a smoother communication with FAGVs regarding using same type of processed outcome. scRSFs as a network of roadside units serving as an edge platform are connected to SC fog platform using fibre-optic cables where available, otherwise wireless as illustrated in Figs. 3 and 4. With this design, non-delay tolerant applications such as collision-avoidance and speed adjustment systems use the parallel processing of information via (scRSF)2(scRSF) at the edge platform. scRSFs are designed to establish a seamless wireless communication channel with FAGVs as service providers and gateways to the SC fog and cloud platforms. Each FAGVs communicates with an scRSF within its ROI (around 50-150 m regarding the sensor ranges) for data/insight exchange. Autonomous UAVs equipped with required sensors both connected to SC and FAGVs can be deployed to capture the traffic flow and road activities for the remote regions with low traffic density where placing scRSFs might be expensive.

Power control and the average transmission power required for communication are the two major issues with the SC facilities regarding the sustainability of SC. scRSFs can be idle with the sleep mode if there is no motion on the roads, particularly during the night time to save energy. The first scRSF at the edge of any road can turn the others into the active mode where a vehicle enters the road.

5) 3D DYNAMIC MODELLING OF CITY ROADS

HD maps with lane-level accuracy are a topic of particular interest to both map providers and car manufacturers [87]. Detailed static 3D HD map for high-precision position fixes down to a margin of error to 10 cm can be created today

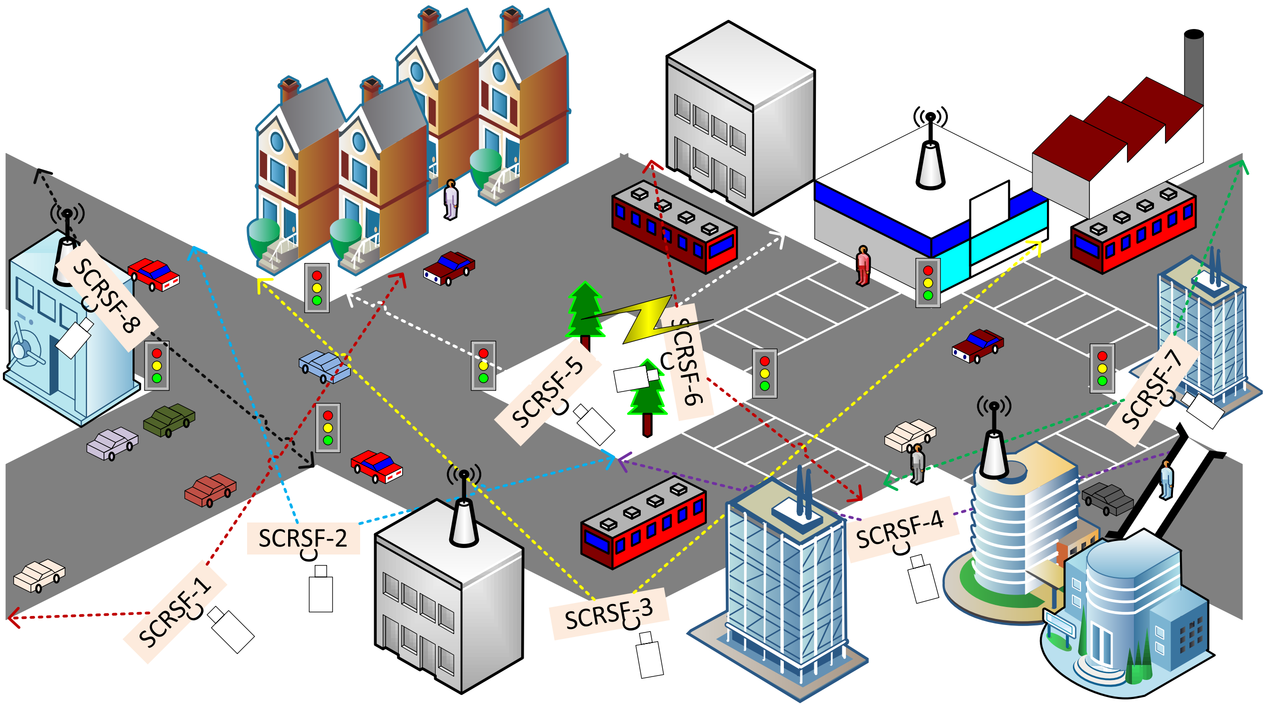

FIGURE 2. Use of scRSFs in SC: The dashed arrows coloured differently indicate the ROIs for each scRSF.

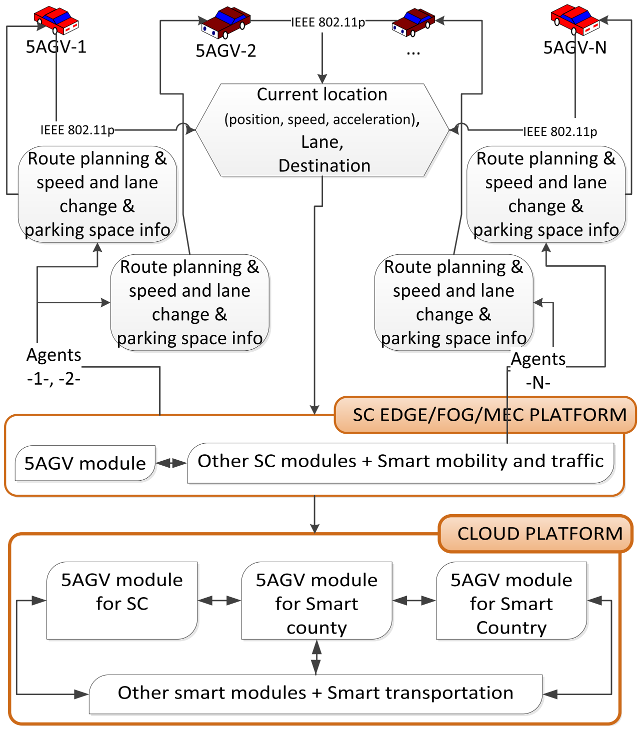

FIGURE 3. Dynamic route planning involving speed and lane guidance: An active agent per FAGV is running in SC as illustrated in Algorithm 1.

using real-time kinematic capabilities [27] and this is ten times as accurate as 2D maps that operate with a margin of error of up to a metre [9]. It is made possible with this 3D mapping to model road surfaces down to the number of lanes and their width, the curvature and slope of the road and surrounding signage [9]. FAGVs using this static modelling involving the map of static obstacles in memory do not need to see the lanes and static obstacles on the roads. Furthermore, with Real-Time Kinematic (RTK) corrections, the solution combining a Global Navigation Satellite System (GNSS) and an Inertial Navigation System (INS) solution can provide both absolute accuracy and continuity for vehicle localisation [87]. More explicitly, the solution provides information on localisation (latitude, longitude, altitude), velocity (w.r.t. east, north, up directions), acceleration (lateral, longitudinal, vertical), rotation (roll, pitch, azimuth) and rotation rate (roll rate, pitch rate, yaw rate) by providing the standard deviations for all these estimates [87]. Using these static and dynamic localisation approaches based on Geodetic coordinates (i.e., latitude and longitude) and Cartesian coordinates, FAGVs can travel from one location to another without using other external sensors if there were not any mobile objects around those vehicles. However, the environment is dynamically changing with traffic participants such as pedestrians, other vehicles, road maintenance, parking space occupancy, changing traffic lights, which requires many other external sensors in order to cope with the challenges in the environment properly. Furthermore, it is urgent to implement near-real-time near-precise 3D dynamic modelling of city roads with all mobile and static objects to make FAGVs react to rapidly changing dynamical city mobility beyond their sensor ability, in particular, to adjust their routes appropriately.

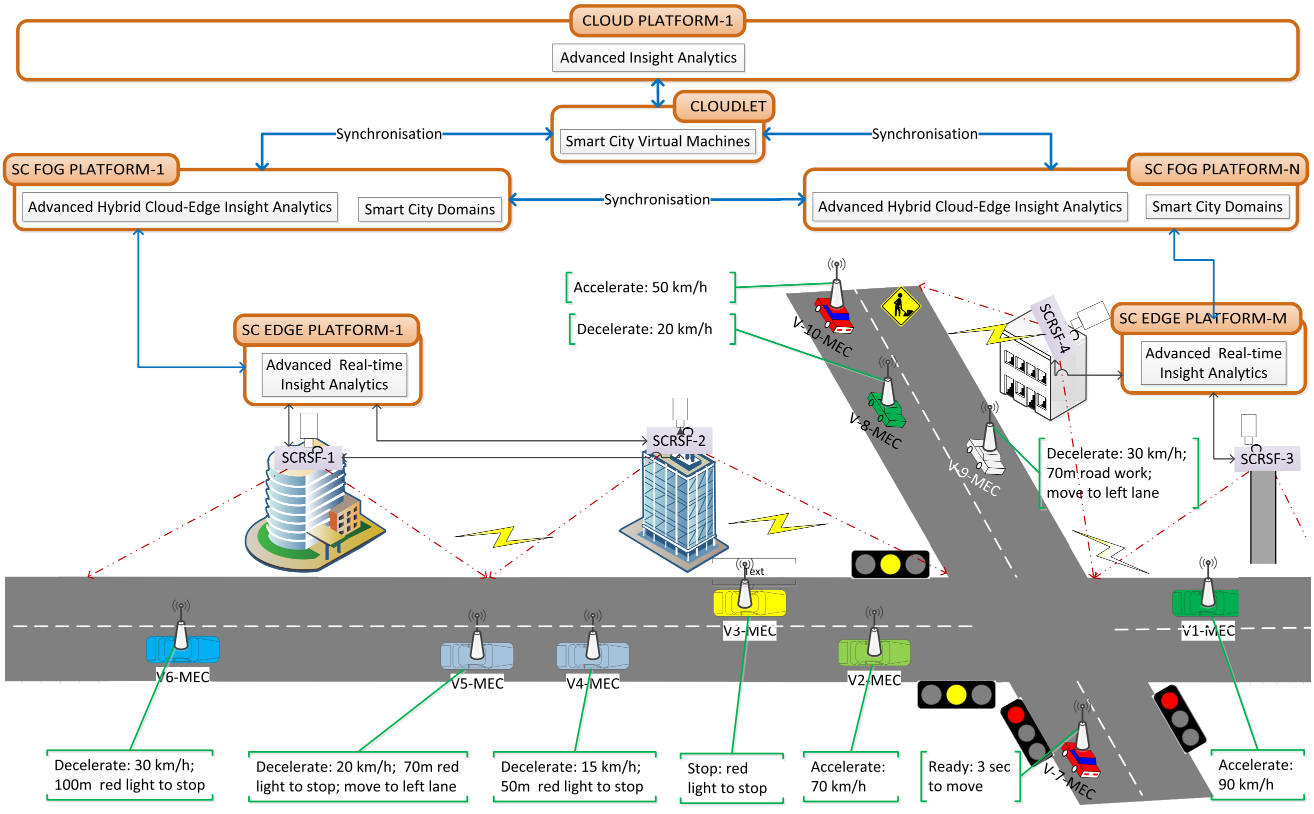

FIGURE 4. **FAGVinSCF: Dynamic speed and lane optimisation: An active agent per FAGVs is running in SC as illustrated in Algorithm 4.**

Near-real-time 3D modelling and mapping of city roads involving all static and mobile objects using the abilities of FAGVs and SC is demonstrated in this section with a new way of thinking. The combination of real-time driving dynamic scenes captured by many FAGVs and the scenes obtained by scRSFs from numerous data points as designed in Section III-B4 is performed to generate 3D dynamic modelling of city roads on realistic maps. First, dynamic scenes (scenes subtracted from the static images) obtained from static scRSF sensors are merged for each street as shown in Eq. 1 to generate the dynamics. Second, scenes obtained from the sensor readings of FAGVs where positional information of FAGVs is of crucial importance are sent to the nearest scRSF and these scenes are mapped for each street based on FAGVs' dynamic locations as shown in Eq. 2. Those particular locational maps can be collected by various edge/fog/MEC platforms established within SC and most recent near-real-time broader dynamic city maps can be established by moulding those particular maps with the instantaneous information collected within SC. Third, these two mappings are rendered to result in one single map to generate the dynamic map of each street as shown in Eq. 3 using the processing power of edge platform (i.e., scRSFs) and finally these street maps are merged to generate a highly detailed 3D dynamic city map as shown in Eq. 4. First three operations are performed on scRDF computing edge units and the final phase are processed on city fog computing units. In this way, the real-time picturing of city streets are exploited by FAGVs on the related street and the HD city dynamic map can be used to direct FAGVs for their routes to arrive their destinations in an optimised manner. scRSFs update SC edge platform as illustrated in Fig. 4 when their current view changed. One agent on the edge platform runs per street for mapping. One agent on the edge platform runs per FAGVs for mapping. The SC edge platform updates first street map and then city traffic map on the SC fog platform. Only changes are registered and rendered on static street and city visual maps to reduce data traffic. Then, those up-to-date city maps out-of-sight of FAGVs can be employed by all FAGVs, mainly to determine the best routes to reach their destination and these routes can be updated during their mission regarding the changing situations (e.g., accident, congestion, difficult road conditions), which is analysed in Section III-B6.

$$StreetscRSF_a.Map = \sum_{n=1}^{t} scRSF_n.Data; \tag{1}$$

$$FAGVs_a.3DMap = \sum_{n=1}^{k} FAGV_n(x,y).Data; \tag{2}$$

$$\begin{aligned} Street_a.3DMap &= StreetscRSF_x.3DMap \\ &\quad + FAGVs_x.3DMap; \end{aligned} \tag{3}$$

$$\begin{aligned} City_A.HD3DMap &= \sum_{n=1}^{t} Street_n.HDMap \\ &\quad + Street_n.3DMap; \end{aligned} \tag{4}$$

Algorithm 1 scRSF Dynamic Street Traffic Mapping (Eq. 1) and City Traffic Mapping Agent: One Agent for Each Street.

```
Data: System input: CityID & AgentID & StreetID &
      scRSFIDs
Data: Instant input: scRSFx.Time &
      scRSFx.ActiveCurrentView
Result: StreetscRSF(StreetID).TrafficMap &
        City(CityID).TrafficMap
=>scRSFs send fused sensed data whenever there is a change;
=>Only difference is sent to reduce data traffic;
=>(scRSFx.ActiveCurrentView = scRSFx.StaticView - scRSFx.FusedSensedData);
while NOT Stopped do
    =>Street agent checks if the view is changed for each scRSF;
    foreach i= 1 to scRSF.number do
        if scRSF(i).ActiveCurrentView != scRSF(i).ActivePreviousView) then
            scRSF(i).Time = CurrentTime;
            scRSF(i).WiewChange = "true";
            =>Update the street map (Eqs. 1 and 3);
            UpdatedData = scRSF(i).ActiveCurrentView;
            StreetscRSF(StreetID).TrafficMap = updateStreetMap(StreetID, scRSF(i).ID, UpdatedData);
            =>Update the city map (Eq. 4);
            City(CityID).TrafficMap = updateCityMap(CityID, StreetID, scRSF(i).ID, UpdateData);
            scRSF(i).ActivePreviousView = scRSF(i).ActiveCurrentView;
        else
            =>Update the database as no change at this time;
            scRSF(i).Time = CurrentTime;
            scRSF(i).WiewChange = "false";
        end
    end
end
```

Algorithm 2 FAGV Dynamic Street Partial Traffic Mapping (Eq. 2) and City Traffic Mapping Update Agent: One Agent for Each Active FAGV

```
Data: System input: CityID & AgentID & StreetID &
      FAGVID & DefinedMaxDataSentTime &
      DefinedLocationChange
Data: Instant input: FAGV.Time & FAGVID (X,Y) &
      FAGV.ActiveCurrentView
Result: StreetscRSF(StreetID).TrafficMap &
        City(CityID).TrafficMap
=>-FAGV sends fused sensed data in various intervals regarding its location change and time elapsed;
while NOT destination do
    =>FAGV and its agent checks if the location is changed as defined;
    foreach -FAGVLocation.changed == DefinedLocationChange && Time.elapsed > DefinedMaxDataSentTime do
        FAGV.Time = CurrentTime;
        =>Update the street map (Eqs. 2 and 3);
        UpdatedData = FAGV(x,y).ActiveCurrentView;
        Street(StreetID).TrafficMap = updateStreetMap(StreetID, FAGV.ID, FAGV.Location(x,y) UpdatedData);
        =>Update the city map (Eq. 4);
        City(CityID).TrafficMap = updateCityMap(CityID, StreetID, FAGV.ID, FAGV.Location(x,y), UpdateData);
    end
end
```

The state of the scene observed is represented on a very high symbolic level by the shape descriptors and the spatio-temporal state variables including spatial velocity components as an integral part (state vector components), which provides an efficient framework for data fusion and active control of the viewing direction [16] regarding not only the current state of imminent 3D modelling of the scene, but also ensuing state of the view using future trajectories of FAGVs with traffic-prediction algorithms where this approach is integrated with the route planning and data obtained from inertial sensors of FAGVs (e.g., speed) as explained in Section III-B6. From a broader perspective, imminent localisation of traffic participants and 3D traffic mapping could be carried out based on the data acquired from both the FAGVs MECs and SC fog computing platform and FAGVs can perform their tasks in an optimum manner using these insights in return. Furthermore, FAGVs using 3D modelling supported by the SC domains providing most urgent information for FAGVs such as weather, road condition and traffic density information can predict how other vehicles on the road will behave to make dynamic decisions in real-time to exploit the most recent picture of the environ-

$$
\begin{aligned}
&Route_{(street_{current(x)} => street_{end(y)})}.TrafficMap\\
&\quad = \underset{street_{current(x)} => \ldots => street_{end(y)}}{\arg\min} f(Time_{(street_{current(x)} => \ldots => street_{end(y)})}).TrafficMap; \qquad (5)
\end{aligned}
$$

ment such as determining the best manoeuvrer for a safe and comfortable trajectory, finding the most appropriate routes, adjusting speed. In other words, 3D instant dynamic mapping is expected to reduce traffic congestion and collisions and to increase the optimisation of mobility.

To summarise this section, the fusing of both data acquired from scRSFs, FAGVs, crowdsourcing and data already on the city fog (e.g., weather, road maintenance) and cloud platforms helps map the most realistic picture of city roads which plays a vital role to help realise the indispensable objectives of FAGVs and SCs in an optimised manner as explored in the following sections.

6) AUTOMATION OF FAGVs WITH SC

FAGVs automated within the SC ecosystem is the imminent future with their immense and immersive abilities and life-saving potential by optimising the mobility, alleviating the FMLM problem with a balance of public and private transportation options and increasing the sustainability of SCs. FAGVs' communication with neighbours and with the surroundings using V2X in real-time with very small transmission and communication delays enables better instant controlling and decision-making in a highly uncertain, unpredictable and volatile vehicle environment. Additionally, for better routing and decision-making, FAGVs need a broader range of information beyond their sensor abilities, which requires a new communication channel and a new approach. Against the numerous improvements and approaches, still, new approaches and techniques are required to cope with the non-linear environment effectively and to optimise C-ITS and mobility with better automation within an orchestrated use of resources involving the automation of all other actors such as traffic police agents, healthcare and highway maintenance. In our approach here, C-ITS is transformed into Automated ITS, in other words, A-ITS where the key enabling communication channel is V2sc using scRSFs. V2sc aims to orchestrate all the required resources within a new framework — FAGVinSCF by optimising the mobility through the real-time and near-real-time exchange of the dynamic information among the road users.

Linking heterogeneous FAGVs in real-time and near-real-time — V2sc based on agreed-upon standards and protocols using the SC abilities empowered with intelligent vehicle-friendly highways and roadway infrastructure can enable low-latency requirements and a smoother life with less accident and less congestion by predicting and planing for upcoming manoeuvres appropriately. If other traffic participants and vehicles could share or even constantly disseminate their plans, vehicles could use this information to reduce the uncertainties and so minimise the buffers within their trajectories and this would enable automated driving vehicles to drive closer to each other (thus increasing the capacity of roads and cities), react more quickly to manoeuvrers, operate with better control, and avoid collisions [68]. Strictly speaking, the establishment of effective communi-

Algorithm 3 SC-FAGV Dynamic Route Planning via Agents Using Eq. 5 and the Dynamic City Traffic Mapping Established by Algorithms 1 and 2. FAGV Updates SC When the Current Street or Destination Changed. SC Proposes a Modified Optimised Route

```
Data: System input: AgentID & FAGVID &
      FAGVStartLocation & FAGVDefaultDestination
      & StartTime
Data: Instant input: FAGVCurrentLocation &
      FAGVCurrentDestination &
      FAGVFusedSensedData &
      FAGVChangedDestination
Result: FAGVubmittedRoute &
        FAGVDestinationArrived &
        FAGVParkingLocation
=>FAGV starts its navigation using its geo-info;
FAGVCurrentLocation = FAGVStartLocation (X,Y);
FAGVCurrentDestination =
FAGVDefaultDestination(X,Y);
FAGVSubmittedRoute = "";
while NOT FAGVDestinationArrived do
    =>Check if the destination is changed during
    navigation;
    if FAGVCurrentDestination ==
    FAGVDefaultDestination then
        =>Find the optimised route;
        $street_{current(x)}$ = FAGVCurrentLocation.Street;
        $street_{end(y)}$ = FAGVCurrentDestination.Street;
        FAGVRoute = findOptimumRoute (Eq. 5 <==
        ($street_{current(x)}$, $street_{end(y)}$));
        if FAGVSubmittedRoute == " " then
            FAGVSubmittedRoute = FAGVRoute;
            sendNewRoute(FAGVSubmittedRoute);
        else
            =>Send the route if it is different;
            if FAGVRoute != FAGVSubmittedRoute then
                FAGVSubmittedRoute = FAGVRoute;
                sendNewRoute(FAGVSubmittedRoute);
            else
                =>Wait until new input comes from
                FAGV;
                LISTEN; SLEEP;
            end
        end
    else
        =>Find the optimised route regarding new
        destination;
        FAGVCurrentDestination =
        FAGVChangedDestination;
        $street_{current(x)}$ = FAGVCurrentLocation.Street;
        $street_{end(y)}$ = FAGVCurrentDestination.Street;
        FAGVRoute = findOptimumRoute (Eq. 5 <==
        ($street_{current(x)}$, $street_{end(y)}$));
        FAGVSubmittedRoute = FAGVRoute;
        sendNewRoute(FAGVSubmittedRoute);
    end
end
FAGVParkingLocation =
findParkingLocation(FAGVCurrentDestination);
sendParkingLocation(FAGVParkingLocation);
```

Algorithm 4 SC-FAGV Velocity Control and Lane Management via Agents Regarding Differential Vehicle Dynamics (e.g., Slip-Based Tire/Road Friction Estimation) Based on Weather Conditions and Street Traffic Mapping Established by Algorithms 1 and 2 Using the Eqs. 3 and 4

```
Data: System input: AgentID & StreeID & StreeMap
      (Algorithm 1) & TrafficLightInfo &
      TrafficSignInfo & JunctionStreets.TrafficInfo
Data: Instant input: FAGVsLocation(xy) &
      FAGVsLane & FAGVsSpeed &
      OtherVsLocation(xy) & OtherVsLane &
      OtherVsSpeed
Result: FAGVsAdvisedSpeed & FAGVsAdvisedLane &
        OtherVsAdvisedSpeed & OtherVsAdvisedLane
        & Vehicles.RequiredInfo
while NOT Idle do
    =>Detect active traffic on the street and analyse it
    using the detected vehicle info (e.g., speed, lane
    shared by vehicles or detected by the sensors on
    street scRSF), traffic signs and lights (Fig. 3);
    [StreetID.TrafficFlowInfo,
    StreetID.TrafficLaneFlowInfo,
    StreetID.LaneDensity, TimeElapsed]
    =analyseTrafficOnStreet (VehiclesIDs,
    Vehicles.Speed, Vehicles.Lane);
    =>Determine the advised speed and lane for better
    traffic flow regarding the traffic signs and light info;
    [Vehicles.AdvisedSpeed, Vehicles.AdvisedLane,
    Vehicles.RequiredInfo] =
    determineVehiclesSpeedLane
    (StreetID.TrafficFlowInfo,
    StreetID.TrafficLaneFlowInfo,
    StreetID.LaneDensity, StreetID.TrafficSignInfo,
    StreetID.TrafficLightInfo, VehiclesIDs,
    StreetID.Tire/roadFrictionEstimation,
    TimeElapsed);
    =>Send the determined advised info to vehicles
    (Figs. 3 and 4);
    submitAdvisedSpeedLaneInfo
    (Vehicles.AdvisedSpeed, Vehicles.AdvisedLane,
    Vehicles.RequiredInfo);
    =>Report vehicles to police if they are behaving
    strangely out of the rules;
    reportVehiclesToPolice (Vehicles.Speed,
    Vehicles.Lane, Vehicles.PoliceInfo);
    warnVehicle (Vehicles.Speed, Vehicles.Lane,
    Vehicles.WarningInfo);
end
```

cation links between FAGVs and SC facilities and domains provides promising outcomes such as 1) reducing the collisions in understanding others' next intention better, reducing congestion by signalling each other, 2) reducing fatalities with better reaction times, better sensory abilities, better judgement, 3) smoother traffic, 4) protecting the environment with less congestion, energy efficiency, less fuel consumption or green power (e.g., electrical batteries), and 5) reducing the need for parking space leading to allocation of parking spaces for other purposes where most of the times (above 95%), worldwide, over 1 billion personal vehicles are in the parking mode when they are not used. For transportation efficiency applications, the Car-to-Car Communication Consortium (C2CCC) analysed exemplarily enhanced route guidance and navigation, green light optimal speed advisory, and lane merging assistants: whereas for the first two applications, roadside infrastructure is considered a prerequisite, the lane merging assistant is assumed to be based on V2V communication [64]. Within this context, in this section, we would like to cover the management of these three cornerstones of ITS, namely, i) route planning, ii) lane management, and iii) velocity involving the traffic light management for optimising the mobility using the framework of FAGVinSCF within the concept of A-ITS in order to visualise how effective the automation between SC and FAGVs can be established.

a: ROUTING WITH FAGVinSCF

Most of the current route planning approaches are mainly based on the current static situations, in other words, dynamic traffic of cities is not incorporated into those approaches, which poses many challenges to cope with in city roads. Dynamic route guidance of FAGVs can be performed using their current position, known destination information based on 3D near-real-time visual modelling of the city roads with exact roadmaps, active vehicles on them and their future locations regarding their route planning, which contributes the efficiency of city traffic flow significantly, primarily benefiting vehicle and citizen better mobility and safety with the distribution of traffic dynamically based on the current traffic/rush state, and energy efficiency with less carbon emission (i.e., the sustainability of SC). FAGVs interconnect with SC via the closest scRSFs and share their basic information such as current location and destination and they are guided through the best available routes as illustrated in Fig. 3 — e.g., to routes with less congestions. The conceptual dynamic optimal route planing of the vehicles is shown in Algorithm 3 using the Eq. 5. This equation aims to choose the best available route with optimal waypoints that result in the shortest time from the current location that is frequently changed to the final destination or many temporary destinations as in ride-sharing. An agent per vehicle in the FAGVinSCF framework finds the best route based on all the circumstances on the roads, mainly traffic flow and the shortest time to reach the destination by incorporating the imminent traffic flow into the system based on i) the previously planned routes of all other vehicles with the prioritisation of the emergency vehicles such as ambulance, police and fire engines, ii) their speed and iii) imminent changing locations. The previously specified route can be updated with new calculations based on the most recent dynamic road maps by the agent whenever the street location of the vehicle changes. This routing scheme can be updated under the current circumstances (e.g., depending on an accident in a pre-specified route) at any time.

b: VELOCITY CONTROL AND LANE MANAGEMENT WITH FAGVinSCF

Velocity control and lane management of vehicles are carried out concerning the traffic flow, traffic signs and lights, traffic density, road conditions on particular lanes by the FAGVinSCF framework using Algorithm 4 as illustrated in Figs. 3 and 4. An agent for each street and direction runs to regulate and optimise the traffic flow using safe paths via better simultaneous localisation and mapping (SLAM). The agent communicates with the vehicles on the road and other agents on the junction streets using SC edge platform — scRSFs and FAGV MEC to satisfy the latency requirements using near-real-time dynamic traffic activities. More explicitly, first, the agent detects the active traffic on the street and analyse it using the detected vehicle info (e.g., speed, lane shared by vehicles or detected by the sensors on scRSFs), traffic signs and lights (Fig. 3). Second, it determines the advised speed and lane for each vehicle aiming at a better traffic flow regarding the fused information about the traffic signs and lights, weather, road conditions, and other vehicles. Third, it shares the determined advised info with the vehicles as illustrated in Figs. 3 and 4 and reports vehicles to authorised entities or police if they are behaving strangely out of the rules regarding any vehicle hacking to provide road safety for other road users.

FAGVs requiring an unobstructed view of the sky for localisation and navigation regarding the use of GPS are very sensitive to adverse weather such as snow, fog, heavy rain, hail [26], [27], [88] resulting in poor on-board sensor performance even though those sensors are designed to complement one another. For instance, the detection range of millimetre-wave radar can be reduced by up to 45% under severe rainfall conditions [26]. Within SC, FAGVs will be able to follow the traffic lights and other traffic signs without needing to visualise, particularly during adverse weather conditions. The FAGVinSCF framework becomes the eyes of FAGVs under difficult road conditions or where any sensor failures or mechanical errors emerge on FAGVs.

7) MODELLING AND SIMULATION OF FAGVinSCF

A traffic simulation and modelling platform was built using the MATLAB programming language and VISSIM traffic simulation tool. From a technical point of view, the algorithms 3 and 4 for the route planning and lane and speed control respectively were implemented using MATLAB to perform the optimal vehicle self-driving behaviour where the visual simulation environment as illustrated earlier in Figs. 3 and 4 was built using VISSIM. More explicitly, the urban traffic is generated and active traffic map is observed within VISSIM as illustrated in Algorithms 1 and 2. The real-time data transfer interface between MATLAB and VISSIM is established through the COM interface. With the model and simulation, the objectives are 1) performing various levels of FAGV penetration ranging from varying mixed traffic environment to solely FAGV traffic environment, 2) finding the most appropriate routes, 3) optimising FAGV behaviour concerning the density of road segments, lanes, proper left/right turning, and 4) adjusting their speed with appropriate acceleration and deceleration.

The simulation was performed at the centre of the Preston city as specified in Fig. 5 and the modelling of the urban traffic in VISSIM is shown in Fig. 6.[15] To show the merits of the approaches proposed in this article in simplistic terms, the

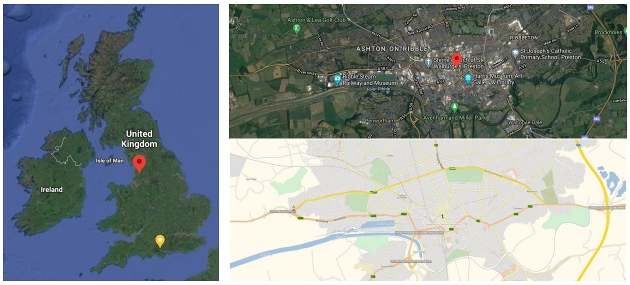

FIGURE 5. Traffic simulation area: The centre of the Preston city where The University of Central Lancashire is located.

TABLE 3. Order of the road segments within the routes. The arrows indicate the route directions concerning the road segments that are shown in Fig. 6.

Route	Road segments							
1	101→	102→	103→	104→	105→	106→	301	-
2				→	407→	504→	106→	301
3		↓	↓		→	408→	205→	301
4		↓	↳	404→	503→	504→	106→	301
5		↓			→	408→	205→	301
6		↓		↳	405→	204→	205→	301
7		↳	402→	502→	503→	504→	106→	301
8					→	408→	205→	301
9				↳	405→	204→	205→	301
10	201→	202→	501→	502→	503→	504→	106→	301
11					→	408→	205→	301
12		↓		↳	405→	204→	205→	301
13		↳	203→	204→	205→	301	-	-
14	401→	103→	104→	105→	106→	301	-	-
15			→	407→	504→	106→	301	-
16	↓	↓		→	408→	203→	301	-
17	↓	↳	404→	503→	504→	106→	301	-
18	↓			→	408→	205→	301	-
19	↓		↳	405→	204→	205→	301	-
20	↳	402→	502→	503→	504→	106→	301	-
21				→	408→	205→	301	-
22			↳	405→	204→	205→	301	-
23	403→	404→	503→	504→	106→	301	-	-
24			→	408→	205→	301	-	-
25	↳	405→	204→	205→	301→	-	-	-
26	406→	504→	106→	301→	-	-	-	-
27	→	408→	205→	301→	-	-	-	-

---

[15] We will be modelling a comprehensive simulation environment in our following studies to carry out the swarms of FAGVs in larger urban areas with various scenarios as specified in Section V.

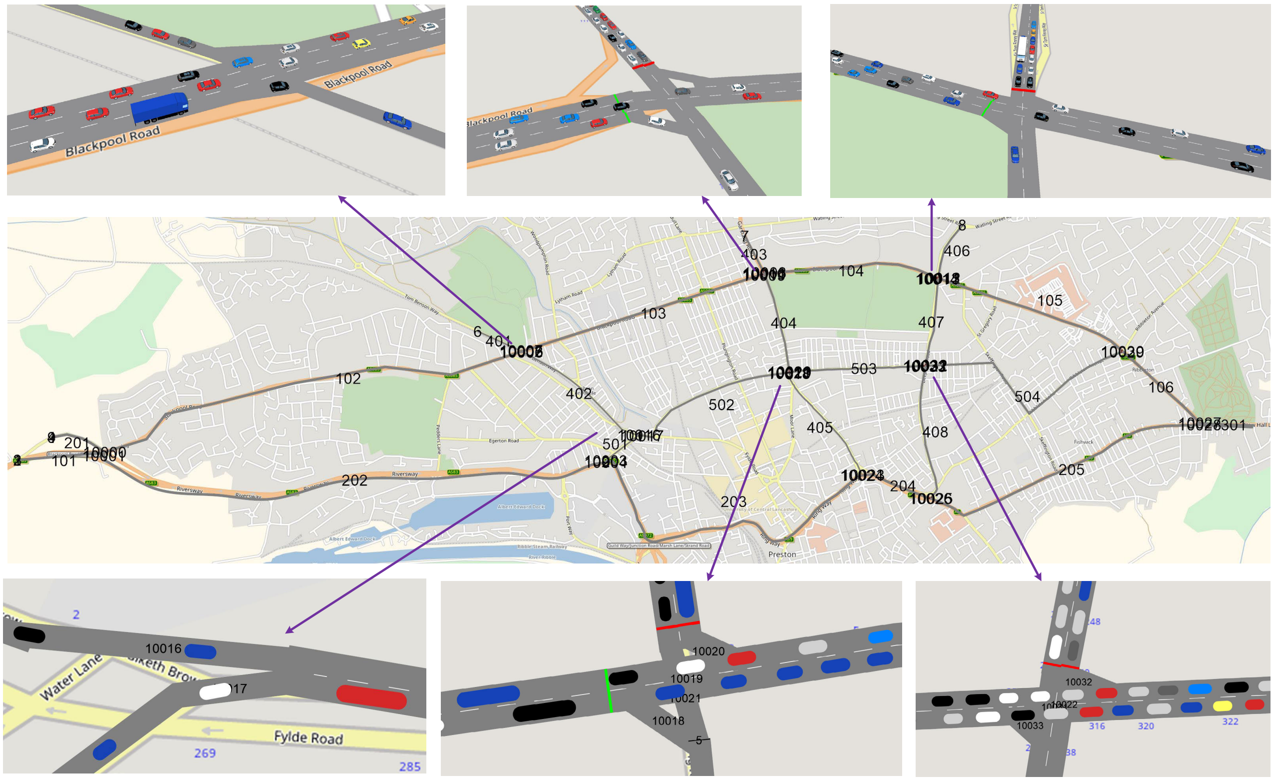

FIGURE 6. Modelling of the urban traffic with the road segments using the VISSIM interface and 2D/3D visualisation of the intersection points during the simulation.

traffic simulation was performed both from north to south and from west to east directions using the dynamic routing with the easily understandable road segments as labelled in Fig. 6. In this regard, all the road segments and the possible 27 routes using those road segments are displayed in Table 3 with the arrows. The simulation was carried out using 14,000 vehicles generated from the road segments labelled as 101, 102, 401, 403, 406 with the vehicle numbers of 5,000, 4,000, 500, 3,000 and 1500 respectively. It was run several times with various penetration levels of FAGVs into mixed traffic (i.e., 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100%) to observe how the proposed framework is affecting the traffic mobility with those varying penetration levels in an hour. The required data such as the locations of FAGVs, their destinations and traffic volumes and flows of the road segments involving the traffic volumes and flows of the particular lanes within these road segments were obtained by the Matlab interface. The control commands per FAGV, in other words, i) dynamic routes that may change based on the varying traffic volumes and flows on other segments where FAGVs move to the next road segment in the pre-specified routes, ii) lane trajectories and velocity based on the volume and flow on the current road segment were fed back to VISSIM in real-time for visualization. The results were acquired after each simulation run and these results are summarised in Fig 7 considering the varying penetration levels of FAGVs within the proposed framework. It is worth noting that during the multiple runs of the simulation with varying penetration levels of FAGVs, all other system parameters were kept same (e.g., the safe distance between the vehicles) and most importantly, any bottlenecks in the system were not attempted to be improved (e.g., congested intersection points by adjusting the signal timing) to be able to compare the possible contributions of the proposed framework with the varying penetration levels of FAGV. The results are explored in Section IV with further discussions.

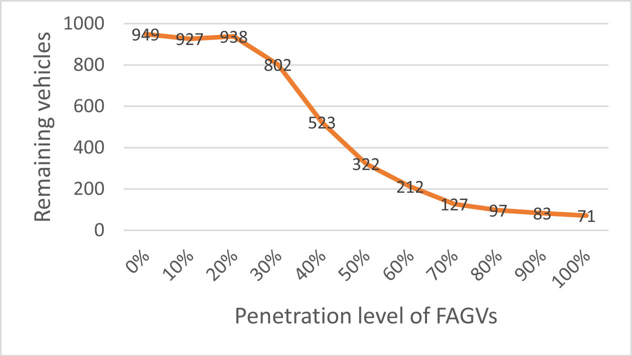

FIGURE 7. Performance of the traffic flow concerning the number of the remaining vehicles not completed their journey based on the penetration of FAGVs.

IV. RESULTS AND DISCUSSION

Even though cities cover just 3% of the earth's surface, they drive our economies, they consume 75% of the world's energy and most importantly, city-based consumption drives

80% of additive greenhouse gases [38]. Additionally, the ownership of vehicles that is now over 1 billion is growing exponentially due to reduced cost, increased income, and increasing population, which exacerbate the predicaments in cities. 1.35 million people die each year on the world's roads as a result of road traffic crashes [89], not to mention the 50 million non-fatal injuries [90], [91], which should be treated as a global health crisis. More than 90% percent of auto accidents result from human impairment such as drunk driving or road rage, errant pedestrians, or just plain bad driving [92]. It seems like a fairly obvious way to reduce crashes is to both reduce the number of humans behind the wheel and reduce the number of vehicles on streets [14]. Moreover, eliminating accidents will save roughly US$200 billion annually in health-care costs [93] not to mention the time wasted behind wheels and in traffic delays and congestions. FAGVs promise to further reduce collisions dramatically by removing the human element altogether [92]. The challenges of urbanisation, if unmet urgently, would entail grave economic and environmental impacts [43]. FAGVs are expected to improve mobility and traffic conditions in cities [94]. Therefore, it is urgent to develop FAGVs integrated with SC to address those challenges and improve our daily commute. Around $100 billion worldwide on R&D was spent by the automotive industry in order to nurture innovation and to stay competitive [12]. Around $80 billion has been spent on self-driving cars [95]. Waymo has spent over $1.1 billion so far to develop its own internal capability, with particularly large investments in simulation and mapping, as well as real-world driving, training, and testing [3]. FAGVs should be perceived not only a transportation aspect but also an upheaval that amplifies the impacts on every and each part of our life, strictly related to all the components of SC. Therefore, FAGVs cannot be treated as independent objects, but a part of its surrounding within SC. FAGVs adapting to the needs of citizens within multi and mixed-modal trip planning are promising less traffic, fewer deaths, less congestion in urban areas. FAGVs with their gratifying abilities provide flexible customised options to their customers regarding individual preferences. For instance, the Mini with shared ownership changes colour for each user [4]. Today, we are witnessing this transformation before our own eyes even though this seems a long way away ahead. To the best of our knowledge, this is the first comprehensive study both on the use of autonomous ground vehicles within SC and on the integration of these two rapidly developing disciplines.

Since FAGVs can free the drivers from hard driving work and reduce the number of traffic accidents, more and more people believe that FAGVs will be the bounding trend in the near future [5]. However, the introduction of new digital technology into the automotive industry has always raised anxieties [96]. Nevertheless, in a survey, autonomous cars were perceived as a "somewhat low risk" form of transport and, while concerns existed, there was little opposition to the prospect of their use on public roads [97]. The acceptance of FAGVs by citizens opposing thus technology lies in successfully addressing the safety concerns and it looks like this is going to take a long time. For instance, bicycles are hard to spot and much less predictable than cars [98]. The California Bicycle Coalition started a petition to stop FAGVs from being tested on California streets because they worry that the tech isn't powerful enough to see cyclists after the Uber crash in 2016 [14]. One of the owners of Tesla that is developed in California noticed that in winter on snowy roads, salt lines might confuse the Tesla's autopilot with the lane lines.[16] Those types of arising problems specific to particular city dynamics can be mitigated properly within a synergistic integration of SC and FAGVs (e.g., FAGVinSCF) to control and direct FAGVs appropriately, which brings numerous benefits, primarily, transforming citizens' daily life into safer and more peaceful hormones functional environment. For instance, FAGVinSCF can intervene and direct FAGVs to behave properly under any violation of lane lines. SC can integrate all the transport options in a customised way empowered with mission/service-oriented cooperation using real-time insights by making timely decisions within the concepts of A-ITS and AoE. Within this context, the results (Fig 7) of the simulation performed to show the virtues of FAGVinSCF in Section III-B7 shows that traffic mobility can be increased significantly with the orchestration of the components of FAGVs and SC (Fig. 1) within FAGVinSCF. More specifically, the flow of the traffic benefits substantially in optimising the behaviours of FAGVs where FAGVs start dominating the roads with higher penetration levels — > 40% (i.e., 436 (949 - 513) more vehicles where it is 40% and 567 (949 - 382) more vehicles where it is 50% complete their journey) whereas smaller levels requires the adaptation of FAGVs to the dominant environment of conventional vehicles leading to a modest improvement (i.e., 11 more vehicles complete their journey where the penetration is 20%). In the narrow sense, in our simulation study, the traffic mobility is getting optimised with a penetration level of over 70% (i.e., only 83 vehicles cannot complete their journey where it is 80%) and therefore no more significant improvement can be realised after this level where the road segments with the intersection points already become optimised, which helps avoid getting congested easily. Furthermore, these results suggest that traffic flow can be optimised within mixed traffic without huge changes to the infrastructure where the penetration level of FAGVs gets dominant with the proposed framework.

It is boldly envisioned that by 2040, all vehicles will be completely driverless, and it might even be illegal for humans to drive on public roads in a new traffic ecosystem in which all vehicles are centrally controlled [90]. It is obvious that FAGVs will gradually dominate the transportation market [99]. The sensor and mapping technologies within driverless cars create a huge amounts of data, and to make sense of it, cars will become the supercomputers of the future presenting a MEC platform with very high computing power. Today's discussion no longer revolves around whether the

---

[16] https://twitter.com/amywebb/status/841292068488118273?lang=en

technology will deliver on its promise but whether people want what the technology can deliver.[17] Studies have shown that high market penetration of level 5 automation rather than other lower 4 levels is likely to have the most significant positive impact on society and policymakers can make this work through extra focus and funding for the development of FAGVs [12] and their integration with SC. Widespread use of FAGVs will impact SCs and urban planning dramatically, particularly, 1) road, parking, and pedestrian infrastructure, 2) vehicle ownership and sharing, travel behaviours, 3) health and comfort of citizens with less worldwide traffic accidents and carbon footprint, and 4) the sustainability of cities with less emission (60% reduction of CO_2 [100]), less congestion and more efficient fuel consumption with better automation of SC smart components. Likewise, SCs equipped with immersive communication technologies and SC facilities equipped with powerful computing capabilities will enable FAGVs both to be connected to each other more than ever and to use real-time and near-real-time insights for better decision-making. To make sure the HD maps that FAGVs use contain up-to-date information, HD maps should be refreshed weekly and generating and maintaining HD maps can cost millions of dollars per year for a midsize city [27]. Various companies, primarily Google have put huge investments into creating highly accurate HD maps [100]. Those HD maps can be generated readily by the help of the up-to-date 3D traffic maps acquired from both the sensing abilities of scRSFs and FAGVs, and the information/DINSaaS within SC using existing digital maps at the bottom of the HD Map (Eqs. 1, 2, 3, 4), which reduces the cost significantly.

One of the biggest concerns is just how a machine will deal with the unexpected: those events or situations that are impossible to predict [9]. However, self-learning abilities and their integration with SCs will fasten their adaption to the changing environment enabling more successful FAGVs. Instant learning and directions from the SC edge/fog/MEC platforms and cloud platform will be essential mechanisms for FAGVs. We will be witnessing simulation tools with extreme accuracy emulating the real city roads by which FAGVs can be improved and tested in order to rapidly adapt the mission-critical tasks on roads [9]. We envision that Passive Deep Reinforcement Learning (DRL) is a very promising candidate to fill this gap. The merge of DL and RL within a recently used concept DRL will be the key enabler in order to provide the fast and continuous learning of vehicles. We are witnessing very successful applications of DRL in a variety of application fields. With DRL, machines can learn how to play chess, go, poker in several hours/days and can beat the world champions. Similarly, vehicles soon will be able to learn how to behave from experiences on best practices by watching many hours of videos recorded on the roads. This area requires extensive meticulous research. Simulators can facilitate the development and testing of autonomous vehicle control algorithms, complementing the road tests [101]. FAGVs can learn continuously by interacting with simulation systems and watching real-time traffic videos — correct things to repeat, wrong things to avoid again using DRL techniques. Nevertheless, FAGVs will clearly be never perfect. They may cause many fatal accidents. But, we should keep in mind that even the best drivers are clearly far from perfect. Machines tend to be superior to humans in terms not only of strength and precision but also of reliability in controlling complex processes and the capacity to learn from mistakes [102]. Within the concept of reaping the benefits of FAGVs, Gary Shapiro, the president of Consumer Technology Association (CTA) says that "Driverless cars could eliminate over 90% of deaths and injuries caused by human errors [103] by taking more proper action than actions followed by most of the human drivers. But if we wait until this technology is perfect before we deploy it, hundreds of thousands of lives will be lost. 'Perfect' is an impossible expectation — but 'very good' driverless technology will deliver safer roads, enable more efficient travel and save lives". With such a high-tech vehicle involved in the incident, there will be plenty more data available to determine exactly what went wrong, why the car made an error, and ideally, what can be fixed to prevent it from happening again [28]. If it was the sensors that indeed failed, the data should include information beyond what humans are able to see in a video [28]. With the framework, FAGVinSCF proposed in this study, making FAGVs approach near-perfect can be possible, mainly making FAGVs readily adopt and adapt their dynamic environments benefiting both the control of FAGVs, and sustainability and safety of SCs in multi-directional ways.

With FAGVinSCF, not only are current statuses of all FAGVs involving all other traffic participants known, but also, the future statuses of FAGVs and traffic flow are known with their trajectories, and accordingly, a better way of traffic management and mobility can be provided with sufficient amount of continuous information input and continuous traffic planning. The integration of SCs with FAGVs reducing uncertainties for FAGVs, finding most appropriate routes, adjusting the speed with proper acceleration and deceleration not only substantially decreases the fuel consumption and CO_2 emission, but also, provides a comfortable travel experience for their passengers. Directing FAGVs for better navigation of ambulances, fire engines, other vehicles, cyclists, and pedestrians can make cities safer places and more liveable where trajectories can be detected with a position accuracy in errors of a few centimetres. Furthermore, relevant features of dynamic modelling data acquired by FAGVinSCF involving real-time multimedia data can be analysed to serve a variety of tasks, mainly in crowdsourcing applications. For instance, the quality of lanes on the road or further immediate road maintenance requirement can be detected. We envision an SC future with AV-based public transportation system integrated with the abilities of SC using the FAGVinSCF framework. Is it far away to witness a future that FAGVs integrated with SC will be able to find their destinations with no sensors using the available end-to-end communication channels within SC?

---

[17] https://www.mercedes-benz.com/en/next/automation/

Establishment of FAGVinSCF requiring specialized SC facilities brings initial setup costs to the infrastructure along with continuous energy use, but, benefiting both the efficacy of FAGVs and sustainability of SC in the longer period. The architectural design of urban streets and roads in SCs is expected to change drastically in order to accommodate more rooms for FAGVs. We envision that adoption of FAGVs technology by a large percentage of citizens will be very fast as we have embraced the recent technology very quickly as in the use of smartphones. With upcoming more accessible and convenient FAGVs services along with the social benefits in various aspects, private vehicle ownership will be impacted drastically. The SC movement has been growing worldwide, but it will take another couple of decades for SCs to realise their game-changing potential [38]. Therefore, one of the main objectives of this article is to make policymakers and city governors aware of that the changes related to FAGVs and SCs are on their way and necessary planing to adopt these technologies and carry out the necessary steps in their cities are prime important.

FAGVs by saving our time, lives and environment within SC with improving moral/ethical judgement abilities will be a fundamental part of our daily life, which will enable us to focus on other things in our life with the created extra time such as socialising more, reading a book, watching a film, doing our meetings while commuting instead of driving long hours eyes on the road. To conclude, there is no point to wait to make FAGVs perfect. They will never be perfect and there is a very good reason to unleash them onto public roads if the abilities of them outperform those of humans in driving. FAGVs follow the rules too well, and don't anticipate human behaviour [28]. To make this transformation smoother and truly make self-driving technology the safest it can be, all the vehicles on the road should be fully autonomous — not just programmed to obey the rules of the road, but also to communicate with each other [14] and all other SC facilities within the concept of AoE. Most companies assume self-driving cars will be shared and used in restricted, geofenced areas, like downtowns or college campuses [18]. Most of the accidents with AGVs have been caused by human behaviours as shown in Table 2. Overall, 86% of documented incidents with AGVs are either rear-endings or sideswipings that result from a human's misunderstanding of an FAGV's behaviour [88] where currently the intention of human drivers cannot be calculated by FAGVs. Therefore, the perfect environment for FAGVs can be established where city roads are left to sole self-driving vehicles in the long run for a safer and more optimised mobility.

To summarise the key findings in this article, the framework — FAGVinSCF aiming at seamless interaction between SC and FAGVs shows that i) FAGVs and SC can be integrated in a synergistic manner using the hardware, software, network and infrastructure components they have (Fig. 1) with the various levels of alterations despite the challenges mentioned in Section IV-A, ii) the approaches within FAGVinSCF can improve the traffic mobility, in particular, traffic flow in urban areas substantially with effective path/trajectory planning in a highly connected city without huge changes to the traffic infrastructure based on the results obtained from the modelling and simulation study performed in Section III-B7, iii) FAGVs within FAGVinSCF can improve the urban mobility further where their penetration into mixed traffic is increased, and most importantly, iv) the main objectives of SCs such as sustainability (less CO_2 footprint) and improved mobility can be realised with the optimisation of the traffic mobility using FAGVs within FAGVinSCF leading to the increased competitiveness of SCs.

A. CHALLENGES

The essential challenges are summarised as follows:

1) Readiness: Our cities, politicians, policymakers, governors, city planners and legislators don't seem ready to embrace this forthcoming technology right into the heart of our cities within a forward-thinking policy. There is plenty of room for controversy in the management of FAGVs properly and ethically. All stakeholders are needed to come together not only to think this fully-autonomous-future, but also to adapt this technology, plan accordingly and integrate with SC.

2) Communication standards between FAGVs and SC: A big challenge for the establishment of smoother low-latency communication between the SC facilities and FAGVs by avoiding channel congestion is optimally adjusting and synchronising the many communication/networking parameters both in SC and in FAGVs (Fig. 1 C and D) to match the goals of these two advanced application disciplines.

3) Communication standards between FAGVs and other users and components of streets: Intelligent AI approaches related to the communication with the pedestrians, old-fashioned vehicles and traffic signs are required to increase the synergistic integration of all components leading to the orchestration of all resources based on the constraints and rapidly changing circumstances.

4) Different communication standards between countries: Some of the communication standards in USA, Europe and in the other countries are different from each other, which makes it difficult for FAGVs to talk to and understand each other using the same protocols, specifically, during their navigation between states and countries.

6) Denial-of-service attacks: Malicious interference may be readily originated from a radio transmitter located in the vicinity of communicating vehicles to cause denial-of-services via jamming of cooperative awareness messages (CAMs) or basic safety message (BSM) and decentralized environmental notification messages (DENMs) [68], specifically, using a jammer with the reaction time in the order of tens microseconds, which can substantially increase the packet loss ratio at V2V links as demonstrated in the various experiments [74], [104]. New effective jamming detection and avoidance techniques are required to retain the wireless services active at all time in order to avoid packet loss or packet transmission delay.

7) Prioritisation of conflicting insights: Fake insights can be sent with M2M communication. FAGVs should be well programmed to confirm the insights using their sensors and the other sources, mainly the agents as moderators within SCs mentioned in this article.

8) Rules and regulations: The cities in which residents and other vehicles do not obey with the traffic rules may postpone the release of FAGVs to the market until the traffic rules, particularly traffic lights are complied with to ensure safety and optimise mobility. Furthermore, from a perspective of regulatory framework, the traffic rules and legislations are needed to be amended and expanded to include the specific characteristics of FAGVs and the interrelation of FAGVs with people and other vehicles (e.g., in case of an accident, insurance issues requiring new models of risk management).

9) Ethical concerns: How FAGVs deal with difficult situations or should behave under emergency should be programmed based on agreed-upon ethical and legal aspects established with the involvement of all the stakeholders. FAGVs must decide quickly, with incomplete information, in situations that programmers often will not have considered, using ethics that must be encoded all too literally in software; a solution doesn't need to be perfect, but it should be thoughtful and defensible [105].

10) Infrastructural improvements: GPS-denied manoeuvring of on-road vehicles is essential, especially in densely populated areas with high rising buildings and tunnels, where data link loss along with missing map data is a possibility [8]. The effectiveness of the sensor technology decreases during extreme weather conditions such as fogy or snowy weathers. Where infrastructure is designed with robocars in mind, many of the hardest problems will be easier to solve in which FAGVs will talk to the road, to the traffic signs, and one another [2]. SC road infrastructure in the vicinity of FAGVs, traffic and road signs and traffic signals are required to be regulated concerning the features of FAGVs to increase the efficacy of this upcoming technology.

11) Effective management of geo-distributed BD: A huge amount of data volumes are generated by the sensors of FAGVs and this very BD needs to be processed swiftly to support near-real-time decision-making, which requires effective collaboration between FAGV MEC, SC fog and cloud platforms. Recently several approaches and techniques have been proposed to mitigate the difficulties in BD management, one of the most recent one is "Management of geo-distributed intelligence: Deep Insight as a Service (DINSaaS) on Forged Cloud Platforms (FCP)" [106]. With this approach, BD are processed using Advanced Insight Analytics and ready-to-use insights are transported to be input to the other systems, which not only significantly reduces the data traffic, but also, decision-making abilities are accelerated.

B. LESSONS LEARNED

1) The demands of city services equipped with better infrastructure and smart technologies are increasing at an alarming rate as the urban population continues to rise with many challenges to cope with [43]. City infrastructure supported by advanced road-sensors with scRSFs needs new architectural design concepts to facilitate FAGVs to function better. We envision that road infrastructure, particularly RSUs will change substantially regarding the development of FAGVs and their integration with SC in which FAGVs can talk to traffic signs increasing the efficacy of the city mobility. Aggregated data in the SC fog and cloud platforms acquired from FAGVs and scRSFs can be used both to increase QoS with effective traffic management and advanced up-to-date traffic information systems and to provide future traffic planning involving road infrastructure as an integral part of the urban planning. All the stakeholders such as automakers, policymakers, citizens, governors should collaboratively work together to incorporate FAGVs into SC appropriately and properly.

2) FAGVs will transform our cities within SC into a new area in which sustainability of cities will be increased substantially with better route selection and more efficient use of vehicles leading to reduced fuel, congestion, energy, and carbon footprint. Many insights can be obtained from the huge amount of data acquired from street mapping/city mapping at a time using the abilities of SCs and FAGVs and these insights can be useful in many aspects for many other scientific fields, primarily, to transform our cities into more liveable places.

3) Automated Robots embedded in a car can be better drivers than humans with ever-developing AI approaches and sensor technologies enabling to operate in many challenging circumstances that humans cannot cope with (e.g., difficult weather conditions, dark environment). The accident caused by human errors (i.e., 94%) can be avoided with the use of FAGVs integrated with SC.

4) With the concept of FAGVs, "Alongside the home and office, the car will become the third living environment and a personal assistant" says Bosch CEO Dr Volkmar Denner [4] with the features turning a vehicle from a form of transport into an assistant. The daily life of citizens will be changed significantly where the tasks are taken over by FAGVs capable of solving a variety of real-world problems such as delivering children to their schools and pick up them enabling us to be free to focus other things, which makes our society more functional and optimised by meeting the needs of the citizens in contemporary concepts. For instance, BMW's interior concept has separate areas allowing each passenger to spend the journey as they please [4]. Moreover, the concept of FAGVs can make the most vulnerable people (e.g., blind, disabled, elder people) in the society independent.

5) Use of FAGVs is very profitable by eliminating the wages paid to human drivers. In the fourth quarter of 2017, Uber paid about $8 billion to drivers in earnings and bonuses, or about 72% of its gross revenue for the quarter [107]. On the other hand, many jobs will be lost, particularly driving jobs (i.e., taxi, truck. delivery).

6) FAGVs can be summoned on-demand, routed more efficiently, and easily shared — meaning not just the overall number of single-passenger cars on streets will decline, but

the number of single-passenger trips will be reduced, meaning a reduction in overall miles travelled [14]. FAGVs fuelled by the abilities of SC will enable providing shared rides in regulated fleets, integrate with existing transit, and operate in a way that prioritises a city's most vulnerable humans above all users of the streets [14]. Rinspeed Oasis, Honda Neuv and Mini Vision Next 100 are just some examples of autonomous concepts that come with the car-sharing option [4].

7) Individual vehicle ownership is expected to decrease with respect to the promising advantages of FAGVs. FAGVs will increase per-vehicle occupancy and decrease the number of vehicles on the road with the transformation concept from vehicle ownership to vehicle usership by which overall traffic is expected to improve. Personal cars are statically parked for 96% of the time and if a car does not need a driver, what is to stop it operating 24/7 [4]? The need for parking spaces will reduce significantly with ride-sharing and vehicle-sharing with the use of FAGVs connected to SC. Furthermore, a vacant driverless vehicle can move automatically to remote parking freeing up street parking spaces, which automatically generates uncomplicated road expansion [13]. The need for parking space will decrease significantly with FAGVs where most of the times, old-fashioned personal vehicles are in the parking mode and not parked properly invading more space than required. As a result, we will be able to get our spaces invaded by old-fashioned vehicles back to accommodate for better living purposes, mainly more green spaces.

8) The price range of FAGVs will not be different from the vehicles currently used thanks to the available cheaper sensor and actuator on-board technologies.

9) Intelligent and efficient transportation of goods using intelligent mobile supply-chains with FAGVs makes them cheaper with substantial cost reductions.

10) One of the most important lessons learned during a 13,000 km intercontinental driverless trip from Italy to China is that when driving in real traffic conditions, the autonomous vehicle not only has to follow some predefined rules, but also needs to understand when it is necessary to break them [108] in order to protect itself and others in the environment based on the other road participants' behaviours.

11) Failures with technology may occur anytime, and that's why, we are suggesting that FAGVs should be designed to be able to turn into level-4 AGVs by unfolding steering wheel, brakes and pedals with strictly limited authorised keys, which may be labelled as "Level-4.5 AGV". Furthermore, a recent Kelley Blue Book poll in 2015 found that 51% of drivers want to have full control of their vehicles, even if FAGVs make our roads safer [103]. Therefore, our suggestion will help increase the acceptance of this technology as well.

12) There is some degree of negotiation involved between vehicles either in autonomous or not, and false assumptions in those negotiations are where the crashes can happen [29], particularly where they are in different mode, one is autonomous and the other is human-driven with inexplicable movements from the point of FAGVs' view. Use of only FAGVs on roads or geofenced roads will reduce these conflicts and disagreements significantly enabling a smoother life with less accident and less congestion by predicting and planing for upcoming manoeuvres appropriately.

13) FAGVs should be tested by qualified authorities in both quality fake cities and real-world environment based on agreed-upon standards and protocols for their competence before deployed on city roads.

14) Almost all leading vehicle manufacturers involving Audi, Jaguar, Ford, Toyota, Volvo, and BMW are working toward incorporating health and wellness technologies (e.g., heart rate, body temperature and respiration monitoring) in their cars where the car becomes a health center, monitoring your vitals every day and alerting you and your healthcare provider to potential abnormalities, thereby paving the way for preemptive treatments [109]. FAGVs integrated with "SC smart health and welfare" domain within SC, "smart healthcare" domain within smart country and the health monitoring supported by wearable devices within FAGVs connected to SC will enable to save many lives.

V. CONCLUSION AND FUTURE RESEARCH IDEAS

We envision that the aspirations and investment in commercially available self-driving vehicles will accelerate in an exponential rate in the following years. They might exacerbate the liveability in our cities if we embrace this exciting opportunity as we do in non-autonomous vehicles. To make the transformation from today's driving society to future's driverless society smoother and truly make self-driving technology a harmonious part of our cities, new contemporary approaches and solutions such as the framework proposed in this study — FAGVinSCF are needed. These state-of-the-art approaches can turn the challenges of self-driving vehicles into advantageous and help design more sustainable and liveable cities with orchestrated synergistic integrations, optimised mobility, fewer accidents, reduced car ownership with effective public autonomous transportation, diminished parking spaces and roads, increased green spaces and less footprint, which will make a better urban future. Cities designed for cars can turn into cities developed for citizens by effective use of FAGVs within the framework of FAGVinSCF. With this motivation in mind, this article providing a discussion direction and inventive solutions for the challenges of FAGVs has been developed to i) raise consciousness in this particular field, ii) create inspirational thinking, iii) help FAGVs take their rightful and indispensable place in the schemes of recent SC development initiatives even though they still pose enough research challenges and finally, iv) transform the cities into smarter cities within the concept of AoE. The FAGVinSCF framework orchestrated by the SC facilities and abilities engaging in the A-ITS concept is aimed to both reduce the chaos of sharing a huge amount of data that may cause a massive channel load and make FAGVs function efficiently and properly as an essential part of SCs. The modelling and simulation of FAGVinSCF in this article demonstrate that embracing this new FAGV technology properly and appropriately in our cities can improve the traffic flow in urban areas substantially, even without huge changes to the traffic infrastructure and without enhancing the bottleneck points.

The integration of FAGVs with the SC ecosystem providing the citizens with an unprecedented ability to cope with the difficulties of living in a city is of crucial importance and transforming our cities with FAGVs still needs profound research from a philosophical, economical, behavioural and scientific point of view. Use of FAGVs in public transportation, primarily in ride-sharing to both alleviate the FMLM problem and increase the sustainability of SCs will be our focus in the following years. Furthermore, until the day comes when all vehicles are fully autonomous, self-driving cars must be more than safe and efficient — they must also understand and interact naturally with human drivers beyond mechanical operations [110]. In this sense, the impact of varying AGV rates of penetration into traffic, in particular, the interaction of FAGVs with pedestrians, citizens and human drivers — human-vehicle interactions, understanding human intentions and behaviours as an interesting and imperative research area needs to be focused. Within this context, a comprehensive simulation environment will be modelled in our following studies to carry out the traffic behaviour optimisation for swarms of FAGVs along with other conventional vehicles in larger urban areas.

REFERENCES

[1] S.-C. Chen, "Multimedia for autonomous driving," *IEEE Multimedia Mag.*, vol. 26, no. 3, pp. 5–8, Jul. 2019.

[2] P. Ross, "Robot, you can drive my car," *IEEE Spectr.*, vol. 51, no. 6, pp. 60–90, Jun. 2014.

[3] M. Daily, S. Medasani, R. Behringer, and M. Trivedi, "Self-driving cars," *Computer*, vol. 50, no. 12, pp. 18–23, 2017.

[4] J. Fell, "Cars of the future [concept cars]," *Eng. Technol.*, vol. 12, no. 2, pp. 48–53, Mar. 2017.

[5] R. Hussain and S. Zeadally, "Autonomous cars: Research results, issues, and future challenges," *IEEE Commun. Surveys Tuts.*, vol. 21, no. 2, pp. 1275–1313, 2nd Quart., 2019.

[6] FHWA. *FHWA Forecasts of Vehicle Miles Traveled (VMT): Spring 2019*. Accessed: 2019. [Online]. Available: https://www.fhwa.dot.gov/policyinformation/tables/vmt/vmt_forecast_sum.pdf

[7] ACEA. *The Automobile Industry Pocket 2019/2020*. Accessed: 2019. [Online]. Available: https://www.acea.be/uploads/publications/ACEA_Pocket_Guide_2019-2020.pdf

[8] M. Elbanhawi, M. Simic, and R. Jazar, "In the passenger seat: Investigating ride comfort measures in autonomous cars," *IEEE Intell. Transp. Syst. Mag.*, vol. 7, no. 3, pp. 4–17, Fall 2015.

[9] L. Jones, "Are we ready to the steering [transport automotive]," *Eng. Technol.*, vol. 10, no. 9, pp. 32–36, Oct. 2015.

[10] Y. F. Payalan and M. A. Guvensan, "Towards next-generation vehicles featuring the vehicle intelligence," *IEEE Trans. Intell. Transp. Syst.*, vol. 21, no. 1, pp. 30–47, Jan. 2020.

[11] S. A. Bagloee, M. Tavana, M. Asadi, and T. Oliver, "Autonomous vehicles: Challenges, opportunities, and future implications for transportation policies," *J. Modern Transp.*, vol. 24, no. 4, pp. 284–303, Dec. 2016, doi: 10.1007/s40534-016-0117-3.

[12] J. Nieuwenhuijsen, "Diffusion of automated vehicles: A quantitative method to model the diffusion of automated vehicles with system dynamics," M.S. thesis, Dept. Transp. Planning, Delft Univ. Technol., Delft, The Netherlands, 2015.

[13] Y. Wiseman, "Driverless cars will make passenger rail obsolete [opinion]," *IEEE Technol. Soc. Mag.*, vol. 38, no. 2, pp. 7–22, Jun. 2019.

[14] A. Walker. *Are Self-Driving Cars Safe for Our Cities?* Accessed: 2019. [Online]. Available: https://www.curbed.com/2016/9/21/12991696/driverless-cars-safety-pros-cons

[15] E. Dickmanns and A. Zapp, "Autonomous high speed road vehicle guidance by computer vision1," in *Proc. 10th Triennial IFAC Congr. Autom. Control (IFAC)*, Munich, Germany, Jul. 1987, vol. 20, no. 5, pp. 221–226. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1474667017553203

[16] E. D. Dickmanns and V. Graefe, "Dynamic monocular machine vision," *Mach. Vis. Appl.*, vol. 1, no. 4, pp. 223–240, Dec. 1988, doi: 10.1007/BF01212361.

[17] C. Thorpe, M. Herbert, T. Kanade, and S. Shafter, "Toward autonomous driving: The CMU Navlab. II. Architecture and systems," *IEEE Expert*, vol. 6, no. 4, pp. 44–52, Aug. 1991.

[18] A. J. Hawkins. (2017). *Tesla's Autopilot is Supposed to Deliver Full Self-Driving, So Why Does it Feel Stuck in the Past*. [Online]. Available: https://www.theverge.com/2017/10/24/16504038/tesla-autopilot-self-driving-update-elon-musk

[19] Z. Estrada. (2017). *Lack of Safeguards in Tesla's Autopilot Contributed to Fatal Crash*. [Online]. Available: https://www.theverge.com/2017/9/12/16294684/tesla-autopilot-fatal-crash-ntsb

[20] L. Jones, "Driverless when and cars: Where? [automotive autonomous vehicles]," *Eng. Technol.*, vol. 12, no. 2, pp. 36–40, 2017.

[21] S.-W. Kim, G.-P. Gwon, W.-S. Hur, D. Hyeon, D.-Y. Kim, S.-H. Kim, D.-K. Kye, S.-H. Lee, S. Lee, M.-O. Shin, and S.-W. Seo, "Autonomous campus mobility services using driverless taxi," *IEEE Trans. Intell. Transp. Syst.*, vol. 18, no. 12, pp. 3513–3526, Dec. 2017.

[22] L. Murray, "Hitch a ride with harry [transport driverless cars]," *Eng. Technol.*, vol. 12, nos. 7–8, pp. 62–65, Aug. 2017.

[23] L. Yu, D. Kong, X. Shao, and X. Yan, "A path planning and navigation control system design for driverless electric bus," *IEEE Access*, vol. 6, pp. 53960–53975, 2018.

[24] M. Harris, "State of automation [news]," *IEEE Spectr.*, vol. 52, no. 9, p. 18, Sep. 2015.

[25] J. Loughran, "Only four vehicles complete driverless car race [news briefing]," *Eng. Technol.*, vol. 12, no. 4, p. 16, May 2017.

[26] S. Zang, M. Ding, D. Smith, P. Tyler, T. Rakotoarivelo, and M. A. Kaafar, "The impact of adverse weather conditions on autonomous vehicles: How rain, snow, fog, and hail affect the performance of a self-driving car," *IEEE Veh. Technol. Mag.*, vol. 14, no. 2, pp. 103–111, Jun. 2019.

[27] S. Liu and J.-L. Gaudiot, "Autonomous vehicles lite self-driving technologies should start small, go slow," *IEEE Spectr.*, vol. 57, no. 3, pp. 36–49, Mar. 2020.

[28] P. Sisson and A. Walker. (2018). *Uber's Fatal Crash: Are Self-Driving Tests Endangering Pedestrians*. [Online]. Available: https://www.curbed.com/2018/3/19/17140922/uber-crash-tempe-fatal-driverless-car

[29] C. Ziegler. (2016). *A Google Self-Driving Car Caused a Crash for the First Time*. [Online]. Available: https://www.theverge.com/2016/2/29/11134344/google-self-driving-car-crash-report

[30] A. J. Hawkins. (2018). *Tesla Says Autopilot Was Engaged During Fatal Model X Crash*. [Online]. Available: https://www.theverge.com/2018/3/30/17182824/tesla-model-x-crash-autopilot-statement

[31] D. Shepardson. (2018). *Gm Settles Lawsuit With Motorcyclist Hit by Self-Driving Car*. [Online]. Available: https://uk.reuters.com/article/us-gm-selfdriving/gm-settles-lawsuit-with-motorcyclist-hit-by-self-driving-car-idUKKCN1IX604

[32] B. Menegus and K. Conger. (2018). *Uber Driver in Fatal Tempe Crash May Have Been Watching the Voice Behind the Wheel*. [Online]. Available: https://gizmodo.com/uber-driver-in-fatal-tempe-crash-may-have-been-watching-1827039127

[33] S. Chen, Y. Chen, S. Zhang, and N. Zheng, "A novel integrated simulation and testing platform for self-driving cars with hardware in the loop," *IEEE Trans. Intell. Veh.*, vol. 4, no. 3, pp. 36–425, May 2019.

[34] A. J. Hawkins. (2018). *Tesla Says Autopilot was Engaged During Fatal Model X Crash*. [Online]. Available: https://www.theverge.com/2018/3/30/17182824/tesla-model-x-crash-autopilot-statement

[35] P. Sisson. (2015). *A Fake City's Real Purpose: Test Tomorrow's Driverless Cars*. [Online]. Available: https://www.curbed.com/2015/7/22/9937998/university-of-michigan-fake-city-selfdriving-cars

[36] A. Davies. (2017). *Inside the Ersatz City where Waymo Trains its Self-Driving Cars*. [Online]. Available: https://www.wired.com/story/google-waymo-self-driving-car-castle-testing/

[37] D. Muoio. (2017). *Uber Built a Fake City in Pittsburgh With Roaming Mannequins to Test its Self-Driving Cars*. [Online]. Available: https://www.businessinsider.com/ubers-fake-city-pittsburgh-self-driving-cars-2017-10?r=US&IR=T

[38] P. Wilson, "State of smart cities in UK and beyond," *IET Smart Cities*, vol. 1, no. 1, pp. 19–22, Jun. 2019.

[39] Y. Sun, H. Song, A. J. Jara, and R. Bie, "Internet of Things and big data analytics for smart and connected communities," *IEEE Access*, vol. 4, pp. 766–773, 2016.

[40] P. Kiestra. *Safe Cities Index 2019: Urban Security and Resilience in An Interconnected World*. Accessed: 2019. [Online]. Available: https://safecities.economist.com/wp-content/uploads/2019/08/Aug-5-ENG-NEC-Safe-Cities-2019-270x210-19-screen.pdf

[41] P. Neirotti, A. De Marco, A. C. Cagliano, G. Mangano, and F. Scorrano, "Current trends in smart city initiatives: Some stylised facts," *Cities*, vol. 38, pp. 25–36, Jun. 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0264275113001935

[42] K. Benouaret, R. Valliyur-Ramalingam, and F. Charoy, "CrowdSC: Building smart cities with large-scale citizen participation," *IEEE Internet Comput.*, vol. 17, no. 6, pp. 57–63, Nov. 2013.

[43] K. Kuru and D. Ansell, "TCitySmartF: A comprehensive systematic framework for transforming cities into smart cities," *IEEE Access*, vol. 8, pp. 18615–18644, 2020.

[44] K. Kuru, D. Ansell, W. Khan, and H. Yetgin, "Analysis and optimization of unmanned aerial vehicle swarms in logistics: An intelligent delivery platform," *IEEE Access*, vol. 7, pp. 15804–15831, 2019.

[45] K. Kuru and H. Yetgin, "Transformation to advanced mechatronics systems within new industrial revolution: A novel framework in automation of everything (AoE)," *IEEE Access*, vol. 7, pp. 41395–41415, 2019.

[46] F. Alam, R. Mehmood, I. Katib, S. M. Altowaijri, and A. Albeshri, "TAAWUN: A decision fusion and feature specific road detection approach for connected autonomous vehicles," *Mobile Netw. Appl.*, pp. 1–17, Aug. 2019. [Online]. Available: https://link.springer.com/article/10.1007/s11036-019-01319-2, doi: 10.1007/s11036-019-01319-2.

[47] Y. Zhang, G. Zhang, R. Fierro, and Y. Yang, "Force-driven traffic simulation for a future connected autonomous vehicle-enabled smart transportation system," *IEEE Trans. Intell. Transp. Syst.*, vol. 19, no. 7, pp. 2221–2233, Jul. 2018.

[48] Q. Cui, Y. Wang, K.-C. Chen, W. Ni, I.-C. Lin, X. Tao, and P. Zhang, "Big data analytics and network calculus enabling intelligent management of autonomous vehicles in a smart city," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 2021–2034, Apr. 2019.

[49] K. Kuru and W. Khan, "Novel hybrid object-based non-parametric clustering approach for grouping similar objects in specific visual domains," *Appl. Soft Comput.*, vol. 62, pp. 667–701, Jan. 2018. http://www.sciencedirect.com/science/article/pii/S1568494617306701

[50] Q. T. Minh, E. Kamioka, and S. Yamada, "CFC-ITS: Context-aware fog computing for intelligent transportation systems," *IT Prof.*, vol. 20, no. 6, pp. 35–45, Nov. 2018.

[51] X. Chen, L. Jiao, W. Li, and X. Fu, "Efficient multi-user computation offloading for mobile-edge cloud computing," *IEEE/ACM Trans. Netw.*, vol. 24, no. 5, pp. 2795–2808, Oct. 2016.

[52] M. Chiang and T. Zhang, "Fog and IoT: An overview of research opportunities," *IEEE Internet Things J.*, vol. 3, no. 6, pp. 854–864, Jun. 2016.

[53] B. Hammi, R. Khatoun, S. Zeadally, A. Fayad, and L. Khoukhi, "IoT technologies for smart cities," *IET Netw.*, vol. 7, no. 1, pp. 1–13, Jan. 2018.

[54] P. H. C. Caminha, F. F. da Silva, R. G. Pacheco, R. de Souza Couto, P. B. Velloso, M. E. M. Campista, and L. H. M. K. Costa, "SensingBus: Using bus lines and fog computing for smart sensing the city," *IEEE Cloud Comput.*, vol. 5, no. 5, pp. 58–69, Sep. 2018.

[55] D. Miorandi, S. Sicari, F. De Pellegrini, and I. Chlamtac, "Internet of Things: Vision, applications and research challenges," *Ad Hoc Netw.*, vol. 10, no. 7, pp. 1497–1516, 2012. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1570870512000674

[56] D. Puiu, P. Barnaghi, R. Tonjes, D. Kumper, M. I. Ali, A. Mileo, J. X. Parreira, M. Fischer, S. Kolozali, N. Farajidavar, F. Gao, T. Iggena, T.-L. Pham, C.-S. Nechifor, D. Puschmann, and J. Fernandes, "CityPulse: Large scale data analytics framework for smart cities," *IEEE Access*, vol. 4, pp. 1086–1108, 2016.

[57] G. T. Lakshmanan and R. Khalaf, "Leveraging process-mining techniques," *IT Prof.*, vol. 15, no. 5, pp. 22–30, Sep. 2013.

[58] A. C. Baktir, C. Sonmez, C. Ersoy, A. Ozgovde, and B. Varghese, *Addressing the Challenges in Federating Edge Resources*. Hoboken, NJ, USA: Wiley, 2019, ch. 2, pp. 25–49. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/9781119525080.ch2

[59] I. Yaqoob, I. A. T. Hashem, Y. Mehmood, A. Gani, S. Mokhtar, and S. Guizani, "Enabling communication technologies for smart cities," *IEEE Commun. Mag.*, vol. 55, no. 1, pp. 20–112, Jan. 2017.

[60] A. Gazis, E. Ioannou, and E. Katsiri, "Examining the sensors that enable self-driving vehicles," *IEEE Potentials*, vol. 39, no. 1, pp. 46–51, Jan. 2020.

[61] G. Dissanayake, S. Huang, Z. Wang, and R. Ranasinghe, "A review of recent developments in simultaneous localization and mapping," in *Proc. 6th Int. Conf. Ind. Inf. Syst.*, Aug. 2011, pp. 477–482.

[62] Z. Wang, X. Shi, and X. Li, "Review of lane-changing maneuvers of connected and automated vehicles: Models, algorithms and traffic impact analyses," *J. Indian Inst. Sci.*, vol. 99, no. 4, pp. 589–599, Dec. 2019, doi: 10.1007/s41745-019-00127-7.

[63] Z. Wang, X. Zhao, and Z. Xu, "Offline mapping for autonomous vehicles with low-cost sensors," *Comput. Electr. Eng.*, vol. 82, Mar. 2020, Art. no. 106552. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S004579061931746X

[64] H. Hartenstein and K. P. Laberteaux, "A tutorial survey on vehicular ad hoc networks," *IEEE Commun. Mag.*, vol. 46, no. 6, pp. 164–171, Jun. 2008.

[65] U. Paul, A. P. Subramanian, M. M. Buddhikot, and S. R. Das, "Understanding traffic dynamics in cellular data networks," in *Proc. IEEE INFOCOM*, Apr. 2011, pp. 882–890.

[66] K. Ota, T. Kumrai, M. Dong, J. Kishigami, and M. Guo, "Smart infrastructure design for smart cities," *IT Prof.*, vol. 19, no. 5, pp. 9–42, 2017.

[67] F. Hussain, H. Farahneh, X. Fernando, and A. Ferworn, "VLC enabled foglets assisted road asset reporting," in *Proc. IEEE 85th Veh. Technol. Conf. (VTC Spring)*, Jun. 2017, pp. 1–6.

[68] K. Sjoberg, P. Andres, T. Buburuzan, and A. Brakemeier, "Cooperative intelligent transport systems in europe: Current deployment status and outlook," *IEEE Veh. Technol. Mag.*, vol. 12, no. 2, pp. 89–97, Jun. 2017.

[69] B. Lonc and P. Cincilla, "Cooperative ITS security framework: Standards and implementations progress in europe," in *Proc. IEEE 17th Int. Symp. A World Wireless, Mobile Multimedia Netw. (WoWMoM)*, Jun. 2016, pp. 1–6.

[70] M. Alsabaan, K. Naik, and T. Khalifa, "Optimization of fuel cost and emissions using V2V communications," *IEEE Trans. Intell. Transp. Syst.*, vol. 14, no. 3, pp. 1449–1461, Sep. 2013.

[71] A. Vinel, N. Lyamin, and P. Isachenkov, "Modeling of V2V communications for C-ITS safety applications: A CPS perspective," *IEEE Commun. Lett.*, vol. 22, no. 8, pp. 1600–1603, Aug. 2018.

[72] K. M. Malone and A. M. G. Soekroella, "Estimating benefits of C-ITS deployment, when legacy roadside systems are present," *IET Intell. Transp. Syst.*, vol. 13, no. 5, pp. 915–924, May 2019.

[73] N. Lyamin, A. Vinel, D. Smely, and B. Bellalta, "ETSI DCC: Decentralized congestion control in C-ITS," *IEEE Commun. Mag.*, vol. 56, no. 12, pp. 112–118, Dec. 2018.

[74] N. Lyamin, D. Kleyko, Q. Delooz, and A. Vinel, "Real-time jamming DoS detection in safety-critical V2V C-ITS using data mining," *IEEE Commun. Lett.*, vol. 23, no. 3, pp. 442–445, Mar. 2019.

[75] S. Huang, A. W. Sadek, and Y. Zhao, "Assessing the mobility and environmental benefits of reservation-based intelligent intersections using an integrated simulator," *IEEE Trans. Intell. Transp. Syst.*, vol. 13, no. 3, pp. 1201–1214, Sep. 2012.

[76] K. Zhang, D. Zhang, A. de La Fortelle, X. Wu, and J. Gregoire, "State-driven priority scheduling mechanisms for driverless vehicles approaching intersections," *IEEE Trans. Intell. Transp. Syst.*, vol. 16, no. 5, pp. 2487–2500, Oct. 2015.

[77] K. Zhang, A. Yang, H. Su, A. de La Fortelle, K. Miao, and Y. Yao, "Service-oriented cooperation models and mechanisms for heterogeneous driverless vehicles at continuous static critical sections," *IEEE Trans. Intell. Transp. Syst.*, vol. 18, no. 7, pp. 1867–1881, Jul. 2017.

[78] J. E. Naranjo, C. Gonzalez, R. Garcia, and T. de Pedro, "Lane-change fuzzy control in autonomous vehicles for the overtaking maneuver," *IEEE Trans. Intell. Transp. Syst.*, vol. 9, no. 3, pp. 438–450, Sep. 2008.

[79] A. Dua, N. Kumar, A. K. Das, and W. Susilo, "Secure message communication protocol among vehicles in smart city," *IEEE Trans. Veh. Technol.*, vol. 67, no. 5, pp. 4359–4373, May 2018.

[80] M. Whaiduzzaman, M. Sookhak, A. Gani, and R. Buyya, "A survey on vehicular cloud computing," *J. Netw. Comput. Appl.*, vol. 40, pp. 325–344, Apr. 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1084804513001793

[81] D. Kwak, R. Liu, D. Kim, B. Nath, and L. Iftode, "Seeing is believing: Sharing real-time visual traffic information via vehicular clouds," *IEEE Access*, vol. 4, pp. 3617–3631, 2016.

[82] H. Menouar, I. Guvenc, K. Akkaya, A. S. Uluagac, A. Kadri, and A. Tuncer, "UAV-enabled intelligent transportation systems for the smart city: Applications and challenges," *IEEE Commun. Mag.*, vol. 55, no. 3, pp. 22–28, Mar. 2017.

[83] Z. Ning, F. Xia, N. Ullah, X. Kong, and X. Hu, "Vehicular social networks: Enabling smart mobility," *IEEE Commun. Mag.*, vol. 55, no. 5, pp. 16–55, May 2017.

[84] M. Li, P. Si, and Y. Zhang, "Delay-tolerant data traffic to software-defined vehicular networks with mobile edge computing in smart city," *IEEE Trans. Veh. Technol.*, vol. 67, no. 10, pp. 9073–9086, 2018.

[85] H. Gao, C. H. Liu, and W. Wang, "Hybrid vehicular crowdsourcing with driverless cars: Challenges and a solution," *Computer*, vol. 51, no. 12, pp. 24–31, Dec. 2018.

[86] J. Wang, Y. Wang, D. Zhang, Q. Lv, and C. Chen, "Crowd-powered sensing and actuation in smart cities: Current issues and future directions," *IEEE Wireless Commun.*, vol. 26, no. 2, pp. 86–92, Apr. 2019.

[87] P. Xu, G. Dherbomez, E. Hery, A. Abidli, and P. Bonnifait, "System architecture of a driverless electric car in the grand cooperative driving challenge," *IEEE Intell. Transp. Syst. Mag.*, vol. 10, no. 1, pp. 47–59, Jan. 2018.

[88] M. Milford, S. Anthony, and W. Scheirer, "Self-driving vehicles: Key technical challenges and progress off the road," *IEEE Potentials*, vol. 39, no. 1, pp. 37–45, Jan. 2020.

[89] WHO. *Global Status Report on Road Safety*. Accessed: 2018. [Online]. Available: https://injuryprevention.bmj.com/content/15/4/286

[90] S. Liu, J. Peng, and J.-L. Gaudiot, "Computer, drive my car!" *Computer*, vol. 50, no. 1, p. 8, Jan. 2017.

[91] WHO. *Road Traffic Injuries*. Accessed: 2018. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

[92] V. Dhar, "Equity, safety, and privacy in the autonomous vehicle era," *Computer*, vol. 49, no. 11, pp. 80–83, Nov. 2016.

[93] W. B. Rouse, "The systems, man, and cybernetics of driverless cars: Challenges and opportunities for the SMCS," *IEEE Syst., Man, Cybern. Mag.*, vol. 3, no. 3, pp. 6–8, Jul. 2017.

[94] Q. Lu, T. Tettamanti, D. Hörcher, and I. Varga, "The impact of autonomous vehicles on urban traffic network capacity: An experimental analysis by microscopic traffic simulation," *Transp. Lett.*, vol. 12, no. 8, pp. 540–549, Sep. 2020, doi: 10.1080/19427867.2019.1662561.

[95] L. Alter. *80 Billion Has Been Spent on Self-Driving Cars With Nothing to Show For it*. Accessed: 2019. [Online]. Available: https://www.treehugger.com/cars/praise-dumb-transportation-self-driving.html

[96] S. Kuutti, S. Fallah, R. Bowden, P. Barber, and A. Khajepour, *Deep Learning for Autonomous Vehicle Control: Algorithms, State-of-the-Art, and Future Prospects*. Williston, ND, USA: Morgan & Claypool, 2019.

[97] L. M. Hulse, H. Xie, and E. R. Galea, "Perceptions of autonomous vehicles: Relationships with road users, risk, gender and age," *Saf. Sci.*, vol. 102, pp. 1–13, Feb. 2018. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0925753517306999

[98] P. Fairley, "Self-driving cars have a bicycle problem [News]," *IEEE Spectr.*, vol. 54, no. 3, pp. 12–13, Mar. 2017.

[99] R. Sparrow and M. Howard, "When human beings are like drunk robots: Driverless vehicles, ethics, and the future of transport," *Transp. Res. C, Emerg. Technol.*, vol. 80, pp. 206–215, Jul. 2017. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0968090X17301262

[100] A. Takacs, I. Rudas, D. Bosl, and T. Haidegger, "Highly automated vehicles and self-driving cars [industry tutorial]," *IEEE Robot. Autom. Mag.*, vol. 25, no. 4, pp. 106–112, Dec. 2018.

[101] N. Li, D. W. Oyler, M. Zhang, Y. Yildiz, I. Kolmanovsky, and A. R. Girard, "Game theoretic modeling of driver and vehicle interactions for verification and validation of autonomous vehicle control systems," *IEEE Trans. Control Syst. Technol.*, vol. 26, no. 5, pp. 1782–1797, Sep. 2018.

[102] D. Birnbacher and W. Birnbacher, "Fully autonomous driving: Where technology and ethics meet," *IEEE Intell. Syst.*, vol. 32, no. 5, pp. 3–4, Sep. 2017.

[103] B. Markwalter, "The path to driverless cars [CTA insights]," *IEEE Consum. Electron. Mag.*, vol. 6, no. 2, pp. 125–126, Apr. 2017.

[104] O. Punal, C. Pereira, A. Aguiar, and J. Gross, "Experimental characterization and modeling of RF jamming attacks on VANETs," *IEEE Trans. Veh. Technol.*, vol. 64, no. 2, pp. 524–540, Feb. 2015.

[105] N. J. Goodall, "Can you program ethics into a self-driving car?" *IEEE Spectr.*, vol. 53, no. 6, pp. 28–58, Jun. 2016.

[106] K. Kuru, "Management of geo-distributed intelligence: Deep insight as a service (DINSaaS) on forged cloud platforms (FCP)," *J. Parallel Distrib. Comput.*, vol. 149, no. 3, pp. 103–118, Mar. 2021.

[107] A. Griswold. *Waymo is Readying a Ride-Hailing Service That Could Directly Compete With Uber*. Accessed: 2018. [Online]. Available: https://qz.com/1208897/alphabets-waymo-googl-is-readying-a-ride-hailing-service-in-arizona-that-could-directly-compete-with-uber/

[108] M. Bertozzi, A. Broggi, A. Coati, and R. I. Fedriga, "A 13,000 km intercontinental trip with driverless vehicles: The VIAC experiment," *IEEE Intell. Transp. Syst. Mag.*, vol. 5, no. 1, pp. 28–41, Spring 2013.

[109] K. Grifantini, "Self driving and self diagnosing: With emerging technology, your car may soon serve not only as personal chauffeur and entertainment center but as a health advisor too," *IEEE Pulse*, vol. 9, no. 4, pp. 4–7, Jul./Aug. 2018.

[110] B. Brown, "The social life of autonomous cars," *Computer*, vol. 50, no. 2, pp. 92–96, Feb. 2017.

KAYA KURU received the B.Sc. degree from Turkish National Defense University, the major/A.D.P. degree in computer engineering from Middle East Technical University (METU), the M.B.A. degree from Selcuk University, and the M.Sc. and Ph.D. degrees in computer science from METU. He completed his postdoctoral studies at the School of Electronics and Computer Science, University of Southampton, U.K. He has worked as a DBA, a SW Developer, the SW Development Manager, and the IT Manager of the IT Department, Medical University, for 15 years. He was the Chief Person directing a comprehensive countrywide distributed IT project titled "Health Care Automation System" with a budget of over $50 million. He is currently an Associate Professor in computer-information systems engineering. His research interest includes the development of autonomous intelligent systems using ML, DL, and AI (RL) within the cyber-physical domains in the cloud platform.

WASIQ KHAN received the Ph.D. degree in AI and speech processing from Bradford University, U.K., in 2015. He is currently a Senior Lecturer in artificial intelligence and data sciences with the Department of Computer Science, Liverpool John Moores University, U.K. He is research active within the domain of AI/machine learning, video/speech data processing, and data science. He has been working as a Lead on various large-scale research projects in collaborations with academia and industry. He is an active Reviewer of various top-ranked journals, including IEEE TRANSACTIONS and IEEE ACCESS, and UKRI/EPSRC research grants. He has established academic citizenship within the domain of AI and data processing. He is also a Fellow of HEA and a member of the Computational Intelligence Society.

• • •