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Autonomous Vehicles in Smart Cities

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Abstract: A city becomes a "smart city" by equipping systems and services with cameras, sensors, etc. in order to collect data. Automated vehicles (AVs) are those in which at least some aspects of a safety-critical control function (e.g., steering, throttle, or braking) occur without direct driver input. They can positively contribute to smart cities. Autonomous vehicles in smart cities promise safer, more efficient, and accessible urban transport by optimizing traffic, reducing emissions with electric AVs, and reclaiming space from parking for pedestrians. Smart city planners and carmakers are wrestling with challenges, but they are working at very different paces and often with different technologies — despite the fact that these two worlds will need to be bridged in order to be useful. This paper reviews the application of autonomous vehicles in smart cities.

Keywords: *Autonomous Vehicles, Self-Driving Vehicles, Connected Vehicles, Smart Cities*

I. INTRODUCTION

The mechanical automobile has gradually evolved into our modern connected and autonomous vehicles (AVs)—also known as smart vehicles. An autonomous vehicle is one that is capable of fulfilling the operational functions of a traditional vehicle without a human operator. Examples of autonomous vehicles are shown in Figure 1 [1].

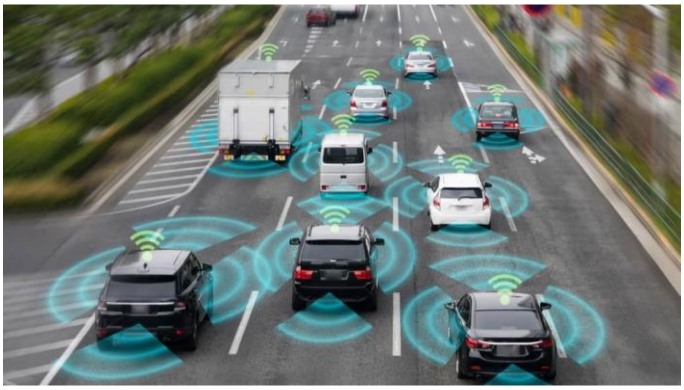

Figure 1: Examples of autonomous vehicles [1].

Similarly, our cities are gradually developing into "smart cities," where municipal services from transportation networks to utilities are integrated. A "smart city" is a city which leverages modern information and communication technologies (e.g., cameras, sensors, networks, data analytics, etc.) to improve the quality and efficiency of urban services. In a smart city, systems and urban services such as transportation networks, utilities, recycling, and even law enforcement can communicate and share data. The idea, with both smart vehicles and smart cities, is that more data leads to better, more informed decisions [2].

II. CONCEPT OF AUTOMOUS VEHICLES

Autonomous vehicles constitute one of the most spectacular recent developments of AI. As opposed to human-driven vehicles, autonomous vehicles essentially refer to self-driving vehicles. They are smart vehicles that are able to perceive their environment and to move on accordingly without human intervention. They operate with the capability to have automatic motions and navigate themselves depending on the environments and scheduled tasks. Figure 2 shows the architecture of autonomous car [3].

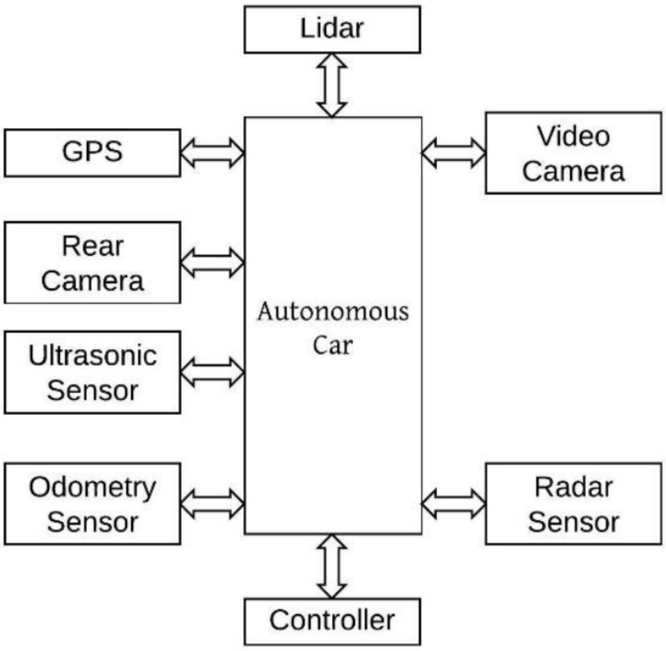

Figure 2: Architecture of Autonomous Car [3].

Autonomous vehicle or driverless car is an ambitious project which requires the fusion of many technologies like electronics, communications, mechatronics, software engineering, artificial intelligence, GPS, and industrial IoT. It is a vehicle that uses a combination of sensors, cameras, radar, and artificial intelligence (AI) to travel between destinations without a human operator. It is designed to be able to detect objects on the road, maneuver through the traffic without human intervention, and get to the destination safely. It is fitted with AI-based functional systems such as voice and speech recognition, gesture controls, eye tracking, and other driving monitoring systems. Several companies have announced their plan to get involved in autonomous or driverless and electric vehicle technology

Connected and autonomous vehicles (Avs) are now becoming a cornerstone of the increasingly connected world. They are receiving a lot of attention from manufacturers, service providers, governments, universities, consumers, and other stakeholders. The main goal of autonomous vehicles is to build a self-driving system that can perceive the road better than the best human driver. They are incredible innovation that will likely transform transportation, especially in urban environments, in the near future. Although autonomous vehicles can improve performance and safety, there are a myriad of serious technology, regulatory, and security challenges to consider in preparation for full vehicle autonomy.

Autonomous vehicles combine artificial intelligence (AI) and robotics. They are regarded as a promising answer to traffic jams, accidents, and environmental pollution. They will constitute the backbone of future next-generation intelligent transportation systems (ITS) providing travel comfort and road safety along with a number of value-added services. They are used in search and rescue, urban reconnaissance, mine detonation, supply convoys, etc. [4]. They can help save lives on the battlefield.

Autonomous vehicle (AV) is also described as “driverless,” “robotic,” or “self-driving.” AV is regarded as a multidisciplinary technology. The enabling technologies in support of connected autonomous vehicles include camera, GPS & GNSS, and sensors, radar , LiDAR (Light Detection and Ranging), and Internet of things. The race to develop autonomous vehicles has heated up with many major automotive manufacturers such as Tesla, Audi, General Motors, Mercedes Benz, Uber, Google, and Amazon [5]. Figure 3 shows how autonomous vehicles work [6].

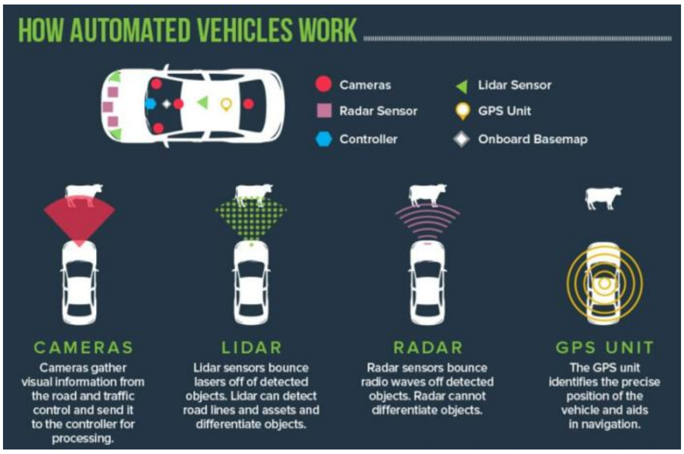

Figure 3: How autonomous vehicles work [6].

III. LEVELS OF AUTONOMY

SAE International (formerly the Society of Automotive Engineers) classifies autonomous vehicles on a scale of 0 to 5. The six levels are presented as follows [7,8]:

Level 0: No automation: All driving tasks and major systems are controlled by a human driver. The automated system has no vehicle control but can issue warnings.

Level 1: Function-specific automation: Provides limited driver assistance. The driver must be ready to take control at any time.

Level 2: Partial driving automation: At least two primary functions are combined to perform an action. The driver is obliged to detect objects and events and react if the automated system does not respond correctly.

Level 3: Conditional driving automation: Enables limited self-driving automation. Vehicles at this level can make informed decisions for themselves. In known environments (such as highways), the driver can safely divert his attention from driving tasks.

Level 4: High driving automation: An automated driving system performs all dynamic tasks of driving. The automated system can control the vehicle in almost any environment, such as extreme weather conditions. and fewer parking spaces.

Level 5: Self-driving automation: An automated driving system performs all dynamic functions of driving. No human intervention is required. A vehicle at this level requires no driver. It is on its own and must be able to react to all situations that might arise.

The six levels are shown in Figure 4 [9] and are summarized as follows: No Automation, Driver Assistance, Partial Automation, Conditional Automation, High Automation, and Complete Automation. The classification has been adopted by DOT. Vehicles sold today are in levels 1 and 2. Levels 4 and 5 will probably increase vehicle prices significantly. But how do we get to Level 5?

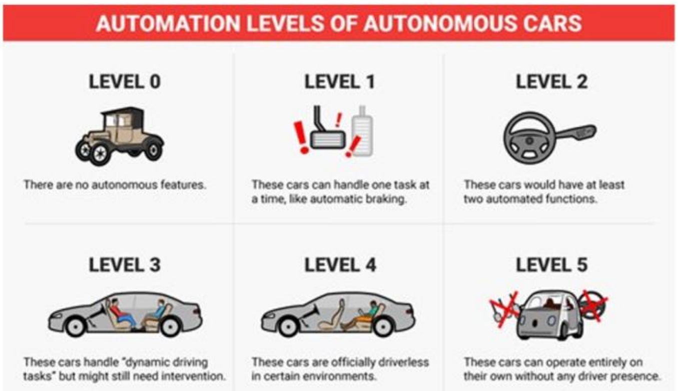

Figure 4: The six levels of autonomy [9].

IV. WHAT IS A SMART CITY?

Cities around the world are being wrecked by the ever-increasing burden of traffic. Smart cities are a recent innovation perceived as a winning strategy to cope with some severe urban problems such as traffic, pollution, energy consumption, waste treatment. Governments can streamline the way cities are run, saving money and making them more efficient as a result. The notion of the smart city captured most people attention during the last decade as a blend of beliefs on how technology in general could be used to transform how cities around the world work, while improving their competitiveness, offering new ways of solving problems linked to poverty, social deprivation, pollution and poor environmental issues [10].

The concept of smart city emerges as a major response to the increasing global urbanization, global warming, sustainable growth, scarcity of resources, and socio-economic challenges faced by cities worldwide. IBM’s Smarter Cities work began in late 2008 as part of the Smarter Planet initiative. The idea of “smart city” first appeared in the 1990s, with focus on the impact of ICT on modern infrastructures within cities. It is the merge of some other more familiar urban policies such as digital city, green city, knowledge city.

The word “smart” can be used to describe any device that can process information and can communicate with something. The term “smart cities” is a fuzzy concept and there is not a one-size-fits-all definition of the concept. The term has gained traction across sectors and has pervaded the fields of sustainability, urban planning, architecture, engineering, and computer science.

As typically shown in Figure 5 [11], a smart city is a high-tech urban area that connects people, information and technologies in order to increase life quality. It integrates ICT in a secure manner so as to manage the city’s assets, increase operational efficiency, share information with the public, and improve citizen welfare. ICT is the key technology that weaves digital intelligence into cities' fabric. The main motivation for using ICT is the desire to eradicate human error. Smart cities are those communities that pursue sustainable economic development through investments in human and social capital and manage natural resources through participatory policies.

Figure 5: A typical smart city [11].

Figure 6: The six major characteristics of a smart City [13].

The main target for developing smart cities is to provide the following services [12]:

1. Convenience of the public services
2. Delicacy of city management
3. Liveable and sustainable living environment
4. Smartness of infrastructures
5. Effective integration of physical, digital and human systems in the built environment to deliver a sustainable, prosperous and inclusive future for its citizens.
6. Adequate water supply and electricity supply
7. Sanitation, including solid waste management
8. Efficient urban mobility and public transport
9. Affordable housing, especially for the poor
10. Good governance, especially e-Governance and citizen participation,
11. Safety and security of citizens, particularly women, children and the elderly
12. Health and education.

Figure 6 displays the six major characteristics of a smart city [13].

V. AUTONOMOUS VEHICLES IN SMART CITIES

Advancements in AI, sensors, and connectivity propel autonomous vehicles in smart cities. One key enabler of autonomous driving is artificial intelligence (AI). Machine learning algorithms, powered by large datasets, allow vehicles to perceive and interpret their surroundings. Cameras, lidar, radar, and ultrasonic sensors act as the eyes and ears of autonomous cars. The rollout of 5G networks plays a role in the development of autonomous vehicles within smart cities [14].

The term "smart vehicle" is used as a synonym for the connected and autonomous vehicle. The motives behind smart cities are quite similar to the motives behind smart vehicles: safety, efficiency, and sustainability are regularly cited as major objectives. The "smart" in "smart vehicle" refers to artificial intelligence. A smart vehicle leverages artificial intelligence to provide data-driven insights, features, and capabilities. Smart vehicles are digitalized vehicles, dependent on electronics and capable of connecting to the Internet, to satellites (e.g., GPS), and to nearby vehicles or infrastructure. They depend on physical assets—traffic lights, road-side units (RSUs), etc.—in order to function [2]. Figure 7 shows a typical AV in a city [15].

Figure 7: A typical AV in a city [15].

VI. APPLICATIONS OF AUTONOMOUS VEHICLES IN SMART CITIES

Vehicles are a concern for anyone looking to become more mindful of the environment. Traffic problems, emission pollution, and danger for pedestrians and bicyclists make vehicles a challenge to integrate with the ideals of smart cities. Common applications of AVs in smart cities include the following [2,16]:

- *Transportation:* Today, self-driving vehicles have become a tangible reality, revolutionizing the way we think about transportation. As more of the world's population moves into these smart urban environments, most people will rely on transportation that they no longer own. The vehicles interact mainly with smart transportation systems (STSs). The main motivation behind smart transportation systems is collision avoidance. Reduced traffic, increased safety, and a cleaner environment are just a few ways smart transportation may impact smart cities worldwide. As the importance of safety, efficiency, and sustainability in urban transportation becomes more apparent, intelligent transportation systems are changing and growing. Figure 8 shows a typical urban transportation [17].

Figure 8: A typical urban transportation [17].

- *Smart Tracking System*: Smart vehicles are equipped with global positioning system (GPS) technologies. GPS technologies can be made bidirectional, enabling a smart city's transportation management organization to locate vehicles, detect speeding vehicles, and deploy emergency services.
- *Smart Sensing System:* As the name suggests, a smart sensing system consists of smart sensors in both smart vehicles and smart transportation infrastructure. Both smart vehicles and smart transportation infrastructure leverage sensing to monitor road and traffic conditions. In-vehicle sensors can detect road reflectors and inductive loops, improving driving safety at night. Road-side sensors collect and share information about traffic density and can identify even fast-moving vehicles. Smart traffic control system uses sensors to detect vehicles waiting at traffic lights. It knows how many vehicles are waiting in each direction, and it knows how long they have been waiting. Figure 9 shows autonomous vehicles with sensing system [18].

Figure 9: Autonomous vehicles with sensing system [18].

- *Smart Intersections:* These are emerging as pivotal components of urban transport, integrating state-of-the-art technologies to create next-generation road transportation systems that seamlessly address modern mobility challenges. Smart intersections play a crucial role in different parts of transportation systems. Technologies such as vehicle-to-everything (V2X) communication, artificial intelligence, multi-sensor data fusion, and more are incorporated into these intersections to improve capacity and safety and reduce damage to the environment. These intersections harness the potential of V2X communication, AI, IoT networks, and some smart sensing for better vehicle-to-infrastructure functions that support smoother traffic management, promote safety, and regard environmental circumstances. Smart intersections are conceived to be interoperable in the world of connected and autonomous vehicles (CAVs). Safety, reliability, and ethical decision-making in mixed-traffic conditions remain a major issue. Operationally, smart intersections effectively prioritize public transportation modes, improving reliability and reducing delays.

VII. BENEFITS

With the introduction of AVs, more excellent road safety is expected for drivers and weak road users with greater accessibility and less environmental impact. It is possible to highlight three main categories of AVs' influence on the urban form: urbanization, road infrastructure, and environmental impact. Self-driving vehicles also offer new opportunities for people with motor problems, including the elderly, people with disabilities, and marginalized groups. Other benefits of AVs in smart cities include the following [2,19,20]:

- *Automation:* Automation of routine tasks is currently a concept that interests many industries. Among the most revolutionary parts of it are autonomous vehicles. Autonomous driving would not need people's decisions, which could often be dangerous and irrational to take you from point A to point B. Well-connected rural areas will gain accessibility in an automated driving environment.
- *Operational Efficiency:* We waste a lot of time in traffic. For the average driver, a combined 4 months of their entire lives is spent at red lights. It is not just time that is wasted in traffic; it is money. But smart cities have a number of transportation technologies that will combat these issues. Smart city technology in transportation will be a game changer that could cut time wasted idling in traffic and maintenance and fuel costs altogether. There also will be efficiencies in terms of cars talking to intersections, via smart traffic signals, whereby the traffic signals can start adapting because they know what the traffic patterns are.
- *Confidentiality:* We must safeguard secret, private and/or critical information from unauthorized parties. In the automotive context, controller area network (CAN) data is transmitted unencrypted, which is a confidentiality failure, enabling attackers to reverse engineer CAN messages in order to conduct attacks.
- *Integrity:* We must ensure that unauthorized parties do not manipulate critical information during transmission. Moreover, recipients of critical information should be able to confirm the integrity of the information—and detect tampering.
- *Availability:* We must guarantee that data, systems, and services remain accessible, even in the event of disasters or attacks. If a smart transportation system goes offline due to a ransomware attack, leaving smart vehicles

stranded and causing the entire transportation system to grind to a halt, then we have an availability failure.

- *Accountability:* We must measure the resources consumed by each user. In this manner, we can optimize resource utilization, plan for the future, and detect suspicious under- or over-usage.
- *Environmental Impact:* The impact on the urban environment following the spread and use of AVs will be significant. A large sum of pollution could be combated by carpooling. Especially when so many people commute from suburbs to the same place, this is a seemingly unnecessary form of pollution. Electric AVs contribute to lower carbon footprints and better air quality. When autonomous driving technology reaches high levels, safety on the roads and environmental sustainability will increase radically.
- *Mobility:* As the population in cities continue to rise, the need for mobility as well as its burdens on the environment, social stability, and the economy will grow rapidly. Unprecedented urbanization and advancements in transportation technologies necessitate safer, faster, and more sustainable mobility solutions. Urban mobility is one issue that can obtain significant benefits from smart city implementation in terms of safety and traffic management. Connectivity is the key to promoting autonomous and sustainable mobility. Mobility is not seen as a goal in itself but as a means of providing access to essential services. Mobility planning within cities and the organization of the various forms of mobility cannot fail to consider two fundamental parameters of the context in which one lives, namely demographic size and the extent of the territory in which one moves. It is estimated that mobility as a service will make the cost of a ride less than the price of a public transport ticket, thus helping to break down the barriers of social inequality.
- *No More Parking:* Looking for a parking spot can be quite stressful. Fortunately, with the revolution of autonomous vehicles, cities will not need any type of parking anymore. Garages will move outside of downtown areas, thanks to the predicted trend of shared mobility. Furthermore, self-driving cars are able to use narrower driving lanes and maneuver better than existing cars, so parking spaces will be optimized to accommodate more cars. All the space that is currently used for parking could find new uses in smart cities.

VIII. CHALLENGES

While the future of AVs looks promising, there are challenges. Unfortunately, the paradigm of smart vehicles in smart cities is rife with danger and ripe for misuse. One vulnerable system or service could become an attacker's entry point, facilitating access to every connected vehicle, device, etc. Smart vehicles, smart transportation systems, and smart cities all have the potential to contribute computing power and resources to destructive botnets. Their costs could be higher and the benefits smaller than expected. Smart cities need compatible infrastructure, from smart highways to charging networks. Other challenges include the following [2,14]:

- *Cost*: Some authors and automobile manufacturers have asserted that real-world exploitation of automotive vulnerabilities is improbable because it would require a significant investment of time and effort. Some say it would be too expensive. Some say it would require too much expert knowledge. Optimized driving and shared models can lower transportation costs for users and cities.
- *Integration:* Seamless coordination with public transport is vital; otherwise, AVs could undermine mass transit. Successful integration depends on holistic planning, focusing on shared use, sustainable electric fleets, and strong integration with public transport to create truly people-centric, efficient, and livable smart cities.
- *Safety:* Safety of autonomous vehicles is a critical aspect that requires aligned technology. AVs can significantly reduce accidents by removing human error, leading to fewer fatalities and injuries. Technology is critical in developing the vehicles but also in creating a safe driving environment for the vehicle as well as those interacting with the vehicles, such as pedestrians, cyclists, and even animals.
- *Cybersecurity:* An attacker on the opposite side of the world can physically harm you or your vehicle. Smart vehicles come with unique attack surfaces and vulnerabilities. Connected AVs are vulnerable to cyberattacks, which could have severe physical consequences. Both smart cities and smart vehicles could become infection vectors or targets. Malware could spread from smart vehicles to a smart transportation system, infecting all vulnerable smart vehicles in the smart city, and since smart vehicles are inherently mobile, they could transport the malware to the next smart city. Thankfully, we have not yet seen automotive cyberattacks in the wild. A cybersecurity model must include *a*uthentication, *a*uthorization, and *a*ccountability. Remote automotive cyberattacks could also facilitate crimes such as abduction (i.e., kidnapping), human trafficking, sex trafficking, sexual assault (i.e., rape), destruction of property, carjacking, stalking, harassment, and intimidation—to name a few.
- *Auto Theft:* When discussing smart vehicles, the most valuable tangible asset is often the vehicle itself. We often think of auto theft as more of an economic concern (i.e., loss of property) than a threat to safety (i.e., loss of life). Vehicle tracking—by unauthorized parties—can aid in various types of theft. In the world of organized crime, vehicles are often stolen to aid in the commission of a particular crime. Once the crime is committed, the stolen vehicle is often abandoned.
- *Terrorism:* Terrorists can seize control of a self-driving vehicle and use it to wreak havoc. If terrorists were to successfully hack a smart vehicle—specifically, an autonomous vehicle—they could reroute it to a crowded area to run over innocent people. If they were to steal or purchase an autonomous vehicle, they could simply load it with explosives and program the vehicle to drive itself to the target. When faced with a terrorist attack, first responders are warned to look out for secondary attacks (e.g., secondary explosive devices) meant to target first responders and onlookers. Attackers can also leverage electric vehicle charging to disrupt entire power grids. They could compromise the charging equipment and then jump to an individual's home network or an organization's corporate network.
- *Behavior Changes:* Safety concerns go hand in hand with consumer unwillingness to change ingrained transportation-related behavior. It takes so much more education and awareness for people to change the way

they get to work. While this is partly about concerns for safety, it is largely about the unwillingness to change an ingrained mindset and daily routine.

IX. THE FUTURE OF AUTONOMOUS VEHICLES IN SMART CITIES

Smart cities and autonomous vehicles are both making progress. Autonomous cars have undergone a remarkable evolution over the years. As autonomous cars continue to evolve, they are becoming integral components of smart cities, contributing to a more sustainable, efficient, and interconnected urban environment. The future of transportation with autonomous vehicles and smart cities is not just an incremental change but a paradigm shift.

In a future in which AVs will be widespread, there will always be a coexistence of private and shared use regarding the transport of people. The introduction of self-driving vehicles will be slow and progressive and will undoubtedly have a different impact on the territory, depending on the type of vehicle and ownership. By many accounts, driverless vehicles are nowhere near ready for prime time. They have experienced numerous failures resulting in stranded vehicles, blocked traffic, crashes, injuries, and at least one fatality [21].

CONCLUSION

Autonomous driving is considered one of the significant innovations of these first decades of the 21st century, capable of revolutionizing the urban and extra-urban mobility system and transforming the lifestyle of people who move daily. Thanks to the introduction of AI in driving systems, vehicles are becoming more and more "intelligent," able to park themselves, change the speed or direction of travel, and react and predict obstacles while driving. However, fully autonomous—i.e., self-driving—vehicles are not yet commercially available; partially autonomous features have been integrated into a number of vehicle makes and models currently on the road.

While self-driving cars are not yet on the roads, local governments are laying the groundwork for the autonomous era. By the year 2030, over half of all vehicles on the road will be equipped with one or more autonomous driving capabilities. The role of government is essential in setting safety standards and protecting everyone on our nation's roads. To stay on top of the developments in autonomous vehicles in smart cities, one should consult the books in [22-25] and related journals:

- *Artificial Intelligence Review*
- *Applied Artificial Intelligence*
- *Artificial Intelligence and Law*
- *AI Magazine*
- *Vehicular Communications*
- *Infrastructures*

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