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AVIN Specialized Reports

Features of the Infrastructure Facilitating the Operation of CAVs

November, 2018

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The Autonomous Vehicle Innovation Network (AVIN) is an initiative by the Government of Ontario

About AVIN

The **Autonomous Vehicle Innovation Network (AVIN)** initiative is funded by the Government of Ontario to support Ontario's competitive advantage in the automotive sector and to reinforce its position as a North American leader in advanced automotive and mobility technologies, including transportation and infrastructure systems.

This initiative capitalizes on the economic potential of connected and autonomous vehicle (CAV) technologies by supporting the commercialization of best-in-class, made-in-Ontario solutions that create jobs, drive economic growth and enhance global competitiveness. AVIN also helps Ontario's transportation systems and infrastructure adapt to these emerging technologies.

Areas of Focus

AVIN programs focus on supporting the development and demonstration of CAV technologies in light vehicles (e.g., cars, trucks and vans), heavy-duty vehicles (commercial vehicles, trucks, buses and RVs), transportation infrastructure, intelligent transportation systems (ITS) and transit-supportive systems.

AVIN is administered on behalf of the Government of Ontario by Ontario Centres of Excellence (OCE). The initiative comprises four distinct programs and a central hub. The AVIN programs are:

- AV Research and Development Partnership Fund
- Talent Development
- Demonstration Zone
- Regional Technology Development Sites

AVIN has five Objectives:

The AVIN Central Hub is a dedicated team that supports delivery and administration of AVIN programming, and provides the following key functions:

- Connect & Coordinate - a focal point to help coordinate activities among industry, academia, research organizations and governments, and connect interested stakeholders and members of the public;
- Opportunity Identification - knowledge translation, research, data/information, trend analysis, and acting as a bridge between technology and policy; and
- Awareness & Education - promote AVIN programs and Ontario's AV testing pilot and build awareness of Ontario's growing CAV community.

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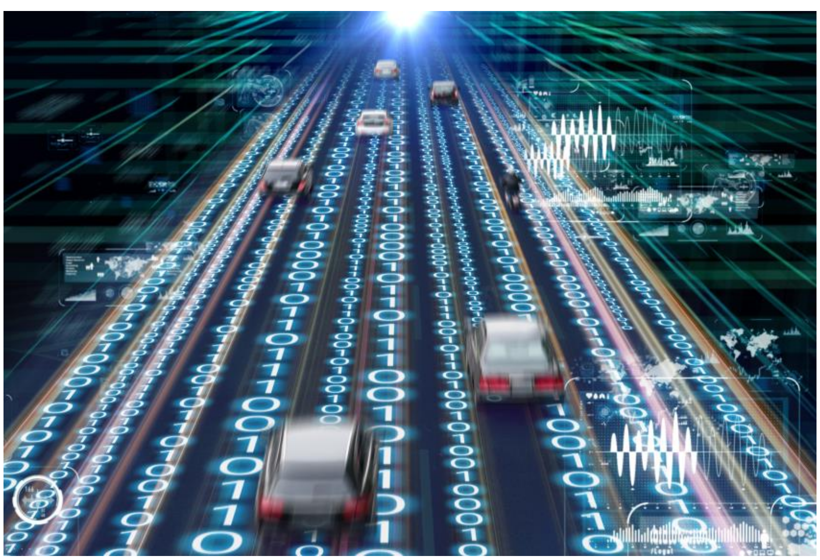
Finally, we would like to thank the Government of Ontario for supporting AVIN programs and activities.

Introduction

Connected and autonomous vehicles (CAVs), encompassing private, commercial, and public transit vehicles, have been attracting significant attention from governments over the past few years. Since automotive technology is advancing at a fast pace, most governments are currently working on their readiness plans to accommodate the rapid automotive developments, primarily CAVs, on their roads. In the previous AVIN specialized report[1], we presented the main technology development areas in CAVs, along with a brief discussion of challenges and key research and development activities in each area.

Although one of the major anticipated gains of having CAVs is reducing the number of on-road fatalities, these smart vehicles require efficient planning and support to avoid encountering negative returns. To be able to safely adopt CAVs and utilize their full potential, governments need first to ensure that road infrastructure, including hardware and software, is ready for use. One of the major challenges to the adoption of CAVs is the unsuitability of the current road infrastructure. Research and development activities have demonstrated that for CAVs to be able to perform their operations safely and efficiently, they need to be surrounded with a compatible physical infrastructure and connected to a resourceful digital infrastructure. For example, roads with unclear or obstructed lane markings and crosswalks cannot be safely driven by CAVs. These road markings should be fixed first and maintained in good order for accurate detection by CAVs. Also, without being able to connect to the road infrastructure, CAVs will only have local road information and limited views of the road network. Connected road infrastructure will significantly add to the safety, accuracy and scope of services offered by and to CAVs.



[1] Autonomous Vehicle Innovation Network. (2018). Regional Technology Development Sites: Technology Focus Areas. Retrieved from https://bit.ly/2DAWXcZ

Motivated by the pressing need for investing in and planning for the enablers of CAVs, this report describes the road infrastructure, both physical and digital, needed for accommodating CAVs and facilitating their operation. We discuss the diverse areas of change and enhancement required to enable future road infrastructure to meet its goals. We conclude the discussion by summarizing the key features of the ideal CAV infrastructure.

Physical Infrastructure

One of the critical factors impacting the successful adoption of CAVs is the physical road infrastructure needed for their operation. Some changes and enhancements to the current road infrastructure are required to facilitate the seamless, safe adoption of CAVs. Governments interested in having CAVs on their roads need to plan for and invest in such changes. In the following sections, we shed light on the different areas of infrastructure changes/enhancements.

1- Road Markings

CAVs mainly depend on detecting the road markings by their cameras for the sake of orienting themselves in the middle of a lane and detecting their safe stopping points at junctions. For accurate detection of these road markings, they should be clearly visible to the CAV camera. This requires recurring inspection and maintenance of the road markings to ensure they are identifiable.

Some weather conditions may impact the visibility of road markings, even if they are well-maintained. For example, snow covering roads would obstruct the visibility of the regular markings of these roads. In jurisdictions that receive regular snowfall, consideration should be given to all-season detectable markings such as position information that can be retrieved from pavement-embedded sensors and/or Radio-Frequency Identification (RFID) tags. On rainy days, wet roads can create challenges for in-vehicle cameras to successfully identify road markings. A solution for this challenge can be the wet reflective markings adopted by Michigan's Department of Transportation.[2]

2- Smart Pavement

Some governments have started to invest in smart pavement due to the wide benefits it can bring to roads[3]. With the availability of CAVs, such benefits would be augmented.

Smart pavement can track vehicle locations and provide CAVs with related alerts when necessary. They can also use the tracked locations for detecting on-road emergencies and traffic conditions and report them, so authorities can take timely action. Smart pavement can also share location information with CAVs to enhance their on-board localization equipment in obstructed areas where GPS is not reliable.

The currently popular smart pavement products depend on the use of sensing fiber cables that are

[2] Roads&Bridges (2017, Aug). Michigan DOT implements first all-wet reflective work zone standard in the nation. Retrieved from https://www.roadsbridges.com/michigan-dot-implements-first-all-wet-reflective-work-zone-standard-nation

[3] Cheng, M. (2018, June). Colorado to Test Smart Pavement for Road Safety. Retrieved from http://www.futurecar.com/2339/Colorado-to-Test-Smart-Pavement-for-Road-Safety
Inside Towers (2018, Jan). Verizon Wireless Is Taking It To the Streets. Retrieved from https://insidetowers.com/cell-tower-news-verizon-wireless-taking-streets/

capable of detecting strains in the pavement. Accelerometers are also embedded in the pavement to detect vibrations and predict the directions of passing vehicles. Magnetometers are used to estimate the vehicle size to predict its type. Electricity is provided from the grid through power-over-Ethernet connections, which are also used to provide connectivity to the pavement.[4]

Although it seems complex to deploy, smart pavement comes with an additional advantage, which is the flexibility to be manufactured off-site and brought to the deployment site as ready-to-wedge concrete slabs.

3- Crossings

CAVs are being trained to detect pedestrians at crossings. However, field tests show that CAVs may fail to detect pedestrians in some cases. Until the detection becomes 100 per cent reliable, CAVs should be assisted from the infrastructure at crossings to guarantee such detection. This can be handled either through road-embedded or mounted infrastructure. For example, magnetic or pressure sensors can be embedded in crosswalks to carry out the detection. Another example is to detect pedestrians using infrared sensors or cameras mounted at traffic lights or electric poles. Warning lights can be added at crossings as flashing beacons to warn approaching vehicles when crossing pedestrians are detected.[5]

4- Charging

There is a general assumption that CAVs will be electrically powered. As the industry moves in this direction, investing in more charging stations will enhance the successful operation and adoption of CAVs. This requires planning by authorities for the effective locations to deploy these stations. Locations can include well-visited spots such as service stations and shopping centres. Some governments are expanding their charging networks through incentivizing vehicle owners to install home chargers and get rebates and/or tax credits in return. Los Angeles Department of Water and Power is one of the pioneers in this respect through its Electric Vehicle Charger Rebate Program, which is part of the "Charge Up LA!" initiative.[6]

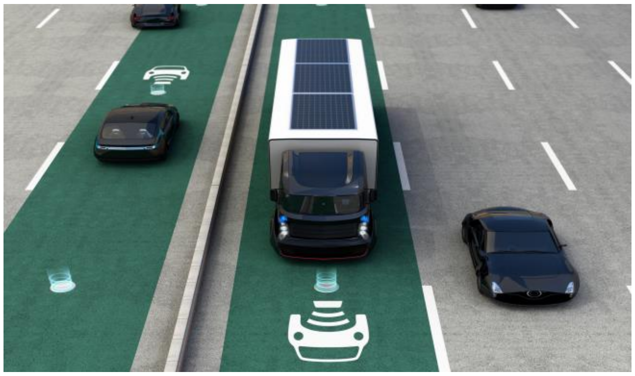
Alternative charging techniques that can accommodate autonomous vehicles with no human on board are also worth exploring. One of these alternatives can be the 'charging on motion' concept. Techniques are currently being explored to charge electric vehicles wirelessly.[7] These include the use of in-road charging plates that can transmit wireless energy to in-vehicle batteries. Roads electrified through tracks of rail is another promising solution. These electric rails transfer energy wirelessly to vehicles driving on them. This solution is currently deployed in Sweden for a

[4] Nordrum A. (2018, Aug). Colorado Prepares to Install "Smart Road" Product by Integrated Roadways. Retrieved from https://spectrum.ieee.org/cars-that-think/transportation/infrastructure/colorado-prepares-to-install-smart-road-product-by-integrated-roadways

[5] Flir (2017, Aug) Pedestrian and bicyclist detection with thermal imaging cameras. Retrieved from https://www.flir.ca/discover/traffic/urban/pedestrian-and-bicyclist-detection-with-thermal-imaging-cameras/

[6] LADWP (2018). Electric Vehicle Charger Rebate Program. Retrieved from https://tinyurl.com/y73fdo4p

[7] Knoss, T. (2018, March). Future electric cars could recharge wirelessly while you drive. Retrieved from https://www.colorado.edu/today/2018/03/27/future-electric-cars-could-recharge-wirelessly-while-you-drive



distance of 2 km, with plans by the government for future expansion.[8]

5- Safe Resorts

In highly and fully automated CAVs, drivers are assumed to be fully disengaged from the driving task. However, in some situations, CAVs may require human intervention. These include abrupt situations such as:

- The in-vehicle system detects a malfunction that may affect its reliability.
- Unplanned road events that the CAV cannot accurately navigate.
- Unusual weather changes that the CAV is not well trained to handle.

In such scenarios, CAVs will need nearby safe spots to resort to until the sudden events are cleared, or human intervention is secured.[9]

The location of these safe resorts should be well-planned. They should be frequent enough to accommodate urgent needs of CAVs to resort, and large enough to accommodate at least two vehicles. They should be well-controlled to prohibit their misuse. Also, they should be well-mapped, and their exact locations should be known to the vehicles to plan for their stop appropriately.

Service stations can be good resorts on highways, with areas designated for CAV safe resting. Since the frequency of service stations may not be enough for handling the pressing needs of CAVs to stop, safe shoulders should be planned in-between, allowing CAVs to pull over.

6- Parking

One of the anticipated advantages of CAVs is the possibility of dropping off their passengers right at their destinations, then going to a parking area on their own. This requires some changes to the current parking lots and meters infrastructure.

Since CAVs may not have humans on board, the common payment methods at parking lots and on-street parking will not be applicable for them. Automated payment methods should be facilitated. The entrance gates at parking lots and the parking meters on streets should be capable of recognizing vehicles. This can be handled through the use of an RFID reader at these points, and an RFID tag on each vehicle. The reader will be able to automatically retrieve the vehicle licence plate number stored in its tag.

An alternative to the RFID technology is to use a camera at the points designated for vehicle recognition. The camera can scan the licence plate

[8] The Guardian (2018, Apr). World's first electrified road for charging vehicles opens in Sweden. Retrieved from https://www.theguardian.com/environment/2018/apr/12/worlds-first-electrified-road-for-charging-vehicles-opens-in-sweden

[9] Transport Systems Catapult (2017, Feb). Future Proofing Infrastructure for Connected and Automated Vehicles. Technical Report.

numbers of parking vehicles for recognition. However, this vision-based technique may face limitations for its use at on-street parking and with vehicle platoons. In these use cases, cameras may have obstructed/limited views of the vehicle plate.

For payment, vehicle owners can pay for their parking using online payment methods, for example.

Digital Infrastructure

To achieve the full potential of CAVs, digital infrastructure is needed to complement the physical one. Information technology support can augment the capabilities of both CAVs and their physical infrastructure. For example, in the earlier discussion of the physical infrastructure, it has been highlighted that adding connectivity to the equipment can help solve many of the challenges. The digital infrastructure can support communication with different parts of the road infrastructure, as well as CAVs, service providers, and authorities. Through this communication facility, along with sufficient data processing and storage resources, a wide scope of services can be provisioned. In the following sections, we highlight the main digital resources needed to facilitate such service provisioning.

1- Connectivity

Many safety, infotainment, and diagnostics applications can be made feasible through equipping the road infrastructure with broadband communication capability. Connected infrastructure can report real-time information about critical on-road events and emergencies so authorities can respond in a timely fashion. Real-time traffic information can be transmitted from the infrastructure to CAVs to enhance their operation. Also, through communications between CAVs at intersections and the infrastructure, adaptive traffic lights can be easily adopted without the need for installing dedicated sensors. Emergency and transit signal priority is also one of the applications enhanced through such communications between CAVs and the infrastructure. Automated toll collection can be also facilitated through such communications. Infotainment services can also be supported through offering free Wi-Fi connectivity to CAVs by either the roadside or pavement infrastructure.

Through broadband connectivity, the road infrastructure equipment can be monitored, diagnosed, and controlled remotely. This brings the great advantage of real-time, easy, and flexible maintenance, compared to the cumbersome maintenance of the unconnected infrastructure.

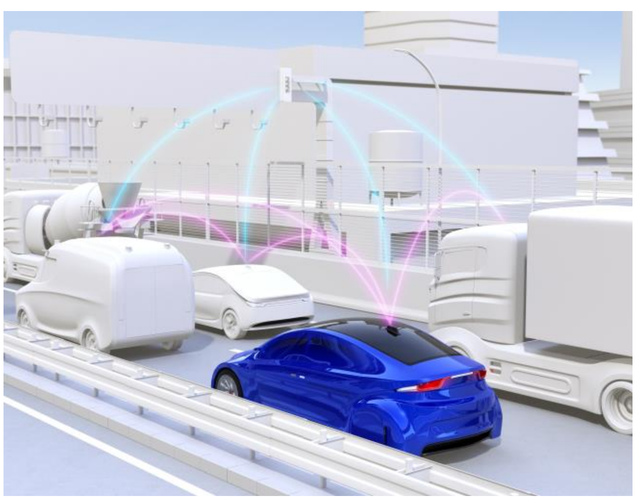
Several communication technologies can be used to provide the infrastructure backbone connectivity. Examples include fibre optics, Ethernet, and cellular communications. Deciding on which technology to use can be based on the existing deployments. For example, a city that mainly depends on fibre optic cables for providing commercial Internet services may prefer to opt for this technology for connecting the road infrastructure to make use of the previously deployed equipment.

For communication with CAVs, the infrastructure needs to be supported by at least one of the vehicular communication technologies, which are highlighted in the following section.

2- Roadside Units

Roadside units (RSUs) are stationary nodes deployed along the roadside or at intersections to enhance the operation of CAVs. Through infrastructure-to-vehicle (I2V) communication, RSUs can provide CAVs with safety warnings, real-time traffic and road condition information, maps, and navigation information. RSUs can obtain this information through backbone Internet connections or through communication with neighboring RSUs. Information can also be retrieved from CAVs through vehicle-to-infrastructure (V2I) communication. RSUs can also work as hotspots providing CAVs with drive-by Internet access.

For communication with CAVs, RSUs have to be equipped with vehicular communication capability. This can be either based on the Dedicated Short-Range Communications (DSRC) technology or the emerging, yet promising, cellular standard for vehicular communication (C-V2X). Deciding on which technology to use should be based on which of them is more adopted by CAVs. Since it is not clear yet which vehicular technology will be dominating the CAV market, governments are advised to hold on the RSU deployments until a dominant technology agreement is reached. But, since RSUs need backbone broadband connectivity for the Internet access and inter-infrastructure communications, governments could meanwhile focus on planning the locations of RSUs and getting the backbone connectivity ready for their use at these locations.



3- Computing Resources

Through its communication and sensing capabilities, the infrastructure collects crucial data. To convert this raw data into meaningful information, the data should be processed and analyzed. It needs also to be stored for the possibility of later access. Such processing and storage requirements entail the adoption of adequate computing resources.

Two major solutions can be considered for acquiring the needed computing resources. Governments can either build data centres and have their own servers or seek outsourced cloud computing services. Either owned or outsourced, these computing resources should have real-time connections with the infrastructure. They should also have sufficient capacity to process the received data and store it as long as it is relevant.

A promising computing resource can also be obtained through utilizing CAVs as vehicular clouds.[10] Through their on-board computing units, CAVs can bring instantaneous computing facilities

[10] Olariu, S., Eltoweissy, M., Younis, M. (2011) Towards autonomous vehicular clouds. *ICST Trans. Mobile Commun. Appl*. 11(7–9), 1–11.

on wheels.[11] While parked or in motion, CAVs can be tasked with computing errands released by the infrastructure. The tasked CAVs should be selected efficiently to ensure their availability and seamless access during the whole task span. Public transit CAVs can be advantageous in this regard due to their well-defined routes and availability.

4- Management Systems

Since CAVs depend on traffic and mapping information to enhance their sensing accuracy, traffic management systems are needed to handle the real-time updates and convey navigation information to CAVs when required. For example, a vehicle crash may result in road closures that are signaled by authorities at the crash location. CAVs may not be able to correctly interpret human signals. Therefore, they need to be updated with such closures and detouring in real-time through a management system that is connected to the road authorities and CAVs through mobile applications. CAVs can then either decide on a detour, or switching to manned control, if a driver is on board. This information can be helpful for non-autonomous vehicles as well for better planning of their trips.

Management systems can be developed as well for adaptively controlling traffic lights. By collecting information from CAVs at intersections, the management system can compute adaptive signal cycles and control the traffic lights accordingly based on real-time traffic demands.

Parking management systems are recommended to facilitate on-street parking. Using their in-vehicle cameras, CAVs can detect available parking spots and report their locations in real-time to a parking management system, which can share them with other vehicles through mobile applications. Other CAVs can be tasked by the system to report on the present availability of the previously reported spots to guarantee that the posted parking locations are still available.

Conclusions

Connected and autonomous vehicles, in their private, commercial, and public forms, have enormous potential. To reach their full potential and ensure safe navigation, CAVs need to be supported by an enabling infrastructure, which is to say, hardware and software resources deployed at and/or connected to the road network. In this report, we highlighted the major changes and enhancements needed for the current road infrastructure to accommodate and meet the requirements of these high-tech, unmanned vehicles. The report covered various areas of change for the physical infrastructure including road markings, pavement, charging facilities, crossings, and parking. It also drew attention to the need for safe resorts as a safety enhancement to the current infrastructure. With the overall physical changes, the road infrastructure will still be in need of digital enhancements to augment its capabilities. In this regard, the report shed light as well on key digital enhancements to the CAV infrastructure including enabling connectivity, installing RSUs, securing computing resources, and developing management systems.

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[11] Abdelhamid, S., Benkoczi, R., Hassanein, H. (2017) Vehicular clouds-ubiquitous computing on wheels. *Emergent Computation*, *Springer*, 435-452.

Based on our discussion and analysis, we summarize the features of the futuristic road infrastructure in the table below.

Governments should consider planning for investments in the areas of change discussed in this report, taking into consideration their highlighted features, to ensure readiness of their roads for CAVs with high levels of safety and quality of experience. Standardization of infrastructure features and deployments should be considered as well to facilitate seamless mobility across jurisdictions. AVIN, through its funding/programs, supports the development of projects targeted towards meeting the CAV infrastructure needs.

Although the timeline of transition to CAVs is not clear, the lifetime of road infrastructure built in the near future will span the transition period.

Features of the CAV-compatible road infrastructure

Visible	Road and crosswalk markings should be visible to CAVs day and night and in all weather conditions.
Smart	Infrastructure should be equipped with sensors and tags wherever possible to add intelligence and automation to it.
Connected	Inter-infrastructure, V2I, and I2V connectivity should be enabled through reliable technologies.
Unmanned	Assumptions that humans will be involved in the interaction between CAVs and the infrastructure should be totally avoided. For this regard, fully automated charging and parking facilities should be provided.
Failsafe	Since most of the CAV applications are safety-related, the infrastructure should be able to handle any sort of equipment failure. This can be mainly accommodated through redundant deployments, such that if a device fails or a network link is broken, a back-up will be available to take over instantly. To handle malfunctions and possible limitations of the automated system of unmanned CAVs, safe resorts should be planned for and offered on roads.
Tech-supported	RSUs should be added to the infrastructure to enable information support, wider views, and broadband access to CAVs. The infrastructure should be packed with computing resources to handle the processing and storage of its generated and collected data. Traffic and parking e-management systems should be developed and connected to the infrastructure and CAVs to facilitate their operation and automation.
Ubiquitous	CAVs are supposed to be available on all roads. Ubiquitous availability of the infrastructure should be planned for and invested in.

Therefore, CAVs should be kept in mind while planning for and developing this infrastructure to avoid costly changes later on. Furthermore, CAVs will need to be accessible for and used by all segments of the population. Consequently, investments in the suburban and rural road infrastructure will eventually be imminent, and governments will benefit by planning for these eventualities.

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