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Opportunities to Encourage On-road Connected and Automated Vehicle Testing

Recommendations for the Saginaw Region



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INTRODUCTION

Connected and automated vehicle (CAV) technology has the potential to revolutionize transportation and mobility. For now, the most promising technologies are still being researched, developed, tested, and evaluated. This work is taking place across multiple industries, as well as in academia and the public sector. Before these technologies are widely deployed on public roads, they must be tested on public roads to assure safety and efficacy. Various states and municipalities have recently become known as hubs of on-road CAV testing. Michigan is among the national and global leaders in such efforts.

With collaboration across city, economic development, chamber of commerce, and corporate representatives, Saginaw is keen to continue its economic growth and position itself as a community highly engaged with connected, automated, and mobility technologies. The Center for Automotive Research (CAR) proposed ideas for four key areas which Saginaw seeks assistance: creating an on-road connected and automated vehicle test environment, freight traffic mitigation, improving overall transit and mobility opportunities for residents, and forward-thinking parking solutions. After discussing these options internally, Saginaw Future requested that CAR move forward with the first option: Connected and Automated Vehicle Testing Activities and Opportunities.

This document provides recommendations for the Saginaw region to pursue toward creating an on-road CAV test environment and ideas for improving regional mobility overall.

METHODS

To address the questions proposed to Saginaw, researchers from CAR employed two primary research methods: a literature review and interviews with stakeholders in the Saginaw region. These two methods are described in more detail below.

LITERATURE REVIEW

CAR researchers explored a variety of topics relevant to on-road CAV test environments. This includes providing an overview and analysis of emerging technologies concerning both connected and automated vehicle technologies, as well as evaluating applicable local, state and federal funding opportunities to assist with any CAV-readiness activities. Researchers also investigated other activities, such as training law enforcement and emergency services, and public education campaigns, that other communities have employed to ensure the safe rollout of CAV technology.

STAKEHOLDER INTERVIEWS

To gain a clear understanding of regional thoughts on connected and automated vehicles as well as mobility overall, Saginaw Future and CAR jointly selected stakeholders to represent a diverse range of people – including public sector, private sector, and academic representatives – who play an influential role on the economy and/or transportation system. Interviewees were drawn from the following organizations:

- City of Saginaw Police Department
- City of Saginaw
- CNXMotion
- General Motors
- Michigan Department of Transportation Regional Office
- Mobile Medical Response
- Nexteer
- Saginaw County Sheriff
- Saginaw County Road Commission (SCRC)
- Saginaw Transit Authority and Regional Services (STARS)
- Saginaw Valley State University (SVSU)

AUTOMATED VEHICLE TECHNOLOGY PRIMER

Automated vehicles and the underlying technology that enables them are not well understood by the general public, planner, and policymakers. Indeed, even in the automotive industry, only a subset of engineers and others are well acquainted with the technology and the surrounding regulatory environment. This section serves to fill in some of the gaps in readers' knowledge base. It provides a basic, but formal, description of automated vehicle technology, driving automation systems, and automated driving systems (ADS).

Even the term "automated vehicle" can be problematic. This report, for example, frequently refers to "automated vehicles," but such vehicles are often referred to casually by various other terms in other contexts, including: "autonomous," "self-driving," "driverless," and "robotic." For the most part, these alternative labels are inaccurate when it comes to describing a vehicle that moves passengers and goods without the benefit (or harm) of a human driver. For example, due to connectivity, these vehicles are very unlikely to be autonomous, and they certainly are not self-driving-someone or something must be doing the driving (usually a computer powered by artificial intelligence in the case of automated vehicles). Thus, because these terms are at best imprecise, they should be avoided in formal technical and policy discussion.¹

DEFINING AUTOMATION

In this report, *automation* is defined as the electronic performance of an action, or series of actions, without real-time human control. A generic automated system consists of three components: *monitoring*, *agency*, and *action*.² Additionally, many automated systems incorporate a *feedback loop*. The relationship between these components is shown in Figure 1.

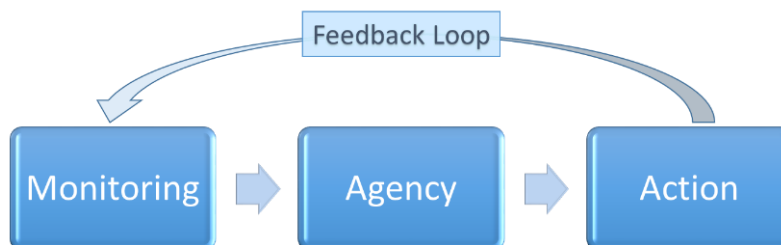


FIGURE 1. RELATIONSHIP BETWEEN AUTOMATED SYSTEM COMPONENTS

¹ SAE J3016.

² These three processes are also often described as: *sense – plan – act*.

- **Monitoring:** An automated system must have one or more methods of accepting input data. In the case of an automated vehicle, this could include data from sensors, input from the driver, and external direction or data received from wireless connectivity (telematics).
- **Agency:** Agency is the most critical part of an automated system; the ‘brain’ of a system. A systems agency is comprised of an algorithm or series of algorithms that take in data from the monitoring process and decide how to act on that data. The agency of an automated vehicle must reside in the physical world—in some kind of processor or network of processors.³ Highly-capable automation architectures often employ distributed processing where the agency component might live across multiple processors and even in the sensors and actuators. Automated driving systems also typically have built-in digital maps as a component of their agency to help the system make context-sensitive decisions.
- **Action:** In a generic automated system, the action component can be something as simple as logging output data. In the case of automated vehicles, the action component is the vehicle control systems that influence the lateral and longitudinal motion of the vehicle (i.e., drivetrain, brakes, steering system).
- **Feedback loop:** Many automated systems incorporate some kind of feedback loop that allows the system to modify its performance in response to actions it has previously taken. This could be very simple and necessary; for example, an automated security light incorporates a feedback loop after it switches on—otherwise the light-sensor might determine the light suggests it is daytime and turn off again. Feedback loops can also be extremely complex, such as in the case of machine-learning algorithms that observe and rate the performance of an automated vehicle and learn from that experience to continually improve the performance of the system.

Vehicles have incorporated automated systems for several decades. For example, variable spark timing is an automated system. However, when we refer to automated *vehicle* systems, we typically mean systems that control the motion of the vehicle by influencing the drivetrain, steering, or brake systems.

The very first automated vehicle systems were active-safety performance-enhancement systems, such as anti-lock brakes (ABS), traction control, and electronic stability control (ESC). These systems electronically manipulate the

³ Depending on a specific ADS architecture, the agency could reside in any combination of central processing units (CPUs), graphics processing units (GPUs), dedicated control circuits, or combinations of these.

braking force on one or more wheels to improve the performance of the vehicle. Automated vehicle systems that have been introduced more recently include automated emergency braking (AEB) and lane-keep assistance.

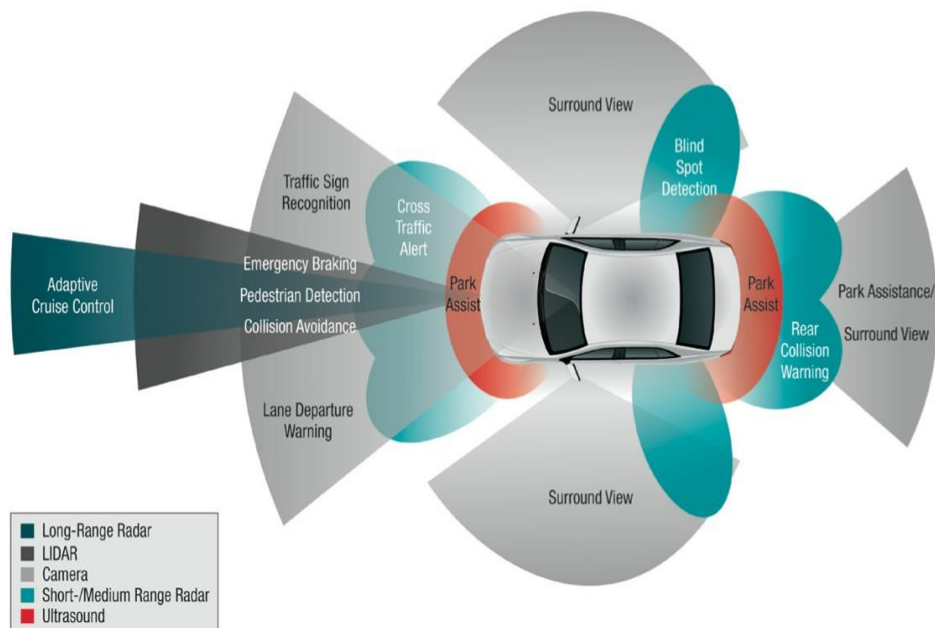
The language describing these systems can be complicated. The automated vehicle systems mentioned in the previous paragraph are all *emergency intervention systems*—automated systems that act only to correct a mistake made by the driver. Thus, these are all defined as level 0 driving automation in the SAE J3016 taxonomy (described in the next section). This report adopts the term *automated vehicle* to refer only to vehicles capable of sustained operation of the entire *dynamic driving task* (DDT). In other words, automated vehicles are those that allow a human driver to divert their attention away from the task of driving for extended periods of time—and may not require a human driver at all.

DEFINING SENSORS

Connected and automated vehicles have two important features with which they can interact with their surroundings. The first is connectivity which comes through utilizing communication technologies like DSRC or high-speed cellular networks (i.e., 4G or 5G) to communicate with other vehicles or Intelligent Transportation Systems (ITS) roadside units.

The second feature is the ability to sense the environment by using sensors. CAVs can utilize a combination of sensors for applications such as advanced cruise control, driver vision augmentation, forward and lateral collision avoidance and parking assistance. Figure 2 displays where these sensors are located on vehicles and their functions. Although there is some disagreement surrounding the type and number of required sensors for ADAS systems, the following are four widely-used types of automotive sensors:

- Ultrasonic (Sonar)
- Radar
- LiDAR
- Image sensors (cameras)



Source: Texas Instruments

FIGURE 2. SCHEMATIC VIEW OF AUTOMOTIVE SENSORS APPLICATION FOR ADVANCED DRIVING ASSISTANCE SYSTEMS

Ultrasonic sensors are mostly used for close range applications (i.e., 10 to 20 feet) such as parking assistance. These sensors emit a sound wave and use reflection waves to measure the distance. Due to signal interference and design complications created by ultrasonic sensors, many believe new generation radars will outperform these sensors.

Radars transmit microwave radiations and collect reflected waves to measure the speed and direction of a surrounding object. Due to characteristics of microwave waves, radars are able to operate under every weather condition (rain, snow, fog, darkness, etc.) with zero to minor attenuation. Radar is the most preferred CAV sensor as it is inexpensive and can perform multiple tasks from short-range to medium and long range applications.

LiDAR or Light Detection and Ranging is a laser light emitter which measures the “time-of-flight between the emitted and returned pulse to determine the distance between objects⁴” (Dennis, Buller, Xique, Bahrani Fard, & Hart, 2017). LiDAR sensors equipped with GPS are able to create high high-resolution 3D maps of surrounding with accurate location information.

⁴ Dennis, E., Buller, W., Xique, E., Bahrani Fard, Z., & Hart, B. “Benchmarking Sensors for Vehicle Computer-Vision Systems. AAA”. 2017

Vision sensors, specifically cameras, are designed to see the world similar to the way human eyes do. As technologies continue to advance, cameras are able to detect color and the exact shape of objects. These attributes are especially important when interacting with the flashing lights of emergency vehicles and traffic lights. Such capabilities have made cameras complementary to Radar and LiDAR for CAV applications.

In addition to these four main sensor types, some of the CAV technology developers have used supplemental systems to enhance their vehicle performance. For example, as Figure 3 depicts, Waymo has used a supplementary audio detection system that can detect police and emergency vehicle sirens up to hundreds of feet away. The audio sensors are designed to discern the direction of sirens.

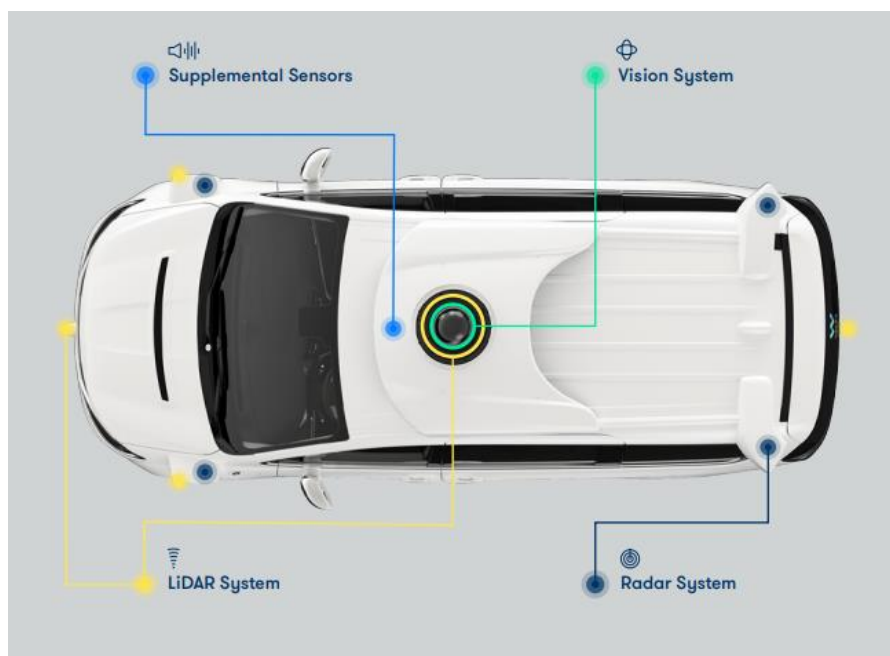


FIGURE 3. WAYMO AUTOMATED VEHICLE SENSORS (SOURCE: WAYMO, 2017)

SAE J3016 TAXONOMY AND DEFINITION OF TERMS RELATED TO DRIVING AUTOMATION SYSTEMS FOR ON-ROAD MOTOR VEHICLES

Automated vehicles have the potential to incorporate a wide range of looks and operational strategies. This diversity complicates the impending public deployment of automated vehicles and has triggered multiple efforts to define and describe them as necessary for rational integration into the existing transportation system and various regulatory structures. Currently, the system that is commonly used in

industry is the SAE J3016 standard, which has emerged as the *de facto* global framework on which to base discussion of automated vehicles.⁵

The best-known aspect of J3016 is its classification of six levels (0-5) of driving automation. The J3016 document includes a summary table (Table 1) of these levels that is frequently used to stand-in for the entirety of the document; however, the taxonomy is deceptively subtle. Thus, over-reliance on the summary table to learn of the levels of automation has led to broad misunderstanding—even among experts. To appropriately understand the J3016 taxonomy, several key definitions and concepts must be understood.

IMPORTANT DEFINITIONS WITHIN SAE J3016

The J3016 summary table of levels includes some technical terms that even industry experts find ambiguous and confusing. Additionally, the standard employs some common words in specific ways with specific definitions in the context of J3016.⁶

- **Active safety system:** Vehicle systems that automatically warn the driver or intervene on the vehicle control systems in order to avoid or mitigate potential collisions. These systems are described in SAE J3063 and are not considered driving automation.
- **Automated driving system (ADS):** A driving automation system capable of performing the entire DDT on a sustained basis (i.e., levels 3+).
- **ADS-dedicated vehicle:** A vehicle designed to be operated only by the ADS, thus lacking usual vehicle controls such as steering wheel.⁷
- **Driving automation system:** An automated vehicle control system capable of operating part or all of the DDT on a sustained basis.
- **Dynamic driving task (DDT):** All realtime functions required to operate a vehicle, including:⁸
 - Lateral motion control (steering)

⁵ SAE J3016 was initially published in 2014, but was significantly updated in 2016. Those referencing the standard should take care to reference the current, active version. SAE J3016_201609 is available for free to SAE members:

https://www.sae.org/standards/content/j3016_201609/

⁶ The definitions provided herein have been modified for brevity and clarity.

⁷ Requires level 4/5 ADS. Can allow for human operation in non-typical situations such as to maneuver the vehicle into a service bay.

⁸ This is colloquially known as driving. The DDT omits “strategic” functions, such as selecting a destination.

- Longitudinal motion control (powertrain and brakes)
- Object and event detection and response (OEDR)
- Maneuver planning (e.g., taking a turn)
- Enhancing conspicuity (e.g., using blinkers)
- **Fallback:** Response of either a human user or ADS to either perform the DDT, or achieve a minimal risk condition in the event of an DDT system failure, or upon ODD exit.
- **Minimal risk condition:** A condition to which a user may bring the vehicle—following fallback—to optimize safety when a trip must be aborted.⁹
- **Monitoring:** Realtime sensing required to operate a vehicle (i.e., paying attention)^{10, 11}
- **Operational design domain (ODD):** The conditions under which a driving automation system is designed to function appropriately. This may include limitations on geography (geofencing), road type, environment (e.g., snow), speed, time-of-day, etc.
- **Receptivity:** Pertaining to the user of a level 3 ADS, the ability to reliably and appropriately focus attention when required by a system-issued request to intervene.
- **Sustained (operation of a vehicle):** Performance of all or part of the DDT both between and across events. In other words, the system must be capable of automatic detection and response to events, as well as operating in the absence of them.¹²

⁹ This concept is necessarily vague as the appropriate minimal risk condition will vary depending on the nature of the ADS system and the failure mode. An example may include pulling off onto the shoulder, or something as complex as returning to a dispatch facility.

¹⁰ This is only one type of the types of monitoring defined in SAE J3016. This term can also be used in the sense of driver-monitoring.

¹¹ A user of a level 3 ADS is obliged to be receptive, but this does not require the user to monitor.

¹² The definition of *sustained operation* is the determining factor between many general vehicle automation systems and driving automation systems. For example, traditional cruise control performs longitudinal control of the vehicle on a sustained basis in absence of events, but does not respond appropriately, for example, in the event of a slower vehicle merging into the driving lane. Thus, cruise control is level 0—not driving automation. Active safety systems impose a different issue; these systems engage *only* in response to events; for example, automated emergency braking engages only in response to an event such as a merging vehicle. Driving automation systems are defined as doing both of these things. For example, adaptive cruise control will hold a vehicle speed in the

IMPORTANT CONCEPTUAL DETAILS

SAE J3016 is a 30-page document describing several subtle details about the levels of automation and associated taxonomy. Many of these details cannot be captured in a summary table (see Table 1 for such a table nonetheless), but knowledge of such details is necessary to comprehend the intent and potential of the standard.

- **Levels are assigned by manufacturer:** SAE J3016 states that it is “not possible” to specify a test to determine the level of automation of an automated vehicle. In other words, the levels are subjective.¹³ They do not describe objectively-measured performance, but classify a relationship and division of responsibility between the driving automation system and a human user.
- **The taxonomy does not apply to intervention systems:** SAE J3016 taxonomy and definitions apply only to driving automation—defined as automated control for sustained periods both across and between events. Emergency intervention systems (e.g., automated emergency braking) are not relevant to this taxonomy, regardless of capability.
- **Operation design domain (ODD) can vary widely within a level:** The range of environments in which a driving automation system can operate is not dependent on the assigned level, but on the operational design domain (ODD), with the exception of level 5 which implies the ODD is equivalent to a human-driven vehicle.
- **Level 5 does *not* mean that a vehicle has no steering wheel:** One common misinterpretation of the J3016 taxonomy is that level 5 vehicles cannot be driven by a person and do not have a steering wheel or throttle or brake pedals (i.e., an ADS-dedicated vehicle). Level 4 and 5 vehicles could be ADS-dedicated vehicles or not. Level 5 describes a vehicle with an ODD equivalent to that of a human driver.¹⁴ Either type, however, potentially could come equipped with an on/off switch for automation, allowing them to be driven by humans at times (e.g., by driver choice).

absence of events, but adjust speed when required by an event such as a merging vehicle. Thus, adaptive cruise control is a driving automation system.

¹³ Levels 0 and 1 can be objectively identified by the number of dimensions of vehicle movement are automated. Levels 2 through 5 are distinguished only by the level assigned by the responsible party.

¹⁴ Many analysts believe that the technology that would enable a level 5 vehicle is decades away, if possible at all.

TABLE 1. SAE SUMMARY OF DRIVING AUTOMATION LEVELS¹⁵

Level	Name	Narrative definition	DDT		DDT fallback	ODD
			Sustained lateral and longitudinal vehicle motion control	OEDR		
<i>Driver performs part or all of the DDT</i>						
0	No Driving Automation	The performance by the <i>driver</i> of the entire <i>DDT</i> , even when enhanced by <i>active safety systems</i> .	<i>Driver</i>	<i>Driver</i>	<i>Driver</i>	n/a
1	Driver Assistance	The <i>sustained</i> and <i>ODD</i> -specific execution by a <i>driving automation system</i> of either the <i>lateral</i> or the <i>longitudinal vehicle motion control</i> subtask of the <i>DDT</i> (but not both simultaneously) with the expectation that the <i>driver</i> performs the remainder of the <i>DDT</i> .	<i>Driver and System</i>	<i>Driver</i>	<i>Driver</i>	Limited
2	Partial Driving Automation	The <i>sustained</i> and <i>ODD</i> -specific execution by a <i>driving automation system</i> of both the <i>lateral</i> and <i>longitudinal vehicle motion control</i> subtasks of the <i>DDT</i> with the expectation that the <i>driver</i> completes the <i>OEDR</i> subtask and <i>supervises</i> the <i>driving automation system</i> .	<i>System</i>	<i>Driver</i>	<i>Driver</i>	Limited
<i>ADS ("System") performs the entire DDT (while engaged)</i>						
3	Conditional Driving Automation	The <i>sustained</i> and <i>ODD</i> -specific performance by an <i>ADS</i> of the entire <i>DDT</i> with the expectation that the <i>DDT fallback-ready user</i> is <i>receptive</i> to <i>ADS</i> -issued <i>requests to intervene</i> , as well as to <i>DDT performance-relevant system failures</i> in other <i>vehicle systems</i> , and will respond appropriately.	<i>System</i>	<i>System</i>	<i>Fallback-ready user (becomes the driver during fallback)</i>	Limited
4	High Driving Automation	The <i>sustained</i> and <i>ODD</i> -specific performance by an <i>ADS</i> of the entire <i>DDT</i> and <i>DDT fallback</i> without any expectation that a <i>user</i> will respond to a <i>request to intervene</i> .	<i>System</i>	<i>System</i>	<i>System</i>	Limited
5	Full Driving Automation	The <i>sustained</i> and unconditional (i.e., not <i>ODD</i> -specific) performance by an <i>ADS</i> of the entire <i>DDT</i> and <i>DDT fallback</i> without any expectation that a <i>user</i> will respond to a <i>request to intervene</i> .	<i>System</i>	<i>System</i>	<i>System</i>	Unlimited

¹⁵ SAE International. "(R) Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles." Page 17. September, 2016.

AUTOMATED METROS, TRAMS, AND SHUTTLES

Public and industry imagination has been captured by the possibility of automated vehicles becoming a viable alternative to traditional light vehicles (cars and trucks). Yet, the technical challenge of level 4 vehicles operating on public roads in mixed traffic is substantial. On the other hand, level 4 vehicles may also operate in a very limited operational design domain (ODD) that does not require accommodating for mixed traffic.

Such vehicles have operated for decades in the form of automated metro systems, such as the monorail systems in Detroit and Las Vegas, and dozens of airport trams. These are fixed-track level 4 vehicles, but rubber-wheeled versions also exist. The earliest of these vehicles—often known as personal rapid transit (PRT)—began operation in West Virginia University in Morgantown, WV in 1975. The Morgantown PRT remains in operation and is in the midst of a modernization project. Despite its success, the concept wasn't popularly adopted—likely because light-rail transit systems can be installed for less cost.¹⁶

There has been re-kindled interest in non-rail, rubber-tire PRT in the last decade. Notable systems have been installed recently at Heathrow airport in London, England and Masdar in the UAE. These early systems are not notably more functional than light-rail because they operate on tracks that are segregated from any crossing by pedestrians and traffic. However, in just the last few years, there have been a few low-speed shuttle systems deployed to operate with full level 4 capability, though in low-speed, low traffic pedestrian areas.

There has been progress toward using such low-speed automated shuttles on public roads in mixed traffic, but so far all on-road demonstrations have included some kind of attendant or safety steward who is able to stop the vehicle immediately if necessary, and assume control through a backup HMI. The automated shuttle company 2getthere had planned on a 2018 expansion of an existing level 4 shuttle service in the Netherlands to include public roads along the route, but this goal was pushed back to 2020.

There are already several self-driving shuttle manufacturers offering automated shuttle services to municipalities, corporations, and any other organization interested in exploring the potential of automated shuttle service. These companies include Navya, 2getthere, Easymile, May Mobility, and others.

¹⁶ West Virginia University. Pod Cars of the Past and Future. WVU Transportation and Parking Division. <https://transportation.wvu.edu/prt>

AUTOMATED INTERVENTION SYSTEMS

As previously described, the SAE J3016 taxonomy and levels of driving automation apply only to automated systems that act on vehicle control systems for sustained periods, both across and between events. As a result, many advanced and functional automated vehicle systems are level 0, because they act only as an intervention system.¹⁷ This includes applications like antilock braking systems (ABS), electronic stability control (ESC), and even automated emergency braking (AEB), and lane-keep assist. Such intervention systems are addressed here only for clarity and are not discussed further.

CURRENT STATUS: PARTIAL DRIVING AUTOMATION (SAE J3016 LEVELS 1 AND 2)

Level 1 automation applies only to systems that act on either the lateral (steering) *or* longitudinal (powertrain and brake) control systems for sustained periods, but not both. Thus, this level tends to be limited to only two general functions, adaptive cruise control (ACC), which controls longitudinal motion, and lane-centering, which controls lateral motion. If these systems are combined together, this is considered a level 2 system.

A level 2 system is one that includes both lateral and longitudinal control, but is not reliable enough to allow the driver to divert attention for any amount of time. Several automakers now offer level 2 systems including Tesla, GM, BMW, Mercedes, Audi, Volvo, and others. These systems can vary widely in ODD and system interface, but share a commonality in that they are capable of controlling steering, powertrain, and brake for sustained periods of driving.

A substantial division between levels occurs between level 2 and three. Per the SAE J3016 taxonomy, a level 2 system is basically advanced cruise control—the driver remains fully responsible for the operation of the vehicle. A level 3 system implies that the Automated Driving System (ADS) is responsible for the entire dynamic driving task, including object and event detection and response (i.e., paying attention). The only responsibility of the human driver in a level 3 system is to remain receptive to a system request to resume control if the system experiences a failure or encounters a limit of the ODD.

¹⁷ Such systems are also known as active safety systems and are described by SAE J3063.

CURRENT STATUS: AUTOMATED DRIVING SYSTEMS (SAE J3016 LEVELS 3-5)

In the SAE J3016 taxonomy, driving automation levels 3-5 are given a specific distinction as automated driving systems (ADS). ADS-equipped vehicles are currently deployed only in very restricted ODDs, such as low speed operation in pedestrian areas. Many entities are in the process of developing ADS-equipped vehicles, but as SAE J3016 defines ADS as a system not requiring a safety driver, most of these systems must be considered level 2 systems intended to be developed into level 3 ADS. The sole exception at this time is Waymo, which has deployed true level 4 operation on public roads near Phoenix, but even this service has not yet been commercialized.¹⁸

As previously explained in the previous section, it is not possible to objectively distinguish between levels 2 and 3. Level 3 can only be assigned by the manufacturer and is essentially a promise to the vehicle user that the system will not fail or hand-back real-time control without appropriate notice.

Level 4 is distinguished from level 3 when the ADS provider asserts that the vehicle itself will be capable of achieving a minimal risk condition in the event that the system experiences failure or the limits of its ODD. A level 4 vehicle is, in theory, incapable of being at-fault in a collision. Any at-fault collision while the ADS is activated would be considered a failure of the ADS system and the ADS provider would likely be liable for any damages. Level 5 is similar to level 4 but with an unlimited ODD.

Highly automated driving in an expansive ODD such as on public roads likely requires very complex control algorithms (the system's agency) developed through deep learning methods. Thus, no known formal process exists to validate this software. The prevailing approach to determining the roadworthiness of an ADS system is simply to allow the ADS to accrue hundreds of thousands of real-world miles and then use statistical methods to determine the factor of safety. While simulation software can augment this process, extensive on-road testing of systems will likely be required for ADS systems for the foreseeable future.

ROLE OF CONNECTIVITY

While it is theoretically possible to design an automated vehicle without wireless connectivity, it is almost certain that connectivity will be included on any deployed

¹⁸ Audi has announced imminent deployment of a consumer available level 3 'traffic jam pilot,' but as of March 2018, this system is not consumer-available.

ADS-equipped vehicle. The majority of modern vehicles already include connectivity to cellular networks, and often support additional connections via Bluetooth, Wi-Fi, etc. Connectivity is practically required to download map data and system updates. Even some current level 2 systems are dependent on connectivity, including Tesla's Autopilot, and Cadillac's Super Cruise.

ROLE OF PUBLIC TESTING

One nuance that is often overlooked when discussing on-road, automated vehicle testing is that these vehicles are not only being tested, they are also being *trained*. Practically all ADS development efforts use machine learning techniques to develop perception and control algorithms that allow the driving automation system to operate at a high level of capability within that specific ODD. Thus, for example, Waymo's deployment of level 4 automated driving near Phoenix was enabled through driving hundreds of thousands of test miles—and likely millions of simulated miles specific to that area. While Waymo has achieved level 4 in this specific ODD, it does not mean that Waymo vehicles could be relocated to another site and quickly begin level 4 operation. Considering this, the majority of on-road automated vehicle testing programs take place either in the vicinity of engineering and programming facilities, or in locations identified as regions of potential commercial deployment.

STAKEHOLDER INTERVIEW RESPONSES

Stakeholders were asked broad questions, such as what they feel is going well in Saginaw overall, what areas could be improved, and more targeted questions such as their understanding of connected and automated vehicle technologies and any mobility issues they either see or experience in the region. A summary of their responses follows.

UNDERSTANDING OF CONNECTED AND AUTOMATED VEHICLES

Apart from automotive company representatives and a few people who are personally interested in the topic, in-depth knowledge of CAVs, and their supporting technologies and applications, is limited. Some interviewees mentioned hearing the topic discussed at a city council meeting, but for several, that was their first instance hearing the topic discussed in detail.

Even without thorough knowledge of the subject, however, everyone reacted positively to the idea of CAV testing and were generally accepting of the fact that these technologies represent the future of mobility. Many people were interviewed the week following the fatal crash in Arizona between a pedestrian and an Uber vehicle in self-driving mode.¹⁹

RELEVANT CONNECTED AND AUTOMATED VEHICLE REGIONAL ASSETS

Thanks primarily to the Saginaw County Road Commission, the region already has a few helpful assets for CAV activities. All SCRC trucks have GPS-based Automated Vehicle Location (AVL) systems, allowing the road commission to track the vehicles and better plan for winter maintenance. The trucks also have sensors to determine amount of salt application.

Perhaps most helpful from a CAV testing perspective is that SCRC has taken the initiative to map almost all roads in their jurisdiction using GIS. These data include material type, total road width, lane width, traffic signs, speed limits, bridges, pavement markings, and parking areas. Though automated vehicles need high-definition, three-dimensional images of their operational domains, a GIS map may save a few steps in the creation of digital maps to facilitate automated driving. At the very least, it should provide ground-truth localization within a few centimeters.

¹⁹ Levin, Sam and Julia Carrie Wong. "Self-driving Uber kills Arizona woman in first fatal crash involving pedestrian." *The Guardian*. March 19, 2018.

POSITIVE TRENDS IN SAGINAW

All stakeholders expressed positive feelings towards the growth path Saginaw has taken over the past several years. Many cite improvements in safety as being the impetus for other growth, especially downtown. Delta College has moved downtown; Central Michigan University built their medical school campus downtown; and other real estate developers and businesses are investing significantly in the area. Perhaps most importantly, the *perception* of Saginaw is improving, and residents are taking more pride in their region than in previous years.

Overall mobility has also been on a positive trend, in particular due to the expanded offerings of STARS, such as Saturday service and expanded service hours.

AREAS FOR IMPROVEMENT

The most frequently mentioned area for improvement was attracting and retaining talent. The downtown improvements have made inroads into this challenge, but the challenge remains. More activities and social experiences were suggested as possible methods to achieve this goal.

In addition, several mobility-related challenges were mentioned. These areas are detailed and explored further in the Solutions to Regional Challenges section.

POTENTIAL FUNDING OPPORTUNITIES

There are currently few funding sources for local governments engaging in connected vehicle or mobility service projects. Rather than dedicated funds, in large part these sources are the same infrastructure programs used for road construction and other transportation system funding.

FEDERAL FUNDING

Two federal funding opportunities are presently available. Both were posted on April 4th, 2018, and close on May 21st, 2018. The Fixing America's Surface Transportation Act created the *Advanced Transportation and Congestion Management Technologies Deployment Initiative* (ATCMTD) under the Federal Highway Administration. This program has annual funding of \$60 million per year through 2020 to support deployments of new transportation technologies, with acceleration of connected and automated vehicle deployment one of the primary program goals.²⁰ This competitive bid grant requires a 50% local match, and individual projects may receive up to \$12 million.

The second current federal funding opportunity is the Federal Motor Carrier Safety Administration *FY 2018 High Priority Grant Program*. One component of this grant program specifically provides funding to intelligent transportation system applications for commercial vehicles. However, only state governments are eligible to apply. Cities are eligible for funding under a different, broader component, which pertains to motor carrier safety projects, with one eligible project category being demonstrations of commercial motor vehicle safety-improving new technologies.²¹ As with the ATCMTD, this funding opportunity closes on May 21st, 2018.

An additional federal funding source is the *BUILD Transportation Planning Grants* program via the U.S. DOT. These grants will cover up to 80 percent of the cost of a transportation infrastructure project in an urban area, up to \$15 million. Research,

²⁰ Federal Highway Administration. "Advanced Transportation and Congestion Management Technologies Deployment Initiative." U.S. Department of Transportation.

<https://www.grants.gov/web/grants/view-opportunity.html?oppld=303763>

Funding Opportunity Number: 693JJ318NF00010

²¹ Federal Motor Carrier Safety Administration. "FY 2018 High Priority Grant Program." U.S.

Department of Transportation. <https://www.grants.gov/web/grants/search-grants.html?keywords=FM-MHP-18-001>

Funding Opportunity Number: FM-MHP-18-001

demonstration, and pilot projects are eligible for funding, provided that they establish permanent new transportation infrastructure. For FY 2018, applications for funding are due July 19, 2018.²²

In the past, CAV and mobility initiatives have received dedicated funding through federal pilot programs and/or research and demonstration funding. In 2015, the Federal Transit Administration (FTA) awarded five grants totaling \$800,000 to support mobility services initiatives which implement intelligent transportation systems to improve on-demand community mobility services.²³ In 2016, the FTA awarded \$8 million to public transportation mobility on demand initiatives through the Mobility on Demand (MOD) Sandbox Program, to support application of new technologies to public transportation and also to develop an understanding of policies and regulations impact new transportation service models.²⁴ Additionally, the FTA is actively evaluating transit automation, with three research projects funded since 2009. The FTA has completed a draft roadmap for transit bus automation, with the final to be published during 2018.²⁵ Currently, the FTA does not have funding opportunities listed for mobility services or vehicle automation deployments. New opportunities may become available with the publication of the FTA bus automation roadmap.

The Intelligent Transportation Systems Joint Program Office in the U.S. Department of Transportation has also funded deployments of connected vehicle technologies, but also does not list current funding opportunities. The most recent funding award was a 2016 issuance of \$45 million to three connected vehicle deployment projects in New York City, Tampa, and Wyoming.²⁶

An additional federal funding opportunity to keep track of is the Infrastructure for Rebuilding America (INFRA) Grant, formerly Fastlane grants. INFRA grant program's goals are to help fix infrastructure by "creating opportunities for all levels of

²² U.S. Department of Transportation. "U.S. Department of Transportation Launches BUILD Transportation Program, Announces \$1.5 Billion Notice of Funding Opportunity." <https://www.transportation.gov/BUILDgrants>

²³ Federal Transit Administration. "2015 Research Funds for Mobility Services for All Americans (MSAA) Deployment Planning Projects." U.S. Department of Transportation. <https://www.transit.dot.gov/funding/grants/2015-research-funds-mobility-services-all-americans-msaa-deployment-planning-projects>

²⁴ Federal Transit Administration. "Mobility on Demand (MOD) Sandbox Program." U.S. Department of Transportation. <https://www.transit.dot.gov/research-innovation/mobility-demand-mod-sandbox-program.html>

²⁵ Federal Transit Administration. "Transit Automation Research." U.S. Department of Transportation. <https://www.transit.dot.gov/automation-research>

²⁶ Intelligent Transportation Systems Joint Program Office. "Connected Vehicle (CV) Pilot Deployment Program." U.S. Department of Transportation. <https://www.its.dot.gov/pilots/index.htm>

government and the private sector to fund infrastructure, using innovative approaches to improve the necessary processes for building significant projects, and increasing accountability for the projects that are built.”²⁷ The 2017-2018 INFRA grant application process closed November 2, 2017, and at the time of this writing, none have been awarded.²⁸

STATE AND REGIONAL FUNDING

Funding may also be available through the Michigan Department of Transportation. Two categories of grants under the *Transportation Economic Development Fund (TEDF)* are worth noting. Neither of these is specific to local government initiatives with connected vehicles, mobility services, or intelligent transportation systems, but these project types can be eligible. Saginaw’s CAV test environment initiative may be eligible under *TEDF Category A - Economic Development Road Projects*, as the infrastructure installation will enable the expansion of private employment in CAV research and development. However, two criteria of TEDF Category A eligibility present a challenge to the use of these funds: To be eligible, the road project must address a demonstrated need in road capacity, condition, safety, or accessibility and completion of the project must increase the local tax base.²⁹ The other state funding source which may apply to Saginaw’s CAV test environment is the *TEDF Category F - Urban Areas in Rural Counties*. If the city can demonstrate that installation of CAV infrastructure can improve the performance of a high-traffic road, this funding could be available.³⁰

PlanetM, part of the Michigan Economic Development Corporation focused on mobility initiatives, will have a forthcoming grant opportunity focused on start-ups. Full details will be available in early June, 2018, but it is something Saginaw should monitor closely.

The final identified source of funds for development of the Saginaw CAV test environment is the *2018 Mini Grant Program* from the East Central Michigan Prosperity Region 5. The establishment of a CAV test environment matches the mini grant program's goals of improving the regional image via the creation of a unique,

²⁷ INFRA Grant Website. <https://www.transportation.gov/buildamerica/infragrants>. Accessed May 14, 2018.

²⁸ AASHTO. “Chao: \$1.56B in 2017-18 INFRA Grants Still Months Away, Coming Perhaps in June.” *AASHTO Journal*. March 9, 2018.

²⁹ Michigan Department of Transportation. “Category A - Economic Development Road Projects.” https://www.michigan.gov/mdot/0,4616,7-151-9621_17216_18230_18235---,00.html

³⁰ Michigan Department of Transportation. “Category F - Urban Areas in Rural Counties.” https://www.michigan.gov/mdot/0,4616,7-151-9621_17216_18230_18239---,00.html

high-tech asset and by encouraging research and development activity within the region. The downside of this funding source is its small scope – the maximum grant is \$20,000.³¹

³¹ East Michigan Council of Governments. "Prosperity Region 5 - 2018 Mini & Micro Grant Program."
www.emcog.org/rp5minigrant2018.asp

STRATEGIES FOR SUCCESSFUL DEPLOYMENTS OF CAVs

Given the relative newness of CAV technologies, communities have employed several methods to help ensure residents are prepared for them. Two, in particular, involve efforts to educate the public on CAV technology and mobility services, and integrating law enforcement and emergency response with the technologies.

PUBLIC AWARENESS CAMPAIGNS

As CAV technologies are discussed more and more outside of industry circles, the general public is increasingly curious as to how these technologies could impact their lives and work. Public education campaigns will help technology developers understand the public's concerns and expectations CAVs, and find ways to work with citizens to gradually overcome some of the most challenging aspects of operating CAV in urban environments.

In October 2017, Waymo helped to launch Let's Talk Self-Driving (letstalkselfdriving.com), the first online public education campaign about connected and automated vehicles. This is a group effort from a group of professionals who are concerned about increasing public awareness about the way automated vehicles work and potential benefits associated with their operation.³² In addition, Columbus, OH, recipient of the U.S. DOT Smart City Challenge grant, recently announced the opening of the Smart Columbus Experience Center.³³ The center's primary purpose is to expose citizens to the myriad of mobility and other smart technology options that exist.

APPLICATIONS FOR FIRST RESPONDERS

To increase public awareness on connected and automated vehicles, some cities have started collaborating with technology developers to launch training programs for first responders. Last year in Arizona, Waymo conducted on-site training for police officers and emergency workers to introduce their vehicles and review the

³² Waymo. "On the Road to Fully Self-Driving; Waymo Safety Report." 2017.

<https://storage.googleapis.com/sdc-prod/v1/safety-report/waymo-safety-report-2017.pdf>

³³ Evans, Walker. "Smart Columbus Launching Experience Center Downtown." *Columbus Underground*. March 20, 2018.

safety features. Since then, a number of other cities have expressed interest in getting hands-on training on CAVs for first responders.³⁴

One direct benefit of training programs is introducing people to the technology early on in its development, so that as the technology advances, it will be easier for first responders to keep up. The training programs can include:

- Explanation of basic CAV technological aspects.³⁵
- Reviews of CAV capabilities, limitations, benefits and threats
- Driving demonstrations.
- Hands on training while driving with CAVs and to review how the automated vehicle responds to emergency vehicles

According to the National Highway Transportation Safety Administration (NHTSA), state transportation agencies should work with jurisdictions, law enforcement, federal agencies and other stakeholders to gather, organize and share information related to the development, design, testing, use and regulation of connected and automated vehicles technologies.³⁶ Understanding these technologies will help law enforcement consider modifications to laws and regulations, update citation and crash report documents and databases with new definitions of the user and system, and implement a framework for insurance and liability regulations.

With this approach, not only service providers would get training but also CAV technology developer will also get the opportunity to test automated vehicle responses to emergency vehicles and validate systems for detecting and yielding to enforcement vehicles.

HOW CONNECTED AND AUTOMATED VEHICLES DETECT AND RESPOND TO EMERGENCY VEHICLES

Technological improvements have helped CAVs react appropriately to emergency situation. The following are a few examples:

- **Detect and respond to emergencies:** Fully automated vehicles will be equipped with emergency braking systems which allow the vehicle to safely stop in an emergency situation. Whether the event is a crash, vehicle maintenance issue, poor weather or road condition, the

³⁴ Marshall, A. "Self-driving Cars Meet Their New Nemesis: Local Politicians". *Wired*.

<https://www.wired.com/story/san-francisco-self-driving-cars-rules-farrell>. March 2018.

³⁵ UDOT & Utah DPS. "Best Practices for Regulation of AVs on UTAHs Highways". Report to the Utah Legislature.

³⁶ U.S. Department of Transportation NHTSA. "Automated Driving Systems 2.0: A Vision for Safety". 2017

vehicle's sensor suite will detect the event and notify the advanced driving system.

- **Discern and react to sirens:** In addition to vehicle-to-vehicle (V2V) communication systems, CAVs will also be equipped with audio sensors which allow them to discern emergency vehicle sirens. With this capability, the car will then safely pull over to allow the emergency vehicles to pass.
- **Record and report crash data:** If an automated vehicle is involved in a crash, it will record and send all relevant accident information to the company to analyze the situation and allow for a response.
- **Facilitate emergency responses:** CAVs could utilize the V2V and vehicle-to-infrastructure (V2I) technologies for optimized routing within the traffic to attend an emergency event. With V2V communication technologies, clearing up the lanes for high speed emergency vehicles passing will be inevitable.

The combination of these sensors, with support from robust artificial intelligence algorithms, enables connected and automated vehicles to discern an emergency vehicle and make a proper response. When the sensor suite detects an emergency situation or vehicle, advanced machine learning algorithms analyze the sensors data to determine whether it is an ambulance, a patrol or a fire rescue vehicle. Those algorithms are able to decode the vehicle characteristics and symbols used on the emergency vehicle to change the lane, yield, pull over to the side of the road, or completely stop.

To develop such algorithms, CAV technology developers need to test their vehicles in a test setting with presence of emergency vehicles and process the test data with machine learning algorithms to improve the accuracy of the reaction. In 2017, Waymo collaborated with the Chandler Police and Fire departments in Arizona to conduct emergency vehicle testing with their automated minivans. According to Waymo, the vehicles' suite of sensors detected the emergency vehicles during the driving tests. Through the test trials, Waymo vehicles sensors were able to collect data which can help the company to develop and analyze advanced artificial intelligence algorithms for CAVs to respond safely and quickly to emergency vehicles.³⁷ The emergence of CAVs also has resulted in interesting advancements in V2V, V2I, signal phasing technologies. By taking advantages of V2I and V2V technologies, connected emergency vehicles will be able to communicate to roadside units (RSUs) and preempt traffic signals through using devices employing

³⁷ Waymo. "On the Road to Fully Self-Driving; Waymo Safety Report." 2017.

IEEE 802.11p standards to override the traffic signals. This is expected to increase driver and pedestrian safety and reduce emergency response times.

Emergency vehicle priority, or signal phasing adjustment for emergency vehicles, requires the emitter device on an approaching emergency vehicle to communicate with the device installed on the traffic signal light. Through this communication, the device on the traffic signal, detects the vehicle's siren, emergency light, radio signal or location to grant the right-of-way to the emergency vehicle safely.³⁸



FIGURE 4. IMAGES OF SIGNAL PREEMPTION DEVICES (SOURCE: MINNESOTA DOT, 2013)

Currently, available preemption technology platform types include acoustic, optical, radio GPS which use emergency vehicle siren, infra-red optical strobe, short-range radio signals (9000 MHz band) or location information to get the traffic signal preemption. These devices can be installed on vehicles and traffic signals, the latter of which is displayed in Figure 4.

³⁸ Maricopa Association of Governments. "Emergency Vehicle Preemption State of the Practice Study." Maricopa Association of Governments. 2016.

RECOMMENDATIONS TO ENCOURAGE RESEARCH, DEVELOPMENT, AND TESTING IN THE SAGINAW REGION

Many communities are vying to be areas for CAV testing and validation, thus Saginaw has significant competition in this space. For the most part, initial on-road testing has been located near the engineering offices of ADS developers. GM, one of the two largest automotive employers in the region, for example, has opted to consolidate most of its on-road automated vehicle validation in San Francisco, where its Cruise subsidiary is located. But there are exceptions to this, and it is possible that developers could be incentivized to locate testing activities in specific regions or municipalities. This chapter discusses potential approaches to attract such efforts, as well as broader opportunities in the area of using advanced vehicle, communication, and computing technologies to solve mobility needs in the region. This latter category could employ some of the same technologies that are beneficial to Nexteer and potentially other companies for testing and validation. This chapter discusses potential approaches to attract such efforts, as well as potential solutions to regional mobility challenges and funding opportunities to pursue.

SHORT TERM RECOMMENDATIONS

As background, in 2013, Michigan became the fourth state to specifically regulate the automated vehicle testing. Public Acts 231 and 251 of 2013 updated Michigan's legal code to allow manufacturers, suppliers, and upfitters of automated vehicle technology to test prototype automated driving systems on public roads when registered with a special license plate (an 'M-plate') provided by the Michigan Secretary of State.

In 2016, Michigan updated the legislation to refine key definitions, remove a prohibition on deployment of automated vehicles, specifically allow platooning of connected vehicles, introduce a regulatory framework for an "on-demand motor vehicle network," and add other various automated vehicle-related language to the legal code. One provision of Michigan's law limits local authority to impose restrictions and fees on automated vehicles.

Thus, from a regulatory standpoint, there are no actions municipalities in the Saginaw region can take to formally permit CAV testing, as State regulations supercede them. But there are other, non-regulatory actions the Saginaw region can pursue to present the region as one that welcomes CAV testing and validation.

LOCAL POLICY ACTIONS TO SIGNAL OPENNESS TO TECHNOLOGIES

The Saginaw region has already shown its interest in promoting advanced transportation technology locally by requesting this research. There are additional ways the region can formally signal its openness to these technologies, ranging from maintaining CAV and mobility expertise within public agencies to developing a vision for mobility and updating transportation policies to reflect that vision.³⁹ The City of Boston offers one example of this latter approach. City leaders led the Go Boston 2030⁴⁰ visioning plan with specific projects and policies to be implemented at various stages. The plan includes an Autonomous Vehicle Policy to create recommendations for on-street testing and explore business models that help address local issues. Closer to home, the City of Southfield updated its Master Plan in 2016 and included a section noting the importance of monitoring activities in the CAV and mobility space to help the city make sound investment decisions. Saginaw could pursue similar avenues, and could also explore using incentive zoning and altering parking requirements such that shared vehicles or other mobility services are encouraged. For further examples, please see CAR's 2017 report, entitled *Future Cities: Navigating the New Era of Mobility*.

IDENTIFY RANGE OF DRIVING SCENARIOS

When exploring public roads for testing, the Saginaw community can identify road segments that together constitute a wide range of road scenarios. Ideally, some of these roads would have the potential to be temporarily closed during agreed-upon times, and would also offer driving scenarios that are challenging for automated vehicles. Saginaw can work with local road commissions and companies to identify the most appropriate areas for validation.

- Straight roads with one or two lanes of traffic
- Curved country roads with one lane of traffic
- Intersections (signalized, stop signs)
- Highway exit and entrance ramps
- Three-mile segment of a highway with one curve
- Urban roads
- Varied road surface quality, from good to poor condition
- Varied levels of road crowns and banking

³⁹ Spulber, Adela, V.S. Brugeman, E.P. Dennis, & Z.B. Fard. "Future Cities: Navigating the New Era of Mobility." Center for Automotive Research. 2017.

⁴⁰ City of Boston. Go Boston 2030 Vision and Action Plan. <https://www.boston.gov/departments/transportation/go-boston-2030#full-report>. Accessed May 14, 2018.

- Varied road slopes; from flat to hillier sections

VEHICLE STORAGE & CONFERENCE ROOM

In the case where a company wishing to test on Saginaw areas roads is not based locally, a secure building where the testing company can store vehicles safely is helpful, assuming the testing company does not have garage space nearby. Such a building would protect the vehicle and sensitive equipment from weather and minimize back-and-forth driving from the testing area to potentially far away vehicle storage space.

Formal test facilities have dedicated indoor spaces for researchers to review results, use computers, and otherwise plan for their test time. If it were possible to allow a test company to rent a building, or part of a building, near the on-road test environment, this would mimic the facilities of a test track. Ideally, a room would hold ten to fifteen people.

CITIZENS ENGAGEMENT PLAN

To generate awareness among local stakeholders as to the potential benefits and implications of CAV and mobility technologies, Saginaw could host information sessions to introduce these technologies to the local citizenry. Such an activity could help familiarize them with its potential benefits like increased accessibility with on-demand services, sustainable land use reforms, increased energy efficiency, enhanced safety, and improved environmental impacts. Public engagement activities could also describe future AV scenarios, such as privately owned vs. shared-use, fleets of fully automated vehicles versus mixed fleets where automated vehicles drive on assigned lanes, etc. Part of these workshops could also clarify what may be expected of citizens, such as more carefully following traffic rules, signs, and using sidewalks for walking and bike lanes for biking.

SOLUTIONS TO REGIONAL CHALLENGES

Perhaps one of the greatest opportunities for the Saginaw region is to ascertain how mobility technologies can improve certain regional challenges. A proven method of connecting communities with advanced transportation technologies is identify challenges the region faces, prioritize them, and then demonstrate how to citizens' lives may be improved by partnering with said technology providers. Government funders also find this approach particularly attractive, especially when it is combined with a joint-approach from industry, government, and academia.

Through discussions with stakeholders, CAR researchers uncovered several challenges relating to mobility, in particular around improving access to those

without vehicles, sourcing talent, and moving talent more efficiently. Saginaw has an opportunity to help solve or at least ameliorate some of these issues with innovative mobility services, which could be a step toward automated vehicles.

IMPROVE MOBILITY FOR RESIDENTS WITHOUT ACCESS TO VEHICLES

The first issue is a need for improved mobility for those without vehicles. Data show that 9.1 percent of Saginaw County households, or around 7,134 families, do not own vehicles.⁴¹ This includes people who are permanent residents and also members of student populations, especially international students who attend regional universities. Without access to a vehicle, residents are primarily reliant on the STARS system, which is an excellent option, though limited by budget. A variety of technologies could augment STARS, such as partnering with tech companies to offer users location-based tracking information to know the real-time bus schedule, carpooling to bus stops, and offering ridehailing and ridesharing discounts in less sparsely populated areas to get people to bus stops.

PARTNER WITH RIDESHARE OPERATOR TO MOVE AND SOURCE TALENT

During the interviews, CAR researchers learned that some companies face challenges finding qualified employees. Innovative mobility services are enabling technologically-advanced enterprise carpooling. These services partner with a company to enable workers to carpool and more easily get to work. Such a program could augment STARS's dial-a-ride service.

For companies with multiple buildings or campuses, time and productivity are lost when employees travel between them alone. These could be saved, however, if employees used shuttles or carpooled between campuses. Contracting with STARS to provide scheduled service between the two campuses, or implementing a ridesharing platform could alleviate this issue. As an example of a short-distance shuttle, last October, Ann Arbor-based May Mobility partnered with Detroit-based Bedrock to move Bedrock employees between offices and parking garages.⁴² From a ridesharing perspective, Detroit-based Splt, now acquired by Bosch, has partnered with corporations to facilitate employee carpooling.⁴³

⁴¹ U.S. Census, American Community Survey. 2012-2016 American Community Survey 5-Year Estimates. Accessed April 23, 2018.

⁴² Bigelow, Pete. "Here's Why Big Automakers Are Investing in May Mobility, an Autonomous-Shuttle Startup." *Car and Driver*. March 2, 2018.

⁴³ Kamps, Haje Jan. "SPLT brings ridesharing to you and your colleagues." *TechCrunch*. March 10, 2016.

LONGER-TERM RECOMMENDATIONS

Beyond the above, additional opportunities exist to encourage CAV testing in the region. The primary difference between short term and longer-term recommendations is that, while also valuable, those included below will take more effort and/or investment to realize.

MAP AND DATA PROVISION

As discussed earlier, highly automated vehicles will likely require digital basemaps to navigate a given operational design domain. One possibility to attract automated vehicle testing and deployment in a local area is to contribute to the production of digital maps through general data provision. A good digital map for ADSs will likely include important real-time information on lane closures, work zones, weather, and other dynamic factors. This could be done at the state or even local levels, and could potentially augment information that SCRC has already gathered in their GIS mapping effort.

The foundations for such a model are already established. For example, dozens of agencies have partnered with the navigation app Waze for data exchange. Established as a two-way data share, Waze receives partner input such as feeds from road sensors, adds publicly available incident and road closure reports from the Waze app.⁴⁴ Another example is the expanding number of transit agencies publishing schedules and vehicle locations using General Transit Feed Specification (GTFS). GTFS (and GTFS-realtime) were developed by Google specifically so that transit schedules and vehicle location data could be integrated into Google's maps and navigation app.⁴⁵ State transportation agencies also coordinate with other data providers such as INRIX, and NAVTEQ.⁴⁶

CERTIFICATION OF INFRASTRUCTURE CONDITION

Liability is widely perceived as an impediment to deployment of automated driving. Automated driving systems almost certainly imply that liability will shift away from the human driver/users of a vehicle and to the manufacturer or others in the supply

⁴⁴ Waze Connected Citizens Program, https://wiki.waze.com/wiki/Connected_Citizens_Program accessed September 2016.

⁴⁵ Roush, Wade. "Welcome to Google Transit: How (and Why) the Search Giant is Remapping Public Transportation." *Xconomy*. February 21, 2012.

⁴⁶ TTI and Lee Engineering. (2011). "Private Probe Vehicle Data for Real-Time Applications: FINAL REPORT. Maricopa Association of Governments. September 23, 2011. http://www.azmag.gov/Portals/0/Documents/ITS_2011-10-27_Private-Probe-Vehicle-Data-for-RealTime-Applications-Final-Report.pdf?ver=2017-04-06-111211-720. Accessed May 2018.

chain. Policies that reduce or redistribute liability away from industry could accelerate introduction and adoption of automated driving. One potential method to distribute liability is for transportation authorities to certify that designated routes are appropriate for automated driving.

Such a certification could include commitments from the transportation authority that the route will not be subject to closure, construction, or other non-typical events without providing appropriate information to mapping services used by automated vehicles. It is likely ADS providers would be more comfortable allowing automated vehicles to operate without direct human supervision if they could be confident that fundamental details of the driving environment do not unexpectedly change.

INVEST IN DIGITAL COMMUNICATIONS INFRASTRUCTURE

There are a variety of investments the Saginaw region could make in terms of promoting digital communication required for connected vehicles, as detailed below.

GNSS/GPS

The most formal and precise way to know where you are in the world is to determine your location with respect to the global Geographic Coordinate System (i.e., latitude and longitude). This can now be done almost instantly with a global navigation satellite system (GNSS)—most notably, the Global Positioning System (GPS) operated by the United States government.

In optimal conditions, a GPS signal can determine location within a couple meters; however, the precision of GNSS is limited by the availability of a clear signal from multiple satellites. Thus, GNSS localization can be impaired spatially (certain locations receive a weak signal), temporally (the strength of a signal varies as satellites relocate), and environmentally (impediments such as tree cover or buildings block the signal). Automated vehicles probably won't need continuous GNSS connectivity to operate, but a reliable signal would certainly be helpful.

GNSS can be made more precise and reliable with correction and augmentation technologies. Using satellites alone, GNSS is capable of localization precision to within about 20 feet.⁴⁷ To improve this accuracy, governments have deployed ground-based augmentation systems known broadly as differential GPS (DGPS).

⁴⁷ Global Positioning System Website. (2018).

<http://www.gps.gov/systems/gps/performance/accuracy/> accessed May 2018.

With combined GPS and GNSS systems, a GNSS receiver can locate itself within a few centimeters in ideal situations.⁴⁸ Further proliferation of DGPS stations could improve the performance and reliability of automated vehicles.

Similar methods could be used for road navigation. Alternative localization methods may also be used. For example, the navigation app provider Waze has begun experimenting with deploying low-cost (~ \$30) battery-powered Bluetooth beacons in tunnels to allow for vehicle localization where GPS signals are not available.⁴⁹

FIXED BROADBAND INTERNET BACKBONE

Automated vehicles are expected to generate and consume large amounts of data. The local availability of reliable broadband may encourage testing and deployment in an area. Much like the U.S. Interstate system provides high-speed, high-capacity, long-distance travel for vehicles, there is a high-capacity digital infrastructure for internet communication formed by long-haul, broadband fiber optic cables. The bulk of the internet fiber backbone has been deployed by private-sector internet service providers (ISPs). However, the public sector has a significant and growing interest in overseeing the operation of ISPs and internet infrastructure. Most long-haul fiber has been installed within transportation rights-of-way (ROW), a practice encouraged by government 'dig once' policies.

CELLULAR V2X AND 5G TRIAL DEPLOYMENTS

Cellular coverage via 4G/LTE has become practically ubiquitous in urban areas in the U.S. These networks will likely be the initial means for automated vehicles to communicate with external data systems. For example, this will include destination and routing directions, real-time driving data, and data exchange with automation providers. Future iterations of cellular networks promise to provide means for rapid, dependable data transfer, and even direct vehicle-to-vehicle communications.

5G is a general term given to next-generation wireless communication technologies expected to offer seamless connectivity and data-transfer speeds much faster than today's LTE technology. At this time, 5G remains somewhat of a hypothetical technology as the industry has not yet agreed upon a full set of standards.

⁴⁸ An additional, satellite-based GPS correction system is called Wide-Area Augmentation System (WAAS). WAAS is used primarily for aviation, but has been utilized for other applications.

⁴⁹ Liedtke, Michael. "Waze Sets out to Eliminate 'Tunnel Blindness' on Mobile Maps." *ABC News*. September 21, 2016.

However, an emerging technology called cellular vehicle-to-everything (C-V2X) has been standardized by the 3rd Generation Partnership Project (3GPP). 3GPP is a consortium consisting of seven individual standards organizations from across the globe, including The Alliance for Telecommunications Industry Solutions (ATIS) representing the U.S. C-V2X is intended to be forward-compatible with 5G, and may be available in consumer vehicles as early as 2019.⁵⁰ Opportunities may exist to engage with providers for trial deployments of next-generation cellular technologies.

DEDICATED SHORT-RANGE COMMUNICATIONS (DSRC) PILOT DEPLOYMENTS

In the United States, an effort to mandate an ITS-dedicated wireless network is under consideration by USDOT through its Connected Vehicle Program. The Connected Vehicle Program leverages a series of standards and protocols collectively known as dedicated short-range communications (DSRC). DSRC technology has been developed and refined through real-world trial projects, including the Connected Vehicle Safety Pilot Deployment in Ann Arbor, and the ongoing pilot deployments in New York, Tampa, and Wyoming. The Program is evaluating both vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) applications.⁵¹

As of April 2018, the likelihood of a V2X mandate is uncertain. NHTSA has been working to deploy DSRC in consumer vehicles for many years without success.⁵² A successful rulemaking must pass stringent cost-benefit requirements as determined by the federal Office of Information and Regulatory Affairs (OIRA).⁵³ Between the standard difficulties of adopting 'economically significant' regulations, and the uncertainty relating to the transition in administrations following the 2016 election, it is difficult to anticipate the future direction of the federal Connected Vehicle Program. NHTSA envisions that in a mature V2X environment, 80% of traffic signal locations would be V2I enabled. The cost of such an infrastructure is expected to be borne by state and local road authorities, but would be eligible for federal aid highway funding. The first generation of V2I roadside units (RSUs) are expected to

⁵⁰ Allevan, Monica. "Qualcomm, Ford go big with plans to deploy C-V2X in Ford vehicles starting in 2018." *FierceWireless*. January 9, 2018.

⁵¹ DSRC communication including V2V and V2I is also known collectively as V2X.

⁵² *Strategic Plan for Intelligent Vehicle Highway Systems in the United States*. Intelligent Vehicle-Highway Association of America (IVHS America). May 20, 1992. Accessed May 2018 at: <https://rosap.nhtl.bts.gov/view/dot/2708>

⁵³ Dennis, Eric Paul. "Barriers to Adoption of a DSRC V2V Mandate." *ITS World Congress*, Detroit. 2014.

cost about \$51,000 on average.⁵⁴ However, more than half of this cost is in providing fiber backhaul. Sites with existing fiber backhaul will cost much less, and all costs can be expected to drop over time.⁵⁵

LONGER-TERM INFRASTRUCTURE INVESTMENT

Several infrastructure characteristics would optimize an on-road testing environment. While some of these might not be feasible for Saginaw, together they constitute an overview of what would comprise an ideal, on-road test environment. These characteristics are listed below and described in more detail in the sections that follow.

- Electric vehicle charging stations
- Parking and loading zones
- Dedicated lanes
- Minimal risk provision
- Localization beacons
- Connected traffic signals

ELECTRIC VEHICLE CHARGING STATIONS

Automated vehicles currently are evolving in parallel with the ongoing evolution of electric vehicles (EVs). This co-evolution brings some synergies due to complimentary features of each system. For example, shared automated vehicles could be programmed to automatically return to a base station for charging when the batteries are running low. Furthermore, the integration of EVs with smart grid technologies could save energy and improve the reliability of electric power delivery. Provision of these systems may incentivize automated vehicle networks services providers. Even absent some kind of self-driving urban taxi network, the provision of EV charging stations and smart-grid infrastructure could provide benefits on their own.

PARKING AND LOADING ZONES

Difficulties in passenger pickup and drop-off already exist for busses and taxis, both of which often must temporarily block a lane of traffic while stopped. In high-traffic/high-service areas, cities often provide bus turnouts and taxi stands so that these vehicles may service passengers without blocking traffic. These facilities work

⁵⁴ 2015 U.S. dollars.

⁵⁵ Government Accountability Office (GAO). *Intelligent Transportation Systems: Vehicle-to-Infrastructure Technologies Expected to Offer Benefits, but Deployment Challenges Exist*. GAO-15-775. September 2015.

well when use is limited, but if a sizable percentage of travelers expect door-to-door transport via shared automated vehicles, additional provisions may be necessary. The increasing popularity of ride-hailing services (E.g., Lyft and Uber) has already highlighted a demand for such options. The availability of such facilities may be helpful or even necessary for self-driving taxi service providers.

DEDICATED LANES

Operating within a dedicated ROW greatly simplifies the problem of automation by limiting the scope of operation of the vehicle and limiting the liability for the vehicle owner/operator. Similarly, deploying automated on-road vehicles in dedicated lanes on fixed routes greatly simplifies the task of automation, even if these routes are intersected by other traffic.

It is probably not feasible or desirable at this time to provide extensive infrastructure for automated vehicle operation, but limited pilot deployments may be beneficial and are, in fact, already happening. Several cities in Europe have deployed self-driving shuttles—commercially available through companies such as EZ Mile and Navya—to transport passengers along fixed routes at low speeds. The routes are chosen—and often modified—to simplify the task of automation. For example, project managers may relocate nearby obstacles such as planters and benches. However, the routes are not blatantly marked or cordoned off. The shuttles are subject to frequent conflicts with vehicles, pedestrians, and other users of public space. The vehicle is expected to operate with a degree of safety at least on par with a human driver (which is why these shuttles are currently limited to about 20 mph or so).

As of April 2018, there are no automated shuttles that operate on public roads without an attendant or “safety steward” to monitor the operation and stop the shuttle if necessary. The first instance of an automated shuttle operating in mixed traffic on public roads without attendant is scheduled to occur in 2020 in the Dutch city of Capelle aan den IJssel.⁵⁶

⁵⁶ 2GetThere website. <http://www.2getthere.eu/1st-autonomous-vehicle-public-road/> Accessed May 2018.



FIGURE 5. BUS RAPID TRANSIT INFRASTRUCTURE⁵⁷

Due to the complexity of operating a vehicle in urban environments, automated vehicles will not likely match the capability of an average human driver for many years. Deploying an automated bus in mixed urban traffic is likely decades away if at all plausible. However, it is possible to introduce automated vehicles into the urban environment with today's technology assuming the scope of vehicle operation is limited. It is reasonably possible that a bus-rapid-transit (BRT) service, as shown in Figure 5, could be fully automated in the near future if the infrastructure is designed as to simplify the automation task and limit conflicts with vehicles and pedestrians.

City and transportation planners may consider future systems where self-driving, on-demand buses provide convenient and efficient public transit. In the meantime, providing dedicated bus lanes and BRT are proven methods of increasing use of public transit. High-traffic areas may benefit from such infrastructure regardless of whether or not vehicles are driven by a human or computer.

MINIMAL RISK PROVISION

One potential application of Level 3 automated vehicles is privately-owned vehicles that are capable of conditional automation on divided, limited-access highways (e.g., Interstates). Many Level 2 systems are already capable of fairly reliable operation in such cases, but they might still encounter situations for which the human driver must intervene. While we might be close to driving automation that allows the human driver to reasonably divert attention away from the task of driving (i.e., level 3 or above automated driving), analysts have cautioned that if drivers are

⁵⁷ Vance, Steven. (2012). "Magic Bus." *The Architect's Newspaper*. November 30, 2012. <http://archpaper.com/2012/11/magic-bus/> accessed October 2016.

truly able to “check out” of the task of driving, there is no reliable way to re-engage them when necessary.⁵⁸

For this reason, NHTSA has defined highly automated vehicles (HAVs) such that they are capable of achieving a “minimal risk condition” if the automated driving system cannot continue the trip and the human driver does not appropriately re-assume the driving task. NHTSA states that a “minimal risk condition means low-risk operating condition that an automated driving system automatically resorts to either when a system fails or when the human driver fails to respond appropriately to a request to take over the dynamic driving task.”⁵⁹ A minimal risk condition “will vary accordingly to the type and extent of a given failure, including automatically bringing the vehicle to a safe stop, preferably outside of an active lane of traffic.”⁶⁰

Although other scenarios are possible, it is difficult to envision a minimal risk scenario other than bringing the HAV to a stop outside of a traffic lane. NHTSA has even stated that a controlled stop within a lane of traffic might even be identified as a safety-related defect and subject to recall.⁶¹ Therefore, allowing the operation of HAVs on highways may necessitate assuring that there are provisions to achieve minimal risk condition. An appropriately wide shoulder would seem to be the optimal choice. In areas where providing a dedicated shoulder is excessively difficult, perhaps HAVs could be provided dedicated pullout areas at strategic locations, such as immediately preceding exit ramps. There is precedent for providing public infrastructure for infrequent uses by a special class of vehicles, such as “runaway truck ramps,” that are built to allow a kind of minimal risk provision for heavy trucks whose brakes have failed at the bottom of large hills. This provision could potentially be related to a route certification framework as discussed previously.

LOCALIZATION BEACONS

Highly automated vehicles will likely locate themselves by combining GNSS data with on-board sensor data with reference to high-definition 3D digital maps. This

⁵⁸ Spulber, Adela. “Impact of Automated Vehicle Technologies on Driver Skills.” Center for Automotive Research. June 30, 2016.

⁵⁹ U.S. DOT NHTSA. “Automated Driving Systems 2.0: A Vision for Safety.” NHTSA. Page 26. 2017. https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/documents/13069a-ads2.0_090617_v9a_tag.pdf. Accessed May 14, 2018.

⁶⁰ *Ibid.*, Page 8.

⁶¹ U.S. DOT NHTSA, Letter of Interpretation to General Motors. Nov 18, 2016. [https://isearch.nhtsa.gov/files/16-1289%20\(GM%20hazard%20innovative\)%20--%2028%20Apr%2016%20rsy.htm](https://isearch.nhtsa.gov/files/16-1289%20(GM%20hazard%20innovative)%20--%2028%20Apr%2016%20rsy.htm).

method works best with strong GPS signals and a unique physical environment. The vehicle can have difficulty locating itself if the road and roadside environment are relatively featureless or monotonous.

Uber has been notably troubled by this limitation when testing automated vehicle technology in Pittsburgh. Intersected by three rivers, Pittsburgh has over 500 bridges. As reported by Uber's former CEO Travis Kalanick, "bridges are really hard" for automated vehicles to navigate.⁶²

The reason bridges are hard for HAVs is that there are few distinguishing roadside features for the vehicle's sensors to detect. On a city street, the vehicle can sense trees, buildings, roadside infrastructure, and other permanent elements, the unique combination of which matches a specific location correlated to the digital map.⁶³ When crossing a bridge, these environmental cues fall away. Looking beyond the guardrail, an HAV would sense nothing, the algorithmic equivalent of blindness. Consequently, the center of a bridge may look to the vehicle just like the end. Even worse, one bridge may look just like another. If the vehicle does not have a reliable GPS location, it could become very confused about where it is in the world. The localization problem is even more difficult in tunnels—where GPS signals are entirely blocked.

The process by which an HAV (or any mobile robot) can robustly locate itself in the world while accounting for variability is known as *simultaneous localization and mapping* (SLAM). The SLAM process is simplified if the HAV is provided with unique permanent "landmarks."⁶⁴ In typical conditions, the vehicle can self-map landmarks as described above. But bridges, tunnels, and other featureless roads can get lost. If road authorities wish to facilitate HAVs, they could integrate unique landmarks into the infrastructure in areas where the environment is relatively monotonous. Helping lidar and vision-based sensors could be achieved with very simple low-cost solutions. Something as simple as bolting 2x4 pieces of lumber to a guardrail in distinct patterns could allow an HAV to recognize where it is. Localization can also be augmented with digital signals. This has long been done with GNSS

⁶² Chafkin, Max. "Uber's First Self-Driving Fleet Arrives in Pittsburgh This Month." *Bloomberg Business Week*. August 18, 2016.

⁶³ Shladover, Steven, and Richard Bishop. "Road Transportation Automation as a Public-Private Enterprise." Appendix A, pp. 40-64, Commissioned White Paper 1, in *Towards Road Transport Automation: Opportunities in Public-Private Collaboration*. TRB Conference Proceedings 52. Summary of the Third EU-U.S. Transportation Research Symposium. Washington, D.C. 2015.

⁶⁴ Riisgaard, Soren and Morten Rufus Blas. "SLAM for Dummies. A Tutorial Approach to Simultaneous Localization and Mapping." Massachusetts Institute of Technology. 2005.

augmentation, but there are other methods. For example, Waze has begun installing low-cost Bluetooth localization beacons in tunnels so that users maintain localization within the navigation app when they lose a GPS signal.⁶⁵

CONNECTED TRAFFIC SIGNALS

One of the anticipated benefits of HAVs is that they will be able to optimize operation to improve efficiency, thus decreasing energy use and providing environmental benefits. In city driving, being able to adjust vehicle speed to minimize the time waiting at red lights is a very good way of improving efficiency. The USDOT connected vehicle program includes a ‘Signal Phase and Timing’ (SPaT) application to facilitate such efficiency gains in a DSRC connected-vehicle environment. However, direct communication is not necessary to enable SPaT. Communicating signal phases via cellular connections is completely sufficient to achieve the same goal. In fact, communicating signal timing may be deployed in the near term. Because many cities manage traffic signal timing through central traffic control centers, the real-time signal phases can be made available to developers. BMW and Audi are already involved in preliminary projects to bring signal timing information into vehicles.^{66, 67} If more municipalities published real-time signal data, automakers and app developers could create new uses, potentially including automated driving optimization for efficiency. Even in the absence of HAVs, having real-time signal data could improve the performance and convenience of human drivers.

LONGER-TERM SOLUTIONS TO REGIONAL CHALLENGES

Through stakeholder interviews, a few longer-term options to solve regional challenges were mentioned, as described below.

PREDICTIVE MAINTENANCE SENSORS

Vehicle wear-and-tear is a common issue fleet owners face. Predictive maintenance is an area of connected vehicle services where sensors help determine when maintenance is needed, as opposed to on a set schedule. Companies exploring

⁶⁵ Liedke, Michael. “Waze Sets out to Eliminate ‘Tunnel Blindness’ on Mobile Maps.” *ABC News*. September 21, 2016.

⁶⁶ Audi Press Release. <https://www.audiusa.com/newsroom/news/press-releases/2016/08/audi-announces-first-vehicle-to-infrastructure-service> accessed September 2016.

⁶⁷ Marshall, A. “EnLighten App Uses AI to Predict When Lights Will Turn Green.” *Wired*. October 30, 2016.

these technologies could partner with road commission or emergency vehicle providers.

PARTNER WITH LAW ENFORCEMENT AND EMERGENCY VEHICLE OPERATORS

As discussed, much work remains in determining how automated vehicles will interact with law enforcement and other emergency vehicles. Opportunities exist to partner with local law enforcement and emergency vehicle operators to test connected and automated vehicle technologies, such as signal preemption technologies, and automated vehicles' interactions with and responses to law enforcement and emergency vehicles.

FUNDING STRATEGY

Dedicated funding for CAV and mobility services projects, especially when conducted by a local government, is rare. Most support for such initiatives have been awarded through federal research and demonstration programs. Identifying a start-up to partner with to help solve a regional mobility challenge and apply for forthcoming PlanetM funds may be the Saginaw region's best opportunity at funding. Prosperity Region 5 mini-grants are also a good opportunity, if the grant amount could be used to leverage other funds or used in a very targeted manner.

Among current opportunities at the federal level, the ATCMTD is the most relevant for Saginaw's initiative. Given the application deadline of May 21st is rapidly approaching, however, the Saginaw region may wish to pursue the 2019 ATCMTD when it opens.

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APPENDIX: BRIEF HISTORY OF ON-ROAD AUTOMATED VEHICLE RESEARCH

The auto industry has been envisioning self-driving vehicles at least since General Motors presented its “Futurama” concept at the 1939 World’s Fair. GM’s self-driving Futurama road system used a combination of road-embedded magnets and radio communication to guide vehicles without driver control.⁶⁸

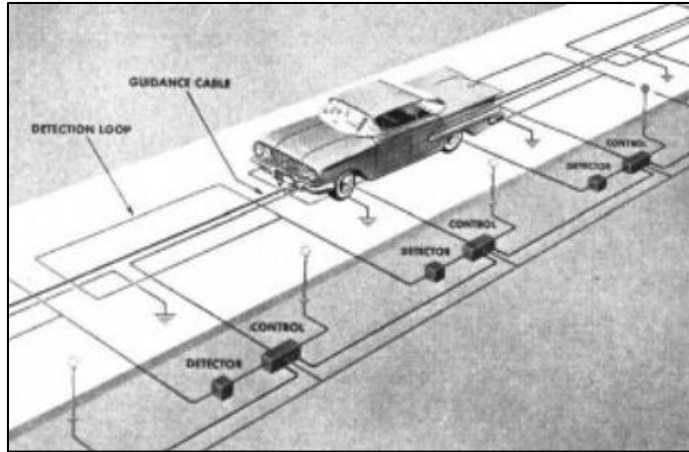


FIGURE 6: THE RCA/GM AUTOMATED HIGHWAY SYSTEM

GM was not the only one dreaming of a self-driving future decades ago. Around 1950, RCA engineers began experimenting with an automated driving system that used roadway-embedded wires to steer a car.⁶⁹ GM soon teamed up with RCA to begin development of automated driving via an “electronic highway.”⁷⁰ Figure 6 shows the RCA/GM automated highway system, developed in the 1950s, used pavement-embedded detection loops for longitudinal control, and a guide-wire for lateral control.⁷¹ The electronic highway was demonstrated through a public-private partnership in Lincoln, Nebraska in 1957. A specially-equipped public highway and specially-fitted cars demonstrated the ability to transmit safety-related messages, and even “guide a car securely ... under conditions of zero visibility.” This system used a combination of sensors embedded in the pavement and radio

⁶⁸ Sven Beiker. “History and Status of Automated Driving in the United States” in *Road Vehicle Automation*, Lecture Notes on Mobility. Editors G. Meyer and S. Beiker. Springer International Publishing Switzerland. 2014.

⁶⁹ “Possibilities of Electronic Control of Automobiles Explored by Dr. Zworykin.” *Of Current Interest*. September 1953.

⁷⁰ RCA. “Highway of the Future” *Electronic Age*. January 1958, pp. 12-14

⁷¹ Ibid.

communication.⁷² RCA even built a test-track to develop this electronic “smart road,” allowing GM to test their prototype “automatic pilot.”⁷³

GM publicly touted their developing system and envisioned it would be a common reality by 1976. A promotional video made for GM’s 1956 Motorama exhibit described a network of control towers guiding a concept vehicle (the Firebird II) at high speeds in dedicated lanes.⁷⁴ It also included self-driving cars guided by pavement-embedded sensors, radio communication, and a series of control towers.⁷⁵ Figure 7 shows a still from that film.



FIGURE 7: STILL FROM THE 1956 GENERAL MOTORS PROMOTIONAL FILM

The GM/RCA concept of an electronic highway was conceptually mature by 1960. It was believed that such a system could make highway travel safer and more efficient.⁷⁶ In the subsequent years, however, the early ideas of a tower-based traffic-control system gradually faded from memory as deployment efforts failed to

⁷² Ibid. (RCA 1958)

⁷³ Doc Quigg. “Reporter Rides Driverless Car: ‘Smart Road’ Used to Test ‘Smart Auto.’” *The Press-Courier*. Oxnard, CA. June 7, 1960.

⁷⁴ Michael Kidd (Director). “Key to the Future” (Film) GM Motorama Exhibit 1956.

⁷⁵ Ibid. (GM 1956)

⁷⁶ L. E. Flory. “Electronic Control of Highway Vehicles.” *Journal of the Institution of Electrical Engineers*. Volume 7, Issue 77, May 1961. pp. 271-273.

materialize. Meanwhile, new computing technologies made other self-driving scenarios possible.

Through the 1960s, the concept of automated highways was increasingly studied in various universities, public agencies, and corporate R&D departments in the U.S. and Europe. A 1969 article in *IEEE Spectrum* claimed that there were nearly 1,300 possible system architectures for vehicle automation.⁷⁷ Considering the cost of rebuilding highway infrastructure to accommodate integrated vehicle-highway systems, it was assumed that conversion of the highway system to an automated highway system would have to be a step-wise, evolutionary process: First, infrastructure-to-vehicle communication would provide drivers with information. The second stage would involve the partial automation of the driving task, with a third and final stage culminating in complete vehicle control.⁷⁸

By 1969, it was no longer thought that an automated highway system would involve control towers along the highways, but it was still assumed that roadway embedded instrumentation (e.g., a guidewire) would be required.⁷⁹ The potential costs of revamping infrastructure to facilitate vehicle automation consistently foiled deployment efforts, leading to alternative approaches that did not depend on specialized infrastructure.



FIGURE 8: CMU'S NAVLAB 1

⁷⁷ Robert E. Fenton and Karl W. Olson. "The electronic highway." *IEEE Spectrum*. Vol 6, Issue 7. July 1969.

⁷⁸ Ibid. (Fenton 1969)

⁷⁹ Ibid. (Fenton 1969)

The first real road vehicle ever to successfully operate hands-free was Carnegie Mellon University's (CMU) 1986 NavLab 1, shown in Figure 8. While the operational domain and capability was modest, NavLab 1 was the first robotic vehicle that was "self, contained, ... not subject to telemetry bottlenecks, communication faults, or dependence on stationary infrastructure."⁸⁰

In the mid-1980s, the U.S. Defense Advanced Research Projects Agency (DARPA) was also conducting automated vehicle research at this time, notably producing a completely robotic 8-wheeled autonomous land vehicle (ALV), depicted in Figure 9. DARPA partnered with Lockheed Martin and the University of Maryland to develop and demonstrate the ALV platform.⁸¹ ALV was likely the first ADS-dedicated vehicle that lacked any provision for internal human operation (i.e., it lacked a cab).⁸²

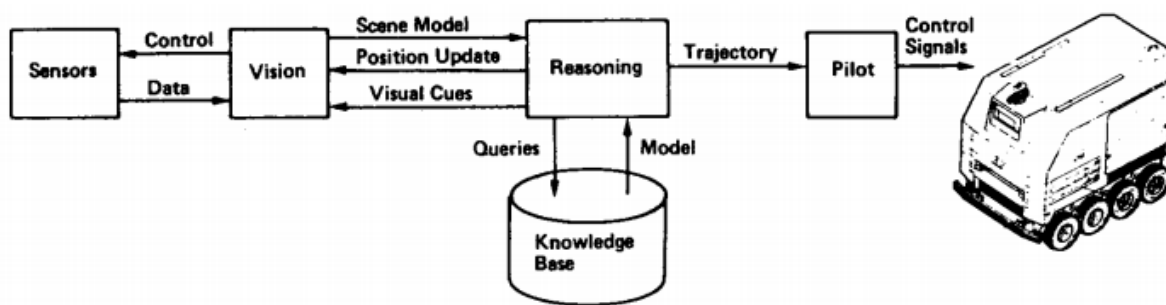


FIGURE 9: THE AUTONOMOUS LAND VEHICLE (ALV) PLATFORM

THE 1990s

NavLab 1 and DARPA's ALV were primitive, but the influences of these programs are seen even in today's prototype automated vehicles, including utilization of lidar, digital maps, and novel machine-vision and decision algorithms trained with artificial neural nets.^{83, 84} By 1991, NavLab 2 was demonstrated on public roads at speeds up

⁸⁰ NavLab 1 (1986) : Carnegie Mellon : Robotics Institute History of Self-Driving Cars

⁸¹ Ibid. (Turk 1988)

⁸² Turk, Matthew et al. "VITS – A Vision System for Autonomous Land Vehicle Navigation," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 10, No. 3. May 1988. pp. 342-361.

⁸³ Thorp, Charles et al. "Toward Autonomous Driving: The CMU NavLab." *IEEE Expert*. August 1991.

⁸⁴ Pomerleau, Dean A. "ALVINN: An Autonomous Land Vehicle in a Neural Network." CMU-CS-89-107, Jan 1989.

to 70 mph and for distances of up to 90 miles without a human ever touching the wheel.⁸⁵ In 1995, NavLab 5 commenced a “No-hands Across America” tour of thousands of miles, 98% of which were in automated mode.⁸⁶

Concurrent with CMU’s 1990’s NavLab research, the USDOT resumed investigation of infrastructure-supported automation through the development of intelligent vehicle-highway systems (IVHS), including automated highway systems (AHS).⁸⁷ The 1991 reauthorization of the Federal-aid Highway Program created hundreds of millions of dollars of funding and research opportunities for various types of intelligent transportation systems. In fact, the funding bill, ISTEA, mandated that the USDOT “demonstrate a fully automated vehicle highway system on a roadway or test track by 1997.”⁸⁸

One lasting outcome of this effort was the development of a connected-vehicle system that eventually evolved to become known as *dedicated short-range communication* (DSRC).⁸⁹ The precursor to DSRC was developed most-specifically to enable automated highway systems (AHS), allowing automated lane-keeping and longitudinal control via platooning. A public-private consortium (The National Automated Highway System Consortium) was formed under the guidance of the USDOT to work towards “hands-off, feet-off” operation.⁹⁰ Core participants included UC Berkeley’s Partners for Advanced Transportation Technology, CMU, Delco Electronics, General Motors, and Parsons Brinkerhoff.⁹¹

The AHS program culminated in a Proof-of-Technical-Feasibility demonstration on Interstate 15 near San Diego, CA. The demonstration showcased seven unique technical approaches (use cases), including transition from manual to automatic control, platooning, and automated highway maintenance vehicles. This approach to automated driving *did* involve permanent infrastructure to some extent—at least in concept. The I-15 test track included pavement embedded-magnates, and

⁸⁵ KDKA News, 1997. (video)

⁸⁶ Carnegie Mellon University. No Hands Across America website. Accessed March 2018.

⁸⁷ Though not prioritized, the 1992 IVHS plan envisioned IVHS-enabled advanced vehicle control systems including automated ‘co-pilot’ systems (IVHS America 1992, pp. III-34).

⁸⁸ NAHSC. “National Automated Highway System Consortium Technical Feasibility Demonstration Summary Report.” February 1998.

⁸⁹ Nita Congress. “The Automated Highway System: An Idea Whose Time Has Come.” *Public Roads*. Vol. 58, No. 1. FHWA 1994.

⁹⁰ National AHS Consortium (NAHSC). “The Birth of the NAHSC.” *AHS Update*. A newsletter for the National Automated Highway System Consortium. Vol. 1, No. 1, Nov. 1994.

⁹¹ *Ibid.* (NAHSC).

specially-designed radar-reflective pavement markings.⁹² While the demonstration was considered a success, it did not lead to commercial deployment of any of the demonstrated technologies.

THE CONTEMPORARY APPROACH

While the IVHS work of the 1990s led to some forward progress, the AHS concept was largely forgotten.⁹³ In an odd but direct way, the current generation of automated vehicle research is a result of the terrorist attacks of September 11, 2001. The research from CMU in the 1980s and '90s was also critical in developing the contemporary approach to driving automation.

In the aftermath of these attacks, the United States became involved in military ground operations in Afghanistan and Iraq. In both campaigns, the U.S. military incurred substantial casualties from improvised explosive devices (IEDs) placed along roadsides. In response, the FY 2001 defense appropriations bill stated, "It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that ... by 2015, one-third of the operational ground combat vehicles are unmanned."

In response to this congressional mandate, in 1994, DARPA initiated the first autonomous vehicle "Grand Challenge," a race through an off-road desert course with a \$1 million prize. None of the entrants even completed the course in 1994, so DARPA held the competition again the following year with the prize doubled to \$2 million.⁹⁴ The competition attracted dozens of applicants, but the overwhelming favorites were from two Universities with an established history in vehicle robotics: Stanford University and CMU. The 1995 Grand Challenge was won by Stanford's "Stanley," while CMU vehicles took second and third place.

DARPA held a follow-up competition in 2007, this time providing a 60-mile course through a simulated urban traffic environment, including interaction with other vehicles and compliance with traffic laws. CMU and Stanford again led the pack, with CMU's Boss taking first place. In all, six teams completed the 2007 course—demonstrating rapid development of self-driving technology within several universities.

⁹² Ibid. (NAHSC)

⁹³ The IVHS Program led to the FCC licensing 5.9 GHz spectrum for connected vehicle applications.

⁹⁴ U.S. DOD, Defense Advanced Research Projects Agency.

While the DARPA challenges kick-off a new era in automated driving research, the technology has not progressed to provide reliable driving automation capability in unconstrained environments. The 2015 deadline to have 1/3 of the military's ground vehicles unmanned has passed. While the military has developed multiple uses for robotic and autonomous systems (RAS), automated land vehicles have not proven able to replace trained drivers in the field, and are not expected to do so in the near-term.⁹⁵

INITIAL COMMERCIAL R&D

The impetus for the DARPA Challenges was to develop autonomous vehicles for military use. However, the success of the DARPA Challenges rekindled interest in the possibility of developing automated vehicles for consumer use on public roads.

Google was the first company to take commercial interest in furthering the technology demonstrated in the DARPA Challenges, hiring several members of the most successful teams—notably from CMU and Stanford in 2009. Google quietly advanced this technology until October 9, 2010, when Google announced the existence of its self-driving project, and that the vehicles had already logged over 140,000 miles.

After this initial announcement, Google's self-driving project and automated vehicle research faded from the public spotlight until 2012 when the project team released a video of a legally-blind man using a prototype self-driving car on public roads. While there was also an engineer in the vehicle, and the demonstration was extensively planned and coordinated, the video showed that Google had made great advancements in driving automation capability since the DARPA Challenges.

The demonstration took many industry-watchers by surprise. The promise of highly capable automated vehicles imposed a possibility of a paradigm shift in transportation and the automotive industry. Multiple OEMs, suppliers, and technology startups initiated their own ADS-development efforts an attempt to capture new markets enabled by automated driving.

There are now literally dozens of organizations developing on-road automated driving systems (ADS). Yet it is evident that Google's technology remains the most advanced. Now spun-off under as a subsidiary of Google's parent company, Alphabet, the DARPA-derived Google approach continues to be developed within Waymo—a Google spin-off focused on automated vehicle technology and deployment. Waymo is now one of dozens of companies testing driving automation

⁹⁵ [The U.S. Army Robotic and Autonomous Systems Strategy. March 2017.](#)

systems on public roads, and Waymo is the only company to have deployed vehicles on public roads without a safety driver.

As an objective milestone, the removal of safety driver is a critical step. Automated vehicles have been tested on public roads since the mid 1980's. Without insider knowledge of research and development programs, it is very difficult to determine how close any given program is to deployment—*unless* the company has determined the system is safe enough to deploy without a test driver. In November 2017, Waymo announced they had been testing (at least) three vehicles on public roads without a test driver.

As of April 2018, Waymo is the only program operating true level 4 ADS on public roads. While this feat has not been matched by any other company, it remains unclear just how close Waymo is to commercializing this service. Members of the public are able to volunteer to test Waymo's self-driving service, but this is a free trial. Additionally, Waymo's testing still involves a company employee inside the car—though this person is in the back seat and not able to intervene (and thus is not identified as a test driver).

The next milestone in ADS will occur if/when Waymo or another ADS provider has enough confidence in the system to operate these vehicles on public roads without dedicated supervision. Waymo has not given a timeline to commercialization, but does appear to be preparing to deploy a commercial self-driving taxi service in the Phoenix area in the near-term.

MILESTONES IN ON-ROAD AUTOMATED DRIVING (SUMMARY TIMELINE)

- 1939: GM Futurama exhibit at 1939 World's Fair
- 1952: RCA begins research into vehicle automation
- 1956: GM Motorama Exhibit: Concept Firebird II Auto Pilot
- 1957: GM/RCA Electronic Highway POC in Lincoln, NE
- 1986: Carnegie Mellon NavLab 1 autonomous road vehicle
- 1986: DARPA autonomous land vehicle (ALV) project
- 1995: CMU NavLab 5 "No Hands Across America" demo
- 1997: Automated Highway System Platooning Demo, I-15, San Diego, CA
- 2005: DARPA Grand Challenge 2 (desert race)
- 2007: DARPA Urban Challenge
- 2009: Google initiates self-driving car project
- 2012: Google 'blind-driver video' demonstrates prototype level 4 on-road automation
- 2017: Waymo deploys true level 4 ADS public road testing in AZ