Conduent Transportation
Roadway Charging & Management

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Connected and automated vehicles: The role of toll road operators

Connected and automated vehicles are all the rage. There are conferences to talk about them, test beds to evaluate them, government policy initiatives to regulate or mandate them. But what exactly are connected and automated vehicles, and how will they impact lives of toll road operators?

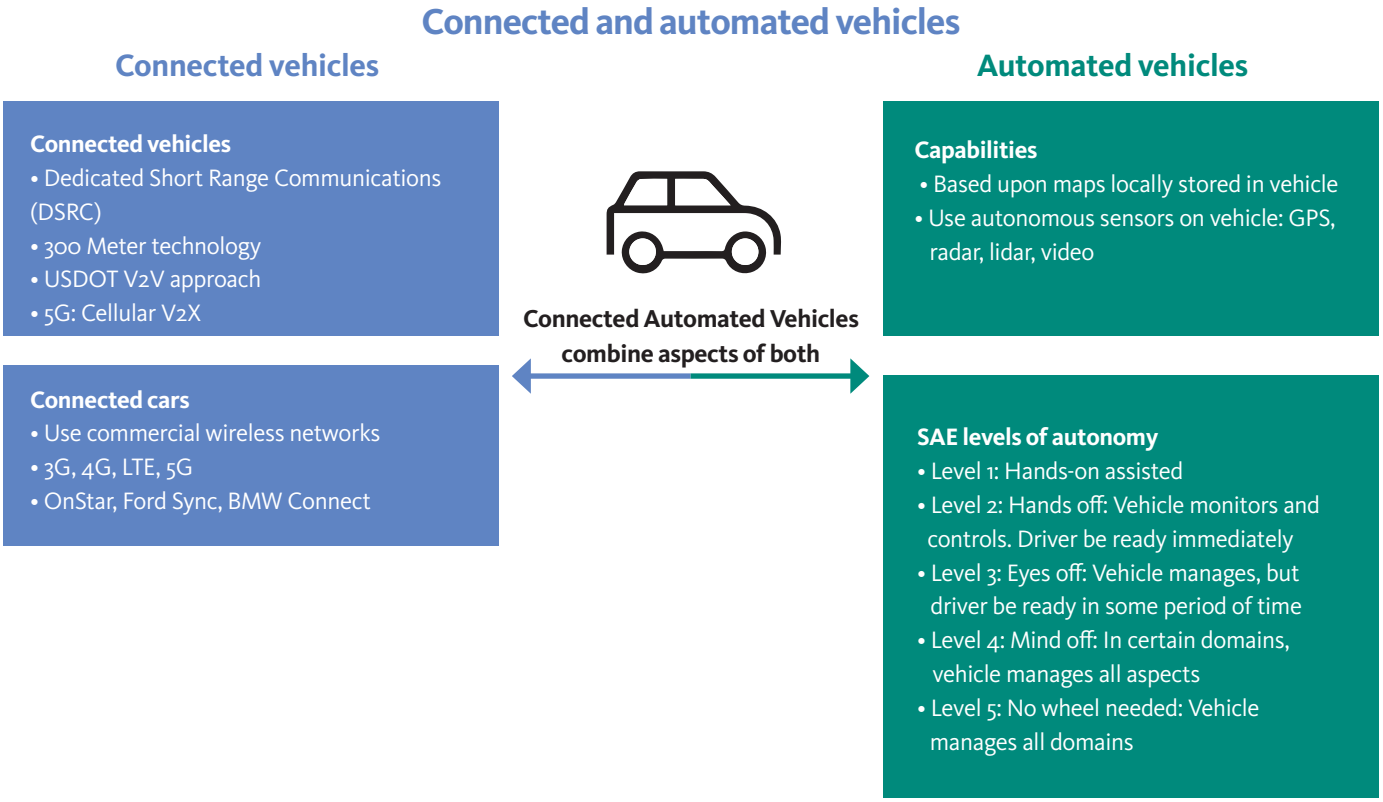
To begin, let's outline the various flavors of connected and automated vehicles, discuss the likely path to adoption, how toll road operators can leverage the capabilities, and some of the fundamental factors to consider as we move to deployment.

Connected and automated vehicles—is this really a term we should be using?

Concepts around connected vehicles have existed for some time. Ford launched the first original equipment telematics system (called Remote Emergency Satellite Cellular Unit –RESCU) that connected vehicles to a call center and provided the GPS location to the call center operator in 1996. OnStar, of course, eclipsed its cousin later in 1996, and offered a full array of services that went beyond emergency calling. OnStar today is the largest and most widely adopted version of a connected vehicle. Later in the mid-2000s, Ford would counter with their SYNC product which allowed users to bring their own Bluetoothenabled phone, and connect to vehicle systems and wireless services.

Automated vehicles as a concept gained notice after the DARPA (Defense Advanced Research Projects Agency) challenge in 2007, and then attracted widespread attention when Google established the team which created their self-driving car. Automated vehicles are the most important phenomena to hit the automotive industry since electronic fuel injection, and have the potential to be the most disruptive change to the business model since Henry Ford began use of the assembly line.

Figure 2: Connected and automated vehicles



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Many people use the expression "CAV" as though connected and automated vehicles are made from the same cloth. They are similar in that they use technology advances to change the way we drive, but there are some key differences.

As illustrated on the previous page in Figure 1, automated vehicles are characterized by their ability to work in an automated or autonomous fashion. The key to understanding automated vehicles (AV) is that most of the initial designs that are produced will basically mimic the functions of humans. The AV will evaluate the roadside using systems that are not based upon sending wireless data to the vehicle or through the use of telemetry. The AV as designed is essentially a substitute for the human, and uses RADAR (Radio Detecting and Ranging), and LIDAR (Light Detecting and Ranging) technologies. Self-driving car designers have no expectation of the roadway operator other than, if possible, the road-striping should be maintained. However, even this is a soft request, since snow obscures road markings anyway. For the most part, the automated vehicle is designed to perform as a human would – no special markings, no special signage, no special wireless communications – the vehicle will react to the situation as a human would. A human can be placed basically anywhere and drive themselves out of the situation; the driving ability of humans varies greatly, of course, as we all witness daily.

The advantage of the automated vehicle is that it can perform routine driving tasks in a spectacularly reliable fashion. Imagine stop-and-go traffic on a roadway. Human drivers can slowly ease forward in stopand-go traffic, alternating between accelerate and brake, accelerate and brake, until one of the humans in the chain becomes distracted by a text, becomes bored, or looks away for some other reason. Then, suddenly, bumpers collide, vehicles are damaged, and the commute is disrupted.

Automated Vehicles can perform this task with remarkable repeatability. They never get bored, they never send a text, and they don't have emails to read. They have one task and one task only: move forward to the destination while avoiding a collision with other vehicles, objects, and infrastructure in the roadway.

The challenge for automated vehicles is non-routine situations. At the current state of the art, humans (some not all) can adapt better to changing conditions. Snowstorms, unexpected road closures, objects in the road, being dropped in a new location – humans are better equipped to maneuver out of unfamiliar circumstances than are automated vehicles. This will not always be the case, because as vehicle cognition increases, and based upon the vehicle's ability to maintain massive map databases which human brains cannot, vehicles will be able to overtake humans eventually even for the most complicated tasks.

For this reason, the Society of Automotive Engineers (SAE) has created a taxonomy that details the progression from no automation to full automation. As depicted in Figure 1, at full automation, no steering wheel is necessary. The vehicle can manage any situation that it finds. Many people state that they will never get into a vehicle that has no steering wheel, but the reality is we surrender control of travel all the time, whether to bus drivers, airplane pilots or someone else.

At the next level down is Level 4, where the vehicle can manage all tasks within certain domains. Toll roads will be the ideal place to deploy these types of vehicles. The vehicle driver will need to get the vehicle to the toll road, but from that point, the vehicle can manage all the tasks, and the driver can resume other functions – that is, "minds off" with respect to the driving function. Toll roads are ideal for this setting, since they are controlled roads with limited numbers of entry and egress points. Toll roads are also well-instrumented with sensors, electric power and communication, so they can be among the first places to provide vehicles with data wirelessly using telemetry and other cues.

Levels 1 and Level 2 automation (as depicted) are fairly prevalent today. Many vehicles have lane keeping systems or smart adaptive cruise control system. These generally fall into the Advanced Driver Assist System (ADAS) category of automation.

Level 3 is the most challenging case in that in this situation the vehicle is in charge, and the driver is in supervisor mode. The driver must be able to take back control of the vehicle with little notice (seconds), and humans have not performed well as supervisors of machines. Since the machine will work well most of the time, the driver will turn their attention away to other things – email, texting, talking on the phone – and may not be ready to quickly assume control. For this reason, few manufacturers are pursuing Level 3 automation – humans cannot be relied upon to quickly assume control. And what is the purpose of having the vehicle manage itself if you have to be poised at any moment to take back control? This would be a nervewracking experience.

For the purposes of connected vehicles, we have broken them down into twin paths. Connected vehicles generally refers to concepts around Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication paths. Connected cars are systems that rely on commercial wireless networks (AT&T, Verizon, Sprint, T-Mobile), and are more related to accessing key content from the internet such as maps and directions, points-of interest, and the use of commercial wireless for payments.

In this taxonomy, connected vehicles (as opposed to connected cars) will rely on 5.9 GHz Dedicated Short Range Communications (DSRC) which is a communications standard intended to transmit over short distances relevant data such as the Basic Safety Message. This message is transmitted using communications protocols specified by SAE (J2735) and IEEE (WAVE 1609.1 through 1609.4). This does not rely on a central network switch or router, and each vehicle (On Board Unit – OBU) or roadway component (Roadside Unit-RSU) broadcasts their data and does not require management by a central network. Under this peering arrangement, the system will need security credential exchange to protect the operation.

Currently, DSRC is being considered by the National Highway Transportation Safety Administration (NHTSA) as a mandate for all future vehicles. A Notice of Proposed Rulemaking (NPRM) was issued by NHTSA in January, 2017 and comments were due on April 12, 2017. NHTSA is considering the feedback and evaluating whether to proceed with the rulemaking – a final rule is expected in 2019. Among the feedback that the NPRM generated was a proposal by the 5GAA (5th Generation Automotive Alliance) which is proposing that NHTSA use 5G, or the variation of 5G that the 5GAA has developed. (5G is the next generation of wireless protocols which are to follow the current deployments of 4G LTE). 5GAA is comprised of Qualcomm, Audi, Daimler, BMW, Samsung, Nokia, and several other key participants in the ecosystem. The 5G as proposed by 5GAA is essentially a Cellular V2X protocol which builds upon 4G. Conceptually, Cellular V2X could deliver all of the V2V, V2I, and V2X functionality, but will not use the DSRC protocol.

What does this mean for toll road operators?
There is considerable discussion underway about how toll roads can prepare for the coming wave of connected and automated vehicles. One suggestion is to have dedicated lanes for automated vehicles. Another suggestion is the use of DSRC or V2I for tolling. Others believe that these new types of vehicles require unique roadside markings, while others seek development of new policies for automated vehicles to regulate them.

Each of these elements may come to fruition and all are important to consider, but clearly some are more imminent. Let's break out the items into near-term, medium-term, and long-term. Consider nearterm as occurring in the next five years, medium-term as occurring in the time frame from five years to fifteen years, and long-term beyond fifteen years.

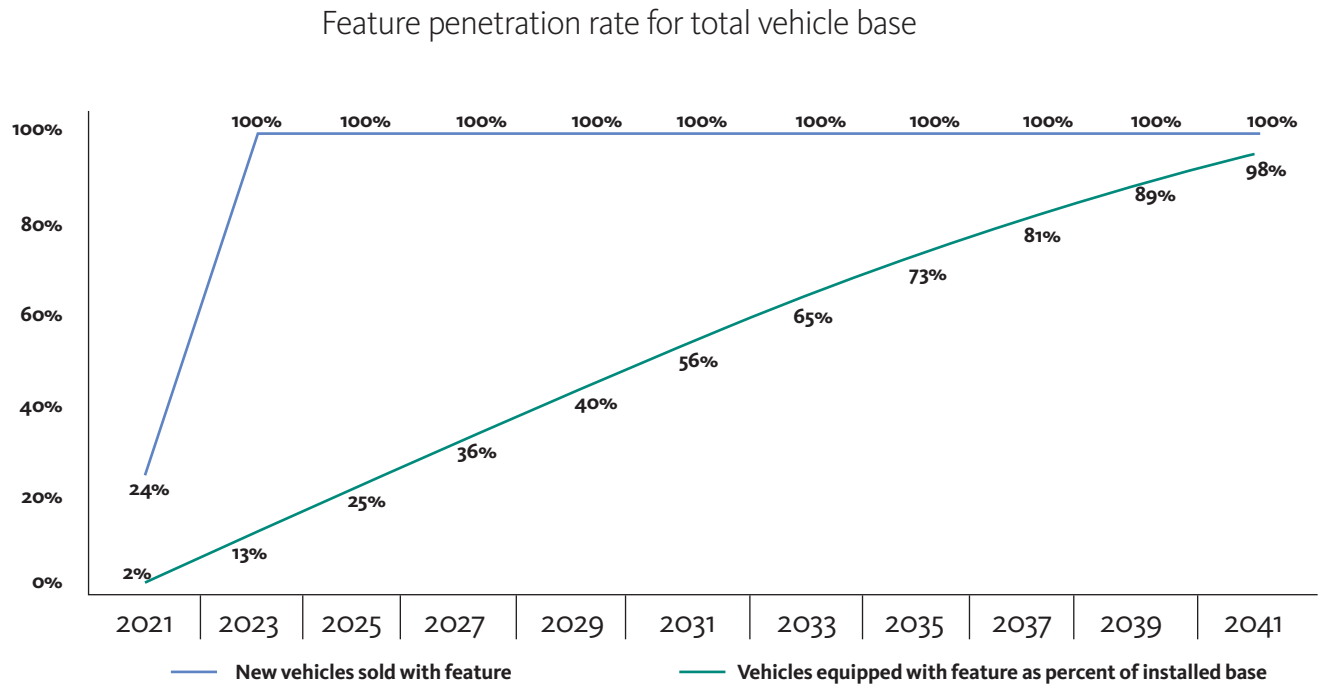
Penetration of connected and automated vehicles into the installed base of vehicles
To understand the basis for the recommendations that follow, we need to establish a set of assumptions and evaluate how much time will elapse before the necessary penetration levels occurs. The analysis for each is similar in that it takes considerable time to penetrate the installed base of vehicles. Considering the United States market, see Figure 2 below.

Figure 2 illustrates the timeframe in which certain penetration levels will occur. This analysis assumes that the installed based begins at zero percent penetration in 2021, and by 2023, 100 percent of new vehicles are sold with the new functionality – be it connected capability or automated capability. This is modeled on the timing that NHTSA has presented in their NPRM for connected vehicles.

The simple math is that there are approximately 270 million vehicles in the US Installed Base of cars and light trucks. Currently there are approximately 17 million cars and light trucks sold each year in the United States. One simple technique would be to divide 270 million by 17 million, which would indicate the base would turn over in roughly 16 years. With somewhat more sophisticated analysis taking into account that 100 percent installation doesn't occur until 2023, and accounting for the fact that some vehicles remain in the installed base – that is the 17 million isn't replacing the oldest 17 million vehicles directly, in fact, the base is growing by about 6 million per year since 10 – 11 million are scrapped.

At this rate of adoption, the installed base will take until 2040 to be virtually turned over entirely. The fact is that if ride-hailing services such as Lyft and Uber slow the sales of new cars, or there is an economic downturn and 17 million is optimistic for new vehicle sales, then the turnover of the installed base will take longer.

Figure 2: Feature penetrate rate for US installed base of vehicles



What Figure 2 illustrates is that any feature change that is mandated or adopted on new vehicles will take some time to achieve nearuniversal acceptance. Certainly, there are some features and functions that can be delivered by sales of aftermarket devices, and this could accelerate the adoption curve. However, this acceleration is not likely to occur for automated vehicles – true vehicle automation is unlikely to be an add-on device. And for connected vehicles, the adoption curve could be pulled forward by some time period, say five years, but universal adoption is a long term phenomena.

Figure 3 (below) illustrates the framework for discussing potential impacts of connected vehicles and automated vehicles. The intent is to lay out which features and functions can be supported in the nearterm, medium-term, and long-term.

Figure 3: Adoption of connected or automated vehicles over time periods

Time frame	Definition	Realistic penetration level	Description
Near term	Within 5 years	< 10%	Available to support some features
Medium Term	Within 5 – 15 years	33%	Available to support many features
Long Term	Beyond 15 years	75 – 100%	Near universal Adoption – likely to be sole means

Let's consider some of the topics that have been floated as potential impacts to toll lanes and illustrate where these developments will occur along the timeline.

1. **Dedicated lanes for automated vehicles:** This approach has some appeal in that automated vehicles can be designed to be narrower since the lane keeping system in the car is superior to humans. Therefore, 12-foot lanes could become 10-foot lanes where space it at a premium. Possibly, the AV lane could be created with no break down lane but just occasional turn off locations, which are well-mapped. Also, dynamic message signs could be replaced with infrastructure-to-vehicle connections which advise the automated vehicle of toll rates – at least for AV-only lanes. Realistically, this is a probably a medium-term development, and possibly a longer-term development. The challenge is that, in a 2 – 3 express lane set up, this would occupy 30 – 50 percent of the lane available, and the number of vehicles able to use dedicated AV lanes initially will be less than 10%. Even at aggressive growth rates (100 percent of new vehicles sold are AV by 2023), the penetration would be at 50 – 60 percent in 2032. This is definitely a medium-to-long-term development, and we will need to see what adoption rates look like.

2. **Use of DSRC or cellular V2X for tolling:** This approach has the appeal that if vehicles come with a capable communications platform in the vehicle to conduct transactions, the road operator/agency does not need to manage transponder inventory. This also is a medium-term development. Toll agencies are looking to upgrade their lane equipment to accommodate the movement to the National Tolling Protocol, which will deliver the goal of interoperability in time. The tolling industry is poised to install new readers which will use one of three existing tolling protocols: 6c, IAG, and SeGo. DSRC or Cellular V2X are not currently being considered but could provide a fast, highly reliable payment method for tolling. While it is appealing to leverage the "no cost" transceiver that comes with each vehicle, the delivery of these "no cost" transceivers will not achieve significant penetration until the middle of the next decade. By 2025 or so, it may make sense to add DSRC or Cellular V2X as an additional protocol to readers, but that will be contingent on NHTSA successfully issuing their mandate. Infrastructure-to-vehicle communications of toll

3. **information with connected vehicles:** This approach could provide drivers information that is relevant to their trip. While reliance on in-vehicle signage will not be a substitute for roadside signs for a long time, this is an approach that holds promise. Automated vehicles will be capable of reading signs but could be better served by delivery of data. Information related to dynamic pricing on toll roads would be very helpful for AVs, and could be delivered over any of the potential protocols. For this reason it may make sense to provide toll price information as an API (Application Peripheral Interface) feed so that AV applications (and even human-operated vehicles) can use the information to plan routes and recognize tolls paid. The approach of publishing APIs allows operators to provide the information without being concerned about the wireless delivery method. The challenge with this approach is that, while it can serve the public and assist in demand management, the return on investment may be low for the road operator. This innovation could be ready in the near term if an agency decides to implement this strategy

4. **Managing vehicle occupancy detection with automated vehicles:** Among the changes that driverless vehicles will bring is that there will be no human driver in the front seat. Historically, HOV enforcement involves looking for passengers in the non-driving seats. This is a minor change to the approach for HOV enforcement but law enforcement on the roadside, and automated enforcement on the roadside will need to account for the fact that there is no driver to account for as you determine if the vehicles is HOV2+ or HOV3+ qualified. This is likely to arise when ride-hailing services deploy vehicles with no driver, and we will encounter vehicles that are truly Level 5 Automation. The key here is that we must exploit automated vehicle occupancy detection to be truly effective, since Level 5 may have no driver to pull over and cite. The technology change can be managed in the near-term, however, the policy change permitting remote, automated enforcement without a physical stop by an enforcement needs to be pursued in state legislatures, which may take time

5. **Improving lane markings for automated vehicles:** This is an approach that can benefit automated vehicles, although most toll roads are among the best maintained with respect to maintaining proper lane markings, and keeping the roadside clear of snow and debris. Since this is fairly standard practice by toll authorities, and automated vehicles will encounter worse conditions than is typical on toll road, this is a solution that essentially exists today on toll roads. And this near term capability makes toll roads suitable for Level 4 Automation.

6. **Policy changes for automated vehicles:** Among the challenges which needs to be considered is assigning responsibility for vehicle/driver behavior. This takes many forms and will alter the way we manage enforcement. Consider the following:

• Ensuring that the vehicle is properly licensed. Historically, if a vehicle doesn't have a license plate or has an expired license plate, the enforcement officer pulls over the vehicle and issues a ticket. In the Level 5 Automation scenario, there may not be a driver at all. Consequently, the enforcement action must be taken against the owner of the vehicle. This lends itself to automated enforcement using an enhanced violation enforcement system. Owners of vehicles must be sent notices fining them for the vehicle violation. And there must be legislation in place that allows for meaningful follow up and collection.

• Moving violations such as speeding. Again, since there is no driver, there is no individual to pull over and cite for speeding. This again, lends itself to an automated enforcement solution where the speeding ticket will need to be issued without pulling over a driver. Today, most automated vehicles are designed to adhere to speed limits and to not perform other moving violations. This may not always be the case, so agencies must be prepared to enforce moving violations with automated vehicles. This is a near-term to medium-term phenomena.

• Proof of insurance. Historically, an enforcement officer will pull over the driver who has committed some offense, and request proof of insurance. Again, when we consider a ride-hailing vehicle that uses Level 5 Automation, there is no driver to produce proof of insurance. Automated enforcement must again be the tool that is available to agencies. The system must be able to capture license plate images, check them against state DMV files, and also against insurance databases to confirm the vehicle is insured. Again, legislation may be required to enact this change, but we may see this situation in the near future. While large companies managing large fleets of Level 5 Automated Vehicles may be found responsible for maintaining insurance, it is not clear if ride-hailing fleets will be comprised of individual owners or corporations. Proof of insurance via automated enforcement will need to be considered.

• Liability for payment of tolls. This is possibly the easiest issue to manage for Automated Vehicles as the liability for the toll will be on the account holder with the toll agency. If the vehicle owner does not have an account with the toll agency, the liability will be assigned to the vehicle owner who will be identified via a DMV look up and sent an invoice.

7. **Roadside applications using connected vehicles.** The American Association of State Highway Transportation Officials, ITS America, and the Institute of Transportation Engineers have formed a group designated the Vehicle-to-Infrastructure Deployment Coalition (V2IDC). This coalition has worked with automakers to identify useful applications that can leverage DSRC in vehicles. Since automakers are installing DSRC in vehicles (see 2017 Cadillac CTS), automakers are looking to how they can use the DSRC technology to improve driving by installing wireless communications on the roadside. Among the applications identified are:

• Signal Phase and Timing (SPAT). Using the DSRC channel, the signal phase at an intersection will be broadcast to any vehicle equipped to receive the SPAT message. This application is being promoted by the SPAT Challenge which seeks to find 50 cities that will install 20 intersections along a corridor by 2020. The 20-50-20 goal is being pursued and several DOTs are pursuing this implementation. Toll agencies are not involved in this process because they typically do not operate signalized intersections, but agencies should be aware of the approach taken by AASHTO and the V2IDC.

• Work zone safety. The V2IDC is seeking to promote the development and deployment of Work Zone Systems that use DSRC.

• Curve overspeed warning. Similarly, AASHTO and the V2IDC promote the use of DSRC on curves where sight lines are limited and DSRC can be used to identify vehicle stoppages ahead even in inclement conditions.

• End of queue warning. This is the fourth application that AASHTO and the V2IDC is promoting. DSRC can be used to signal at locations where traffic jams form repeatedly. A DSRC system could alert drivers to the fact that this is a high-likelihood area for traffic jams, and identify the end of queue.

• Simple data gathering. While AASHTO has not promoted this approach, a relatively easy entry point for toll agencies is to set up DSRC receivers for the purpose of speed collection. DSRC radios in vehicles are broadcasting ten times a second key data points about the vehicle: speed, direction, location of the vehicle. The data is anonymous and the basic safety message (BSM) does not include a VIN or other identifier. These sensors are not in a position to displace microwave vehicle detectors or radar sensors, but could be used as a calibration and audit tool to provide a basis for comparison with existing roadside sensors. The speeds provided by the BSM are very accurate, but initially there will be too few vehicles to record this data. Some states and agencies have opted to equip their maintenance fleet with OBUs that will broadcast to the roadside units so that there will be a baseline of measurement. Also, as more DSRC equipment is installed in vehicles, there will be more vehicles to sample speed from.

Connected and automated vehicles are coming

There are many implications to this change for roadway operators. The path forward is not entirely clear with respect to which wireless protocol will be used to deliver, but that is not the key to the discussion. The ability to set up tests and operationalize Connected Vehicle and Automated Vehicle applications can be pursued independent of the wireless protocol.

There will be many changes that will occur due to the introduction of CV and AV to roadside from technology to policy. The key is to align with partners that are knowledgeable and have the flexibility to adapt to changing conditions. This will bring a significant change to roadway management and ultimately lead to better service for the driving and riding public.

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